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Stride variability measures derived from wrist- and hip-worn accelerometers

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ABSTRACT

Many epidemiological and clinical studies use accelerometry to objectively measure physical activity using the activity counts, vector magnitude, or number of steps. These measures use just a fraction of the information in the raw accelerometry data as they are typically summarized at the minute level. To address this problem, we define and estimate two measures of temporal stride-to-stride gait variability based on raw accelerometry data: Amplitude Deviation (AD) and Phase Deviation (PD). We explore the sensitivity of our approach to on-body placement of the accelerometer by comparing hip, left and right wrist placements. We illustrate the approach by estimating AD and PD in 46 elderly participants in the Developmental Epidemiologic Cohort Study (DECOS) who worn accelerometers during a 400 m walk test. We also show that AD and PD have a statistically significant association with the gait speed and sit-to-stand test performance.

1. Introduction

Accelerometers are now ubiquitous in health studies, where they are used to provide objective and reproducible proxy measurements of physical activity. Examples of such studies include both large surveillance and epidemiological cohorts, such as the National Health and Nutrition Examination Survey (NHANES) [1] and the Baltimore Longitudinal Study of Aging (BLSA) [2], and clinical studies of chronic disease, such as Alzheimer's Disease [3], Multiple Sclerosis [4] and Heart Disease [5]. The primary activity measurements in these studies are usually limited to crude summaries of the 24-h activity cycle such as the total daily activity count, vector magnitude, or number of steps. When walking is of primary scientific interest, steps-based summaries provide useful information about "how much" and "when" the person is walking, but *do not provide any information about "how" the person is walking or "whether" their walking changes during the course of the day.* This type of information can be crucial in clinical and observational studies as it provides information about the intrinsic characteristics of walking and the associated variability. Understanding the association between these characteristics and levels of fatigue and fatigability in healthy and frail populations is a major step towards identifying parameters that are intuitive, can be easily extracted from raw accelerometry data, and are relevant to health studies. Quantifying gait parameters and ambulatory monitoring of changes in these parameters has become increasingly important for epidemiological, clinical and rehabilitation studies.

Several approaches extracting time-dependent gait parameters were developed and successfully applied to data collected from body-worn accelerometers [6–8]. These approaches demonstrated a significant discriminative power in studies of clinical pathology [9,10], fatigability [11,12], and aging [13–15]. Stride-to-stride variability is an important gait parameter that quantifies participants' ability to maintain walking consistency and is strongly associated with motor ability [16,17,9]. Stride-to-stride variability has been linked to Mild Cognitive Impairment [18], dementia [19], and stroke [20]. One of the limitations of current

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approaches is that they are based on data obtained from accelerometers placed around the middle of the body (hip, lower back) [21,22]. However, more research has recently shifted towards wrist-worn accelerometers such as the Actigraph Link, GENEActiv Watch, Fitbit Flex and Jawbone Up. This shift is likely due to their ease of use, increased compliance of study participants, and improvements in size and battery life [1]. This shift raises new challenges to estimating gait parameters, as hands are involved in a much wider spectrum of activities, which results in higher complexity and increased within- and between-subject variability [23].

We propose a method to extract two measures of stride-to-stride variability: Amplitude Deviation (AD) and Phase Deviation (PD). These measures are based on the amplitude of acceleration and duration of consecutive strides, respectively. We compare the performance of AD and PD calculated based on raw accelerometry data obtained from three body locations: the hip, the left wrist, and the right wrist. We evaluate the sensitivity of AD and PD as a function of on-body placement in 46 participants of the Developmental Epidemiologic Cohort Study [24]. To benchmark AD and PD against standard accelerometry summaries and physical function tests, we evaluate their association with four measures: cadence (C), vector magnitude counts (VMC), time on Five-Times-Sit-To-Stand (Chr_{5s}) test [25] and usual gait speed measured on a 6 m distance test ($Pace_{6m}$) [26].

