Parametrization of Physical Activity Aggregation

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Abstract: This work introduces a novel approach to parametrization of physical activity profile. The proposed parameter, named as physical activity aggregation, is useful for evaluating a distribution of daily or weekly physical activity. The parameter takes a large value for a highly accumulated physical activity, whereas is much lower for an evenly spread activity over the monitoring period. The parameter was investigated on step data obtained using a smart wristband on a group of 71 participants with cardiovascular disease. The results of the pilot study show that the proposed parameter is capable of discriminating among different physical activity profiles, including sedentary behaviour, going to and from work, walking in a park and being active the entire day. Moreover, the results demonstrate the tendency that middle-aged and older women are associated with lower aggregation values, suggesting that they probably spend less time in sedentary behaviour compared to men of the same age. The proposed parameter has potential to be useful for characterizing physical activity profile, as well as, for investigating its relation to health outcomes, e.g., during ambulatory rehabilitation after major cardiovascular events.

1 INTRODUCTION

Physical inactivity is often considered among the leading risk factors of chronic diseases, and is closely related to all cause mortality (Biswas et al., 2015; de Souto Barreto et al., 2017). Unfortunately, according to the World Health Organization, more than 80% of the population are insufficiently physically active. It is widely accepted that even low physical activity is beneficial for health (Sattelmair et al., 2011), thus it is recommended to avoid sedentary behaviour as much as possible to reduce the risk of a hazardous outcome (Biswas et al., 2015).

Based on the latest report by the Physical Activity Guidelines Advisory Committee [PAG] (2008), there is an absence of research on optimal physical activity for healthy and unhealthy individuals. Therefore, optimization may potentially lead to an improved general health status and reduced number of deaths (Alves et al., 2016). Positive effect on health is observed for at least of 150 min weekly moderate activity (PAG, 2008). However, there is no consensus on whether 30 minutes in 5 days or 50 minutes in 3 days are more beneficial for health. In most studies, a measure of the total time spent in physical activity is usually employed for investigating causal relationships with chronic diseases and mortality (Warburton et al., 2010; Wilmot et al., 2012). Nevertheless, such factors as activity session frequency and duration may also be desirable to account for in order to comprehensively evaluate physical activity profile (PAG, 2008).

Rapid development of electronics and cloud technology has given rise to various means of long-term physical activity monitoring (Piwek et al., 2016). Therefore, the conventional approach for collecting information on physical activity via questionnaires can now be replaced by objective evaluation. The advancements in technology, capable of tracking physical activity (e.g., smart wristbands, smart watches, smartphones), have led to compact, user-friendly and inexpensive devices, which are especially suitable for monitoring for extended periods of time (months, years). Most of them provide information about the number of steps, sedentary time, climbed floors, travelled distances, etc. It has been shown that these devices are sufficiently accurate in tracking physical activity, therefore, they are becoming increasingly popular for use in research and medical applications (Leininger et al., 2016; Althoff et al., 2017; Leth et al., 2017).

