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Concern about Falling and Complexity of Free-Living Physical Activity Patterns in Well-Functioning Older Adults

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Keywords

Concern about falling · Physical activity · Accelerometer · Patterns · Complexity

Abstract

Background: Fall-related psychological concerns are common among older adults, potentially contributing to functional decline as well as to restriction of activities and social participation. To effectively prevent such negative consequences, it is important to understand how even very low concern about falling could affect physical activity behavior in everyday life. We hypothesized that concern about falling is associated with a reduction in diversity, dynamics, and performance of daily activities, and that these features can be comprehensively quantified in terms of complexity of physical activity patterns. ***Methods:*** A sample of 40 community-dwelling older adults were assessed for concern about falling using the Falls Efficacy Scale-International (FES-I). Free-living physical activity was assessed using a set of metrics derived from data recorded with a chest-worn tri-axial accelerometer. The devised metrics characterized physical activity behavior in terms of endurance (total locomotion time, longest locomotion period, usual walking cadence), performance (cadence of longest locomotion period, locomotion periods with at least 30 steps and 100 steps/min), and complexity of physical activity patterns. Complexity was quantified according to variations in type, intensity, and duration of activities, and was considered as an adaptive response to environmental exigencies over the course of the day. ***Results:*** Based on FES-I score, participants were classified into two groups: not concerned at all/fully confident ($n = 25$) and concerned/less confident ($n = 15$). Demographic and health-related variables did not differ significantly between groups. Comparison of physical activity behavior indicated no significant differences for endurance-related metrics. In contrast, performance and complexity metrics were significantly lower in the less confident group compared to the fully confident group. Among all metrics, complexity of physical activity patterns appeared as the most discriminative feature between fully confident and less confident participants ($p = 0.001$, non-parametric Cliff's delta effect size = 0.63). ***Conclusions:*** These results extend our understanding of the interplay between low concern about falling and physical activity behavior of community-dwelling older persons in their everyday life context. This information could serve to better design and evaluate personalized intervention programs in future prospective studies.

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Introduction

Fall-related psychological concerns are common among older adults, regardless of their health status [1]. People concerned about falling may restrict their mobility and their daily activities [2], thus increasing their likelihood to suffer from adverse consequences such as functional decline, increased risk of falling, restriction of social participation, and decreased quality of life [3]. Even among well-functioning older adults, the negative impact of concern about falling may be significant. For instance, previous work has shown that an increased level of concern about falling (assessed with Fall Efficacy Scale-International, FES-I) in robust community-dwelling older persons was associated with reduced mobility performance of similar magnitude than observed in the presence of a frailty criterion [4]. Therefore, the concern about falling and potential consecutive activity restrictions should be addressed early on to prevent these undesirable consequences [5]. Implementation of effective interventions in well-functioning older adults depends however on the capacity of the assessment tools to identify the dimensions of physical activity (PA) behavior that are mostly affected by concern about falling.

Activity monitors based on miniaturized body-worn motion sensors and data processing algorithms can be used to characterize objectively several aspects of daily-life PA. These aspects include PA type (e.g., sedentary, locomotion), intensity (e.g., body acceleration, walking cadence), duration (e.g., distribution of locomotion periods), frequency (rate of change of body movements and activities), and patterns, defined as the temporal sequence of movements and body postures that occur when individuals engage in daily life activities [6]. Some of the relevant features of free-living PA patterns are their diversity and dynamics that emerge from the moment-to-moment variations in body movements, postures, and underlying activities. Conceptualized in terms of complexity, these features may reflect the ability of the person to timely respond to task/environmental demands and to adapt to internal states [6, 7]. Over the last two decades, age-related functional deficits have been increasingly interpreted within the context of a "low complexity" hypothesis [8]. Indeed, decreased complexity has been described for the gait pattern [9, 10], the trajectory of body sway during quiet standing [11], as well as for the patterns of walking and PA behavior in free-living conditions [12, 13]. This decreased complexity in the output of the locomotor system has been postulated to arise from the degradation in the interactions between various systems such as, for example, the musculoskeletal, proprioceptive, and psycho-cognitive [7, 8, 10, 11]. The concern about falling and the perceived fall risk are controlled by psycho-cognitive processes that mediate the individual's confidence and behavior to carry out specific activities, particularly in challenging conditions [14, 15]. This implies an inverse relationship between the level of concern and activity function, as well as activity performance [16]. The current evidence comes essentially from studies that used measures of walking performance in clinical/laboratory settings [14, 15], and the collected self-reported information about the level of mobility and activities of daily living rather than objective measures [17]. There is a lack of knowledge regarding the association between very low concern about falling and objective features of PA behavior recorded in daily life settings among well-functioning community-dwelling older people.

Considering PA as a multidimensional, quantifiable construct, the purpose of the present study was to: (a) monitor daily-life PA in a sample of well-functioning community-dwelling older adults using a single chest-fixed motion sensor; (b) devise a set of meaningful PA metrics; (c) investigate the association between levels of concern about falling and PA metrics. The hypothesis was that a decreased complexity of PA patterns assessed over prolonged periods will be associated with a higher level of concern. In particular, we hypothesized that within a sample of well-functioning older adults, the subtle differences in PA behavior related to the presence of concern about falling during challenging activities inside and outside the home [16] will be better captured with metrics quantifying the complexity of PA patterns than with usual metrics such as the total time spent walking [13].

