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Short Communication

Relabeling "Movement" In Health Research: Differences Between Accelerometry and Global Position System (GPS) Devices

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ABSTRACT

The concept of frailty presents a paradigm through which aged adults at-risk for adverse health outcomes can be identified by observing the factors associated with vulnerability in asymptomatic stages. Capacity for physical mobility informs this line of research where studies use objectively measured body movements via accelerometers and Global Position System (GPS) devices. Describe how the technological differences in accelerometers and GPS devices measure "movement" differently and suggest more operationally precise labels. Briefly review the technology used in accelerometry and GPS devices and explain how they differ in measuring bodily movements. It is advised that when referring to movements measured with accelerometry, the term "weigh shifting" be considered and when referring to movements measured by GPS, the term "cartographic relocation" be referenced. Because advancing aging research on frailty requires communication amongst international researchers, the refinement of technical language for devices producing objective measures of movements should be continually sought.

Keywords: mobility; physical activity; function; aging; frailty

INTRODUCTION

Physical activity has consistently been shown to be associated with various health outcomes and is investigated in older adults (age $\geq$ 65) because it has been linked to the maintenance of functional independence. Because physical activity may delay the onset or slow the progression of difficulties with mobility tasks (e.g., walking), the measurement of "movement" in the geriatric population cannot be overstated-as early detection may lead to more successful interventions. In the hopes of developing protocols for early detection of subtle events which may indicate an increase in risk for an adverse health outcome, researchers have postulated the existence of "frailty" and begun to delineate the concept. Growing evidence indicates frailty is highly prevalent in older adults. [1] Frailty can be defined as susceptibility to adverse outcomes [2] or more clinically as a syndrome characterized by an increased vulnerability to stressors produced by impairments in multiple physiological systems [3]-e.g., muscle weakness, rapid exhaustion, slow gait, poor endurance, unintentional weight loss, and low physical activity. [4,5] Conceptualizing frailty can be argued to be a means through which at-risk older adults can be identified in order to intervene in modifiable trajectories associated with adverse health outcomes. [6,7] Because frailty has been linked with serious consequences, such as disability, and has been deemed a public health problem with large economic cost [8,9] and shown to increase as a financial burden for those who have disabling conditions over a longer period of time, [10] advancing the methods employed to measure the physical activity associated with the disablement process and the physical mobility component related to frailty is important.

In recent years, frailty related research has made use of objectively measured (e.g., accelerometry) physical activity and mobility. [11] Attempts to trace human activity have existed for decades. [12] Objectively quantifying the characteristics of human actions/movements may allow researchers to investigate topics ranging from: physical function; energy expenditure; physical mobility; and to link enacted physical performance with environmental exposures. Recent work has highlighted the need to gauge physical movements more precisely by using time- and space-aware devices and methods [13] and publications have explained how developing "person-base" (as opposed to "place-base") contextual determinants, via devices that use the Global Positioning System (GPS), of health behaviors and outcomes is crucial to the advancement of public health research. [14] Some have even argued that operationalizing context as measured by the spatial and temporal activities of individuals is essential for advancing place and health research on the aged. [15] Even more geographically aware arguments have posit that using person-based measures of human activity may help mitigate the challenges posed by the Modifiable Areal Unit Problem (MAUP), the Uncertain Geographic Context Problem (UGCoP), [16] and others. [17]

The current project is motivated by the assumption that research on aging and frailty can be advanced by making use of objectively measured physical movements over the environment and that such an enterprise necessitates the use of conceptually and technically precise language. Publications have cogently presented arguments for why studies of human activity require the use objectively derive time- and place-specific measurements. [13] A subtle but important confusion remains: the use of the term "movement" is obfuscated by its flawed usage. Others have eloquently explained why the conjugation of the tenses is important when talking about physical mobility and function. [18] For example, assessing physical mobility through self-reports may capture "self-perceived capacity to function" in the *hypothetical* tense (i.e., assume you had to, would you be able to walk up ¼ mile?) which is in stark contrast to evaluating physical mobility objectively via timed gait speed as "observed performance" an in the *factual* tense (i.e., would you please show me you can walk a ¼ mile?). Because previous work has shown that discordance between the two tenses can exist [18] -reporting to have the capacity (or lack thereof) to perform does not always match with the ability to perform the task-objective measures of physical capacity have been advised.