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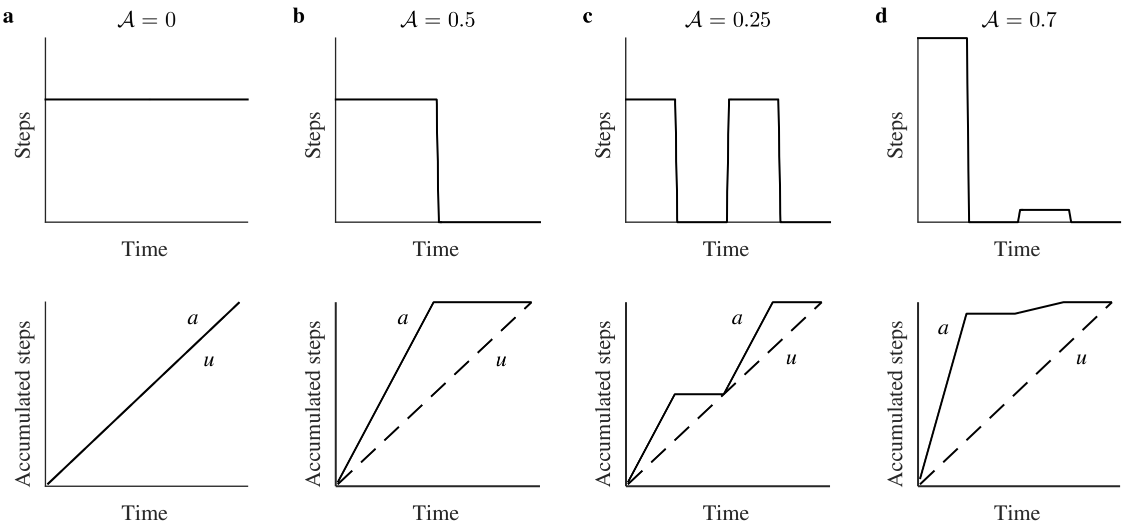

Figure 1: Physical activity profiles (above) with corresponding accumulated steps (below) of actual (a) and reference uniform (u) distributions: a) uniform distribution over the entire monitoring period, b) a continuous single episode taking half of the total monitoring period, c) two episodes of equal intensity, d) two episodes of unequal intensity.

In this paper, we propose a novel parameter for an objective evaluation of physical activity aggregation, allowing to express the distribution of physical activity over time in terms of a single number. The acquired new information can potentially be useful for long-term tracking of changes in the physical activity profile, as well as, for investigating its relationship to health status.

2 METHODS

2.1 Physical Activity Aggregation

In this study, we define physical activity as a number of steps in a time interval. Physical activity aggregation is given by

$$\mathcal{A} = \frac{2}{SN}\sum_{i=1}^{N}|a_i - u_i|, \quad (1)$$

where a_i and u_i are accumulated steps of actual and uniform distributions. The latter is used as a reference for computing the aggregation of actual distribution. S – the total number of steps in a time period under analysis (e.g., day or week), N – the total number of time intervals.

The function of accumulated steps of actual distribution a_i is expressed by

$$a_{i,j+1} = \sum_{k=i}^{i+j} s_k, i = 1,...,N-j, j = 0,...,N-1, \quad (2)$$

$$a_i = (a_{i,j})_{max}, i, j = 1,...,N, \quad (3)$$

where s – the number of steps in a time interval k.

The function of accumulated steps of reference uniform distribution u_i is expressed by

$$u_i = \frac{i}{N}\sum_{k=1}^{N} s_k, i = 1,...,N. \quad (4)$$

Physical activity aggregation $\mathcal{A}$ takes values between 0 and 1. Values close to 0 indicate low physical activity aggregation. This applies for physical activity profiles with steps evenly spread over the monitoring period (Fig. 1 a). In contrast, values close to 1 indicate maximal temporal aggregation, which is inherent for physical activity profiles with a single continuous activity episode (Fig. 1 d). It should be noted, that the aggregation parameter depends on the duration of an episode, i.e., $\mathcal{A}$ becomes larger for shorter physical activity episodes.

2.2 Study Population

Seventy-one participants (37 women), 51 ± 13 years old, with a body mass index of 27.1 ± 4.7 kg/m^2, were enrolled in the study. Most of the participants were diagnosed with serious cardiovascular diseases, namely, congestive heart failure, angina pectoris, myocardial ischemia, atrial fibrillation, hypertension, etc. A signed, written consent to participate in a study was obtained from all the participants.

In order to investigate the differences in physical activity profiles among different age women and men, the participants were assigned to three age groups (see Table 1).

