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Tracking human activity and well-being in natural environments using wearable sensors and experience sampling

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ABSTRACT

A growing range of studies have begun to document the health and well-being benefits associated with contact with nature. Most studies rely on generalized self-reports following engagement in the natural environment. The actual in-situ experience *during* contact with nature, and the environmental features and factors that evoke health benefits have remained relatively unexplored. Smartphones offer a new opportunity to monitor and interact with human subjects during everyday life using techniques such as Experience Sampling Methods (ESM) that involve repeated self-reports of experiences as they occur in-situ. Additionally, embedded sensors in smartphones such as Global Positioning Systems (GPS) and accelerometers can accurately trace human activities. This paper explores how these techniques can be combined to comprehensively explore the perceived health and well-being impacts of contact with nature. Custom software was developed to passively track GPS and accelerometer data, and actively prompt subjects to complete an ESM survey at regular intervals throughout their visit to a provincial park in Ontario, Canada. The ESM survey includes nine scale questions concerning moods and emotions, followed by a series of open-ended experiential questions that subjects provide recorded audio responses to. Pilot test results are used to illustrate the nature, quantity and quality of data obtained. Participant activities were clearly evident from GPS maps, including especially walking, cycling and sedate activities. From the ESM surveys, participants reported an average of 25 words per question, taking an average of 15 s to record them. Further qualitative analysis revealed that participants were willing to provide considerable insights into their experiences and perceived health impacts. The combination of passive and interactive techniques is sure to make larger studies of this type more affordable and less burdensome in the future, further enhancing the ability to understand how contact with nature enhances health and well-being.

1. Background

Over the past several decades, interest has grown on the health and well-being benefits associated with contact with nature. Indeed, it has been revealed that contact with natural environments such as parks and gardens foster recovery from mental fatigue (Hartig et al., 1991; R. Kaplan and Kaplan, 1989; S. Kaplan, 1995), enhance the ability to cope with and recover from stress, illness and injury (Parsons, 1991; Ulrich, 1984; Ulrich et al., 1991), improve concentration and productivity in children (Kuo, 2001; Kuo and Taylor, 2004; Taylor and Kuo, 2009), and is related to overall happiness (Zelenski and Nisbet, 2014) and perceived well-being benefits (Kaplan, 1992; Lemieux et al., 2012). Exercising in natural environments is particularly beneficial, as compared to exercising indoors, leading to improved feelings of revitalization, enjoyment, satisfaction, and energy, decreases in tension, confusion, anger, and depression (Bowler et al., 2010; Thompson Coon et al., 2011) and reduced risk of poor mental health (Mitchell, 2012). Increased time spent outdoors has also been found to increase physical activity and decrease the prevalence of overweight among children (Cleland et al., 2008). Living in proximity of greenspace has also been shown to positively influence the longevity of urban senior citizens (Takano et al., 2002) and lead to positive self-reported health (Maas et al., 2006).

Most of these studies utilize after-the-fact or generalized self-reports following engagement in the natural environment, or controlled experiments (i.e. where the natural environment and physical activity types are controlled in short-term studies) rather than everyday situations. The actual in-situ experience *during* contact with nature, and the mechanism and contributing environmental features and factors that evoke health benefits, have remained relatively unexplored, especially under real-world

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conditions. Rapid development and proliferation of smartphones is allowing unprecedented new opportunities to monitor and interact with human subjects *in-situ* in everyday conditions. Modern smartphones are programmable, have multiple embedded sensors, large high resolution touch screens, powerful processors, long battery life, large amounts of memory, ability to link wirelessly to external sensors/devices, and are considerably familiar to large segments of the population. They are also fundamentally a wireless data communication technology that facilitates data transmission from the body to a remote storage device, such as computer server, where, it can be processed and displayed in support of new types of decision support systems.

This paper explores how smartphones can be utilized to track human activity, perceived psychological health and well-being, and *in-situ* subjective experiences at a fine temporal/spatial scale in natural environments, by combining embedded passive sensing technologies and interactive experience sampling survey techniques custom programmed on such devices. Human activity includes a variety of stationary/sedate activities (sleeping, work, etc.), movements (walking, driving, etc.), and periods of more intense body movement, tracked by time of day and location, of particular interest to studies of physical activity and exposure. *In-situ* experiences can include a wide variety of emotions in a given situation, including especially those related to perceived health and well-being.