Before researchers continue to attempt measuring human movements and explain the geographical/spatial heterogeneity between individuals, [19] we should pause to clarify the proliferating number of new terms, technologies, statistical methods, and conceptual frameworks. In the hopes of providing some clarification on the term "movement," this brief report seeks to explain why the term movement applies *differently* when referring to measures derived from accelerometry and GPS devices. To achieve this, I briefly explain how accelerometry works to measure what could be labeled "weight shifting" and how GPS devices operate to capture what could be labeled "cartographic relocation."

Importance in the use of Terms: A publication by epidemiologist clearly showed how published work erroneously uses "accuracy" and "validity" interchangeably or treats "precision" and "reliability" as the same thing. [20] The use of terms is important, may be crucial to how we understand study findings, and is important when deciding if different studies are comparable. For example, a recent publication in *Nature* showed that reproducing scientific studies is rarely possible. [21] The authors focused their efforts on cancer research to show how only 6 of 53 studies could be reproduced. [21] A big problem was on what measurements meant-the lack of interchangeability in terms used to describe the measurement. The possibility that cancer research, a resource rich research sector populated by trained technicians, could be influenced by "flaws in the system" [21] may raise concerns on the quality of work being produce in research branches copping with low budgets and developing techniques.

At the very least, the publication highlights how precision in the language used to describe measurements can be directly related with reproducibility (or the lack thereof). Begley and Ellis argue that responsibility for the presentation of data rests with investigators [21] -the main argument prompting the formation of this manuscript. Because a large portion of public health research is funded by taxes (i.e., the public), researchers have an ethical duty to be rigorous in their methods and transparent about the meaning of their measurements. Theaxiom from which this technical paper is motivated is simple: Because between-study reproducibility may benefit the public, researchers must use precise language when explaining the meaning of their measurements in order to increase the possibility of appropriate between-study comparisons. Increasing the precision of terms may help reduce the ambiguity created from erroneously comparing studies that on the surface purport to be measuring the same thing: "movement."

Accelerometry: The use of accelerometry as a technique for measuring human activity was early on referred to as being able to measure "human body movements." [22] Accelerometry continues to be referred to as providing "ambulatory monitoring of human movement." [23] Admirable efforts continue to explore how accelerometers compare to other modes of measurements [24] and on the performance of accelerometry devices in smart phones. [25] Some of this work has argued "accelerometry-based motion" is best captured by triaxial accelerometers worn on the waist. [26] Although using accelerometers to measure activity may be problematic, [27] they have been and continue to be used widely in observational studies and clinical randomize trials to measure "movements."

In technical terms, accelerometers have the ability to measure the motion and vibration of human's dynamic load by measuring "proper accelerations." Accelerometers are said to capture *weight acceleration* by tracking change in weight and have been argued to be best suited for tracking flat-ground non-slow gait ambulation. In technological terms, accelerometers measure proper acceleration by detecting shifts between a rest state (where acceleration = 9.81 m/s^2 due to its weight and earth's gravity) and an inertial frame. Because an acceleration is said to have occurred when mass is displaced, detecting proper acceleration leads to unintuitive scenarios. For example, weight shifting may not be detected in a hypothetical bicycle rider who is perfectly still and streaming at 30 km/h down a perfectly smooth road. In this hypothetical scenario, the person is moving over geographical space but not shifting any body weight and thus, no "physical movement" would be detected via the accelerometer.

In relation to GPS devices, accelerometry does not measure physical movements over geographical space-accelerometers do not measure "coordinate acceleration" (explained below). Because of these reasons, I argue accelerometry measures a form of physical movement which could be referred to as "weight shifting." Investigating the relationship between frailty and physiological movements could be possible through accelerometry. This line of research would include studies attempting to understand how frailty is related with inferred energy expenditure, muscle mass, bone integrity, excess adipose tissue, and physical activity.