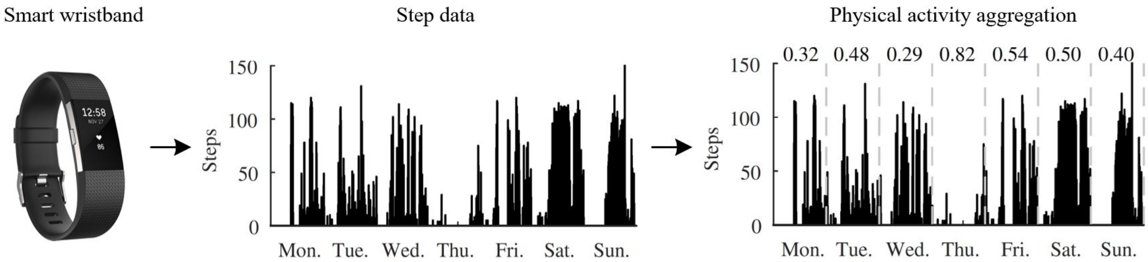

Figure 2: Acquisition of step data and evaluation of daily physical activity aggregation.

Table 1: The number of the participants in each age group.

Age	Women	Men
<50 years	11	16
50-60 years	13	12
>60 years	13	6

2.3 Data Acquisition

Minute-by-minute step data was obtained using a Fitbit Charge 2 (Fitbit, San Francisco, CA, the US) smart wristband. Then, the data was processed and used for estimating the physical activity aggregation, see block diagram in Fig. 2. Since no major activity is expected during the night, this time period was excluded from the computation of $\mathcal{A}$. The onset of the night was set when the number of steps per hour decreased to less than 20. Similarly, the end of the night was set when the number of steps per hour exceeded 20.

3 RESULTS

The obtained $\mathcal{A}$ values for various physical activity profiles clearly show that the aggregation parameter is sensitive to various step distributions (see Fig. 3). For example, a physical activity profile, dominated by a low intensity physical activity, results in a very low aggregation value (Fig. 3 a). Another physical activity profile (Fig. 3 b) demonstrates the case when the largest number of steps is aggregated during time periods corresponding to going to and from work. Such a profile is especially common among those working in an office. Similarly, the profile in Fig. 3 c represents an ordinary workday, however, with additional physical activity in the evening due to a 2 h walk in a park. Since half of the total daily activity is aggregated in the evening, the parameter value approaches 0.5. The example in Fig. 3 d stands for the profile when the participant is only active for a short period of time, therefore, almost all activity is aggregated in a continuous episode starting from 12 pm to 4 pm. For this reason, a highly aggregated physical activity results in a large $\mathcal{A}$ value.

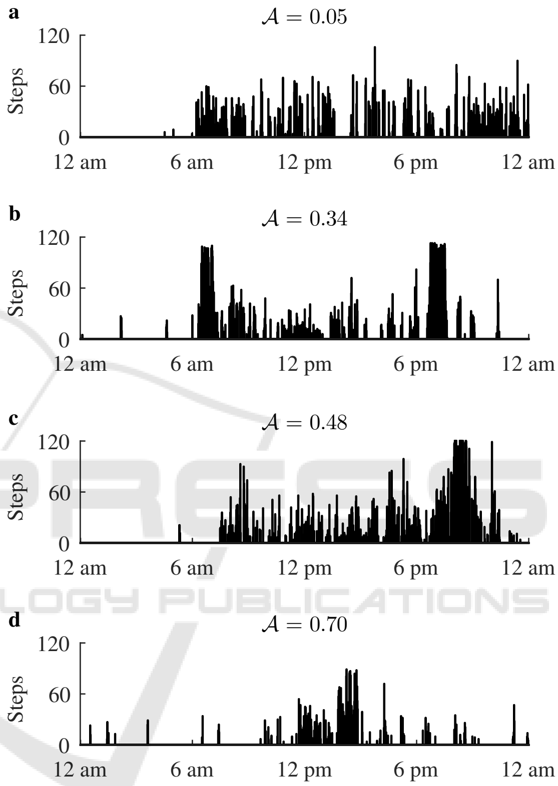

Figure 3: Different physical activity profiles with computed physical activity aggregation: a) uniformly distributed activity, b) aggregated during the time periods corresponding to going to and from work, c) aggregated during walking in the park at the evening, d) most of the activity aggregated in the afternoon.