2. Methods

2.1. Participants

Eighty-nine community-dwelling older adults were recruited from the Pittsburgh, Pennsylvania area for the National Institute on Aging, Aging Research Evaluating Accelerometry (AREA) project, part of the Developmental Epidemiologic Cohort Study (DECOS). AREA was a methodological initiative designed to examine the impact of accelerometry wear location on assessment of physical activity and sedentary behavior. This report includes data from 46 participants (25 males and 21 females; age: 78 ± 4 y.o.; BMI: 26.75 ± 3) who had completed fast paced 400 m walk test, were in a good overall physical health and reported no current history of medical conditions that could affect gait. Individuals were excluded from the study if they suffered from any of the following conditions: hip fracture, stroke in the past 12 months, cerebral hemorrhage in the past 6 months; heart attack, angioplasty, or heart surgery in the past 3 months, chest pain during walking in the past 30 days, current treatment for shortness of breath or a lung

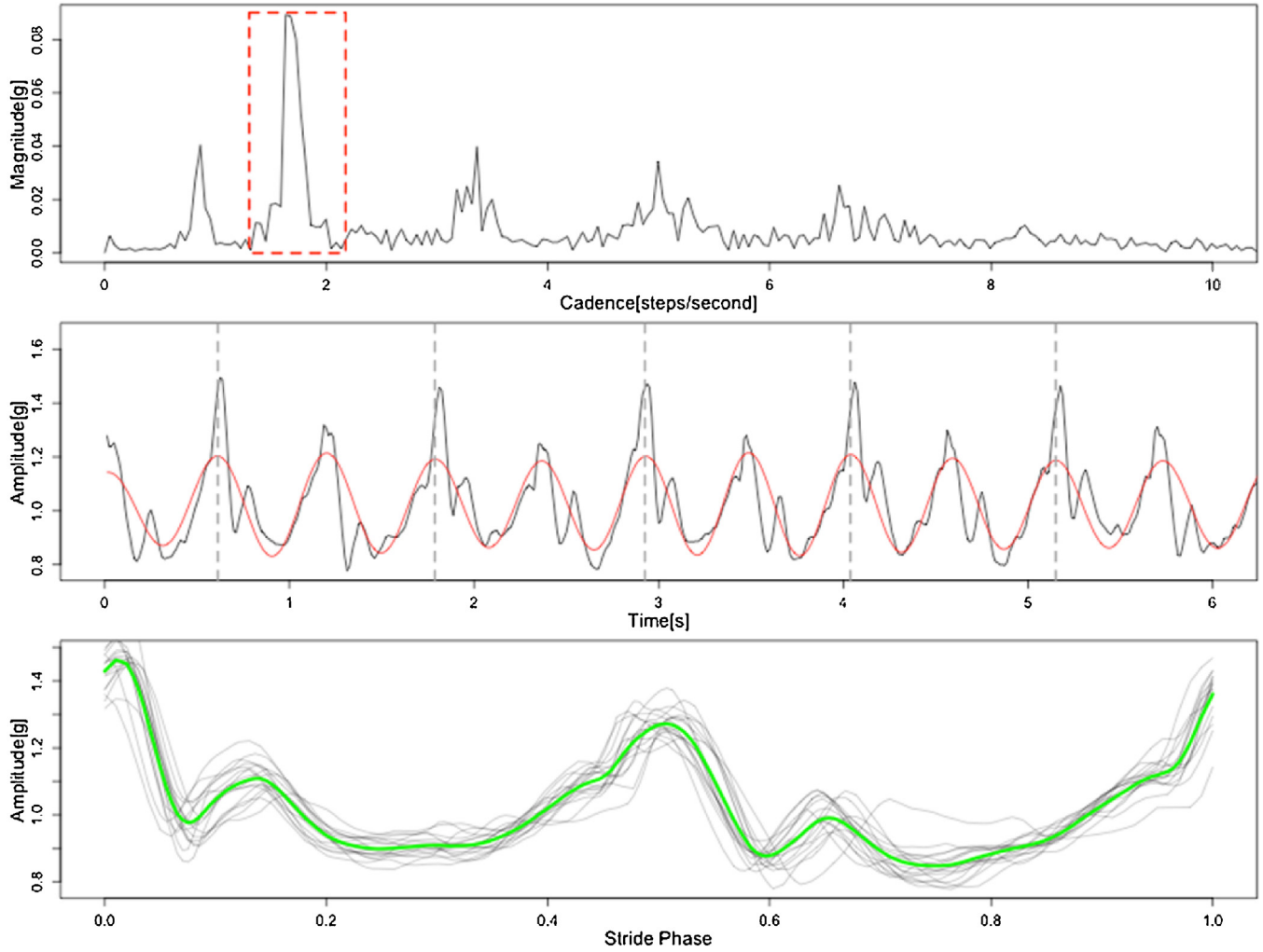

Fig. 1. Stages of strides synchronization process. Top panel – Fourier spectrum of gait acceleration signal. Red box marks frequency range corresponding to step-to-step frequency. Middle panel – Time view of gait acceleration signal (black line) and signal after filtration (red line). Bottom panel – synchronized stride profiles (gray lines) and resulting average stride profile (green line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)