Global Position System (GPS): GPS has been successfully used to measure gait patterns [28] and has been argued to be a useful tool in measuring biomechanics in human locomotion. [29,30] Researchers have argued that accelerometers can be complement with GPS tracking [31] and studies have made use of GPS technology to objectively and precisely measure the movements of humans over their habitat. [31-33] to understand the mechanics of devices using GPS technology, we must understand the origin and operation of the satellites orbiting the earth.

The United States Nava Observatory's (USNO) NAVigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) is a US Department of Defense (DoD) developed a satellite-based radio-navigation system many decades ago. The worldwide radio-navigation (electromagnetic energy traveling at the speed of light) system builds on a constellation of satellites (>24) and their ground stations. It is primarily funded and controlled by the US DoD, which allows civil users (i.e., the private non-military sector) to use Standard Positioning Service (SPS) without charge or restrictions. More technically, SPS is provided on a frequency (GPS L1) which contains Coarse/Acquisition (A/C) codes (at 1.023 MHz chip rate) that provide predictable positioning accuracy of 100 meters (α = 0.05) horizontally and 156 meters (α = 0.05) vertically and time transfer accuracy to Universal Time Coordinate (UTC) within 340 nanoseconds (α = 0.05). By modulating (using a bi-phase shift keying) onto a carrier frequency, ranging codes and navigation message travel from the satellite to the receiver using a 1575.42 MHz (10.23 MHz×154) frequency in SPS GPS L1. GPS L1 is denied full accuracy through Selective Availability (SA) by truncating the orbital information of the navigation orbit data message and/or by intentionally corrupting GPS satellite clock frequency (i.e., clock "dithering"). It also guards against fake transmission of satellite data by encrypting the codes (P and Y) acquired by A/C. It should be noted that recent developments have shown how signal authentication can be vulnerable to "spooking attacks". [34-36]

GPS receivers convert satellite signals to estimate position, velocity, and time by using equations based on the mathematical principle of trilateration-a process that uses circles, spheres, or triangles. [37] In less technical terms, GPS is capable of detecting movement via the measurement of "coordinate acceleration." Movement is said to have occurred when there is a shift from 'position-A at time-1' to 'position-B at time-2.'This is achieved by combining the estimated position, velocity, and time of a GPS epoch (i.e., a time- and space-stamped event) with mapping technology. Mapping software uses mathematical model to represent the threedimensional geographical coordinate system (GCS) used in the transformation to two-dimensional surfaces (i.e., flat map) via mathematical transformation referred to as map projections (MP). Because GPS epochs are given meaning through their mapping, I referred to coordinate acceleration more directly as "cartographic relocation"-i.e., the labeling of a shift over a cartographic plane as movement. Cartography refers to the art and science of representing geographical factors graphically by means of maps.

As explained earlier, accelerometers can measure "proper acceleration" (motion and vibration of human's dynamic load). In contrast, GPS measures coordinate acceleration-here refer to more precisely as cartographic relocation. Acceleration over spatial coordinates is here being conceptualized ashaving congruency between proper time (elapsed time between two events) and coordinate time (elapsed space between two events). Movement could be represented with the following equation:

$$Movement = [(x_2 - x_1) - (y_2 - y_1)], \quad (1)$$

wherex_1 refers to longitude point at Time-1 (t_1);
$y_1$to latitude point at the same period, Time-1 (t_1);
$x_2$to longitude point at Time-2 (t_2); and
$y_2$to latitude point at same period, at Time-2 (t_2).

Cartographic relocation is said to have occurred if $Movement \neq 0$. Here again and as with the accelerometry hypothetical scenario of a bicycler riding down a smooth road, we have another unintuitive possibility: Because GPS devices produce coordinates that are unable to consistently predict the geographical position of a person at less than 2 meters, it is possible that a person could be standing in-place exercising by rotating their body-trunk and be registered as "not moving" via the GPS device. In this second hypothetical scenario, the person is weight shifting but *not* moving over geographical space and thus no "physical movement" would be detected via GPS. Investigating the relationship between frailty and geographical movements could be possible through GPS. This line of research could include studies attempting to understand how frailty is related toenacted mobility, social environments, outdoor behavior, environment exposures, mode of transportation, and activity space.