Figure 4 displays physical activity aggregation among different age women and men. The results show that physical activity aggregation is larger among participants over 60 years compared to those under 50 years, which is obvious since younger individuals are more likely to be physically active, spreading physical activity over the day. Moreover, the results demonstrate the tendency of physical activity aggregation being lower for women than men, suggesting that women spend less time in sedentary behaviour.

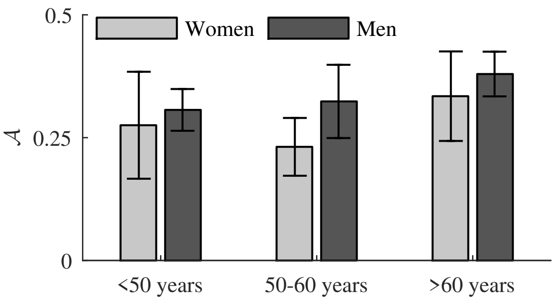

Figure 4: Physical activity aggregation among different age groups. Results are expressed as mean ± two-sided 95% confidence interval.

4 DISCUSSION

The goal of this work is to propose a parameter for an objective evaluation of a physical activity distribution. With such a parameter daily or weekly physical activity profile is characterized by a single number. The results of the pilot study show that the aggregation parameter is capable of differentiating among different physical activity profiles. Therefore, such information, collected over an extended period of time (months, years), could be useful for answering the core question what physical activity profile is optimal for different patient groups.

It is widely agreed that regularly performed physical activity extends life expectancy after major cardiovascular events, such as myocardial infarction. A study on leisure time physical activity influence on survival after myocardial infarction has shown that different survival rates are associated with regular and irregular physical activity, suggesting that a physical activity pattern may play a significant role in life expectancy (Gerber et al., 2011). Therefore, long-term monitoring of physical activity, and required corrections of an activity profile may improve ambulatory rehabilitation. Since a conventional approach using questionnaires is neither sufficiently accurate, nor convenient for both the patient and the physician, objective monitoring of aggregation using smart wristbands may be considered as a promising replacement for conventional methods.

The approach for quantifying temporal aggregation of specific events was first introduced for the purpose to characterize the distribution of self-terminating atrial arrhythmia episodes (Charitos et al., 2012; Charitos et al., 2013). Differently from the original approach, in which a single arrhythmia episode shorter than the total monitored time is always assigned to maximal aggregation, our approach is flexible and duration-dependent. That is, aggregation increases when the duration of a continuous physical activity episode decreases. This parameter update is motivated by the rationale that there is a major difference between a single very short episode (e.g., 5 min) and a long one (e.g., 2 h). Therefore, it is incorrect to assign such diverse physical activity profiles to the same aggregation value.

Large aggregation values represent physical activity profiles dominated by the sedentary behaviour. However, since the aggregation parameter is not affected by physical activity intensity, but rather by distribution itself, the value is the same both for low and high intensities. Based on the current agreement that "some activity is good, but more is better" (Sattelmair et al., 2011; PAG, 2008), the aggregation parameter can be even more valuable if studied with respect to other parameters, such as, physical activity intensity.

4.1 Limitations

The major limitation of this study is the small number of women and men participants assigned to different age groups. In addition, a study cohort preferably should cover a larger span of age to draw a more reliable insights on gender-related physical activity profile.

5 CONCLUSIONS

This study shows that the physical activity aggregation parameter is useful for an objective evaluation of a physical activity profile. The proposed parameter is especially suitable for implementation in devices, capable of tracking physical activity (smart wristbands, smartphones), therefore, can provide additional information on physical activity relationship with health status.

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