Embedded sensors in smartphones include Global Positioning System (GPS) receivers and 3-axis accelerometers. Typical GPS receivers embedded in smartphones are capable of providing a user's location (latitude, longitude) to within about 5–15 m accuracy with an update frequency typically every second. When such data are tracked over long periods (such as a day), and then overlaid on a map or aerial photo, a wide range of human behaviours *and contexts* become easily detectable to the naked eye, including periods of movement, stationary activities and their attributes (e.g., start/end time, location) and built-environment context (e.g., nearest building or roadway). Geographically, this replicates a persons' space-time path (Hägerstrand, 1970) in considerable detail. Recognizing this, a growing number of studies are adopting GPS for detecting activity-travel patterns (D'Antonio et al., 2010; Doherty et al., 2001; Rainham et al., 2008), to develop "prompted recall" diaries (Auld et al., 2009; Clark and Doherty, 2010), detect physical activity (Elgethun et al., 2007; Terrier et al., 2001), and explore links to health and well-being (Doherty, 2012; Rainham et al., 2008).

Accelerometers have long been used to track physical activity (Welk, 2002), but only recently have they been embedded in smartphones to allow the large screens to automatically adjust their orientation. A typical accelerometer embedded in a smartphone measures acceleration in three directions (up-and-down, side-to-side, back-and-forth) at a rate of 15–25 times per second, providing considerable information on the motion associated with the body part it is attached to. When such devices are worn on the body (such as at the hip) and tracked over time, they have the ability to detect the duration and intensity of physical activity (Chen and Bassett, 2005; Doherty, 2009; King et al., 2004; Mathie et al., 2004).

Experience Sampling Methods (ESM) are a technique involving repeated self-reports of a wide variety of experiences, perceptions, emotions, and behaviours as they occur "in-situ" within a natural setting when thoughts and feelings are fresh (Hektner et al., 2007). Subjects are typically instructed or prompted to complete a short questionnaire at regular or random intervals throughout a period of time, and have often involved the use of electronic pagers to remind subjects to complete the survey at a given interval. ESM are commonly used in leisure and tourism studies (e.g., Borrie and Roggenbuck, 2001; Fave et al., 2003), and are analogous to Ecological Momentary Assessment (EMA) methods used in the health sciences (Shiffman et al., 2008). Primary advantages of such studies are minimization of memory recall and distortion, allowance for more in-depth examinations of experiences, and ability to examine the dynamics of experiences as they change over time, rather than a single retrospective assessment (Cerin et al., 2001; Hektner et al., 2007). Some of the challenges associated with traditional ESM include participant difficulty remembering to complete surveys, and the associated invasiveness and burden associated with the use of traditional paper-and-pencil survey techniques. However, the use of hand-held computers to administer ESM/EMA surveys overcomes some of these challenges, and offers additional abilities including automatic prompting of subjects to complete assessments, management of prompting schedules, data storage, time stamping of entries to avoid faked compliance, and ability to directly collect other types of physical or physiological data (Shiffman et al., 2008).

It is easy to see the promise of GPS and accelerometer tracking technologies in providing a highly *detailed*, *accurate*, and *objective* accounting of real-world human activity and mobility over time and space. This would be of considerable value in assessing the human–environment interactions, activity spaces, exposures, and real-life activities/events that contribute to emerging lifestyle-related diseases such as diabetes and heart disease (Doherty and Oh, 2012; Mozaffarian et al., 2009; Zimmet et al., 2001). This data has traditionally been costly, invasive and burdensome to collect using traditional survey methods, but is likely to significantly strengthen the search for the causality of disease (Curtis and Lee, 2010; Rytkonen, 2004).

ESM techniques also provide a unique opportunity to supplement this largely *quantitative* data with *qualitative* information that can only be obtained by interacting with subjects, filling in gaps with respect to the *quality* of the activities, experiences and perceptions associated with them. Knowing a subject's location and activity can also help refine and trigger when ESM prompts are initiated (e.g., when near specific assets such as a recreation facility, or during specific activities such as walking or hiking in a park) and/or lead to varied question sets tailored to the situation at hand. The use of smartphones offers additional ability to present questions on screen with varied ways to record responses, including textual, yes/no, pull-down/check-box lists, verbal, or even through use of perceptual games, not to mention the opportunity for alternative types of data capture such as through pictures and video. Computer processing presents the additional ability to track subject compliance and response rates (through time stamping), track respondent burden/effort, reduce data coding errors, and monitor and obtain data from the field in real time if desired.

Despite the promise, few explicit studies of automated daily activity detection using embedded sensor technologies have been conducted under *real-world* conditions, and none have combined this with in-situ repeated interactive surveys such as ESM. Also, this work has never been done in the context of perceived health and well-being while interacting in a natural environment. Considerable potential exists to combine these approaches to provide a highly complementary, detailed and accurate accounting of real-world human activity and experiences in a variety of environments as they occur over time, with a minimum of subject burden. This paper explores these opportunities and challenges in the context of visitor experiences in natural environments housed in parks and other forms of protected areas.

Even though the focus of this paper is on methods, it proceeds grounded in environmental health theory. In particular, Parkes et al.'s (2003) "Prism framework of health and sustainability" provides a useful framework as it integrates several converging paradigms of environmental health. This framework links