Precise Labeling: More mechanically and via equations, GPS devices measure *change in position over time* by providing a measure of linear acceleration:

$$\bar{v} = \frac{\Delta p}{\Delta t}, \quad (2)$$

Where velocity ($\bar{v}$) is the change (Δ) in position (p) over time (t). In contrast, accelerometers measures *change in* ***velocity*** *over time*, and produce outputs that are affected by linear acceleration and gravity. For example, Figure 1 display a hypothetical two axial accelerometer where a weight (known as the "proof mass") is suspended from four sides with springs (provides a two sensitivity axis). A shift in weight would cause a compression on the 'upright' springs while both gravity and weight shift would influence the 'side-to-side' springs. Although the amount of deflection in the spring is the net acceleration in the proof mass, accelerometers are said to measure linear acceleration caused by motion and the pseudo-acceleration ("specific force") caused by gravity. Thus, the deflection of the springs is the linear acceleration plus specific force-corrected for atmospheric temperature.

Measured acceleration is then subtracted from specific force to estimate linear acceleration due to motion, which is then used with the trapezoidal rule to produce velocity:

$$V_t = V_{t-1} + \Delta t\left(\frac{A_t + A_{t-1}}{2}\right), \qquad (3)$$

where V_t is velocity at current time step;
V_{t-1} is velocity at previous time step;
Δt is the given measurement of sample time by device (e.g., 0.01s);
A_t is the inertial acceleration at time step;
A_{t-1} is the inertial acceleration at previous time step.

To produce position as follows:

$$P_t = P_{t-1} + \Delta t\left(\frac{V_t + V_{t-1}}{2}\right), \qquad (4)$$

where P_t is position at current time step;
P_{t-1} is position at previous time step;
Δt is the given measurement of sample time;
V_t is the inertial position at time step;
V_{t-1} is the inertial position at previous time step.

Unlike accelerometers measuring *proper* acceleration, GPS measures *coordinate* acceleration. With accelerometry, movement actually refers to weight shifting and with GPS, it refers to cartographic relocation. This paper deals with more than just semantics: To say a person is not moving because they are not shifting their body weight enough to trigger the accelerometer may be misleading as is to say a person is not moving because they are not moving over geographical space. The lack of attention to how researchers use the term movement may be unintentionally misrepresenting their interpretations of findings and limiting comparability between studies. This paper stands with others in claiming that terminology matters. [18] GPS measures would be best when movement over geographical space matters most and accelerometry when body weight shifting is of interest.

DISCUSSION

The short communication outlines how two approaches assess movement. It contributes to ongoing discussions calling for advancing the methodological operationalization of mobility-related research. In a recent publication, the term "mobility disability" is delineated to extract flat-surface ambulation and step-climbing into more nuanced labels. [19] The main motivation of the discussion is the view that improving measurement on movement may impact public health and clinical practice by providing more specific information on how adverse health is related to physical movements. Because the advancement of operationalizing measurements may have the potential to advance knowledge, efforts should continue in this field of research.

CONCLUSION

Highlighting the importance of objectively measures of physical activity are discussed and compared is crucial to helping the development of 'up-stream' public health interventions meant to mediate the trajectories associated with adverse health outcomes like mobility disability. Obfuscation of research findings, stemming from the typically unnoticed ambiguity of term usage, could be diminished by making sure the term "movement" is clearly defined in the methods, interpretation of results, and discussion sections. There may be instances (e.g., when measuring activity space) where cartographic relocations matter most and others (e.g., when needing to infer energy expenditure) where weight shifting provides the most insight. The main point is to make sure and understand how the devices investigations use are connected to the terminology employed in conceptual models.

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