Method

Participants

Study participants were community-dwelling older adults (n = 40) who were (eligibility criteria): aged 65 years and over; independent in all basic activities of daily living; able to walk more than 1 km (0.6 mi) with or without assistive devices. In addition, all subjects were assessed for frailty condition using Fried's phenotype criteria (i.e., self-reported low physical activity, slowness, weakness, self-perceived exhaustion, and unintentional weight loss [18]), and only those categorized as non-frail (score 0) or pre-frail (score 1–2) were included. Exclusion criteria included the presence of frailty condition, cognitive impairments and living in a nursing home. The study was approved by the local ethics committee, and written consent was obtained from all participants.

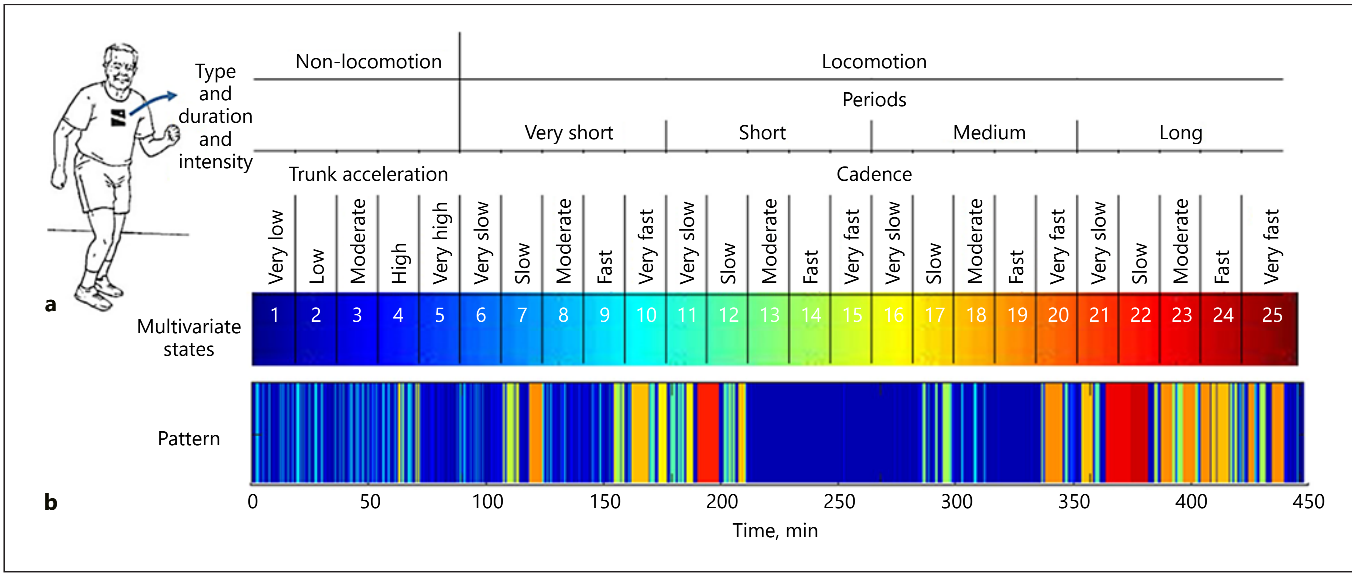

Fig. 1. Assessment of daily physical activity (PA) as a multidimensional construct characterized by type, duration, intensity, and pattern. **a** The fine-grained characterization of PA behavior is obtained by partitioning the possible range of values spanned by each parameter into several intervals, and then by combining parameters across the defined intervals to define 25 multivariate PA states (see Supplementary material for additional information). **b** The PA pattern represented as the temporal sequence of states over the course of the day; the color-based visualization provides a quick overview of the subject's PA behavior during the monitoring period.

Measurements

Demographics, Health, and Functional Mobility Variables

Demographic data included age, gender, body weight, height, and living situation. Self-perceived health status was categorized as very good/good, fair, and poor/very poor. Additional variables were the presence of comorbidities (yes/no), the use of walking aids (yes/no), and the presence of self-evaluated depressive symptoms (yes/no). The number of falls in the previous year was recorded, and participants were categorized as fallers if they had one or more falls over the last 12 months. The level of concern about falling was measured using the FES-I [16]. FES-I includes questions about a person's confidence in his or her ability not to fall when performing various daily activities inside and outside the home. For easier interpretation, the FES-I score was reversed and standardized (rsFES-I) in order to provide a score ranging from 0 to 100, with higher scores indicating higher confidence (no concern). For statistical analyses, the rsFES-I scale was dichotomized as fully confident/not concerned at all (rsFES-I = 100) and less confident/concerned (rsFES-I <100) [4]. Participants' functional mobility status was assessed using the timed up-and-go test (TUG).

Free-Living PA Assessment

Spontaneous PA was monitored in the usual environment of each participant over 2 consecutive days, using a wearable device including tri-axial accelerometer, electronics for data acquisition, memory, and rechargeable batteries (Physilog®; Gait Up, Lausanne, Switzerland). A harness with elastic straps was used to attach the device at mid-sternum level. After recording, the raw data were processed to classify the type of PA as periods of locomotion (i.e., minimum three steps of walking/running) and non-locomotion (including lying, sitting, standing). Locomotion periods were characterized by their duration, number of steps, and cadence. Steps were associated to heel-strike events, identified from the trunk vertical acceleration signal [19, 20]. During non-locomotion periods, PA was characterized according to intensity of trunk movements as very low, low, moderate, high, and very high, using cut-off thresholds for the dynamic acceleration component (gravity subtracted acceleration norm, see online suppl. material; see www.karger.com/doi/10.1159/000490310 for all online suppl. material). These basic parameters reflecting the type, duration, and intensity of PA were used in further analysis to: (a) devise a set of metrics to quantify aspects of endurance and performance in the context of free-living activity; (b) define patterns of PA and quantify the underlying behavioral features in terms of complexity metrics.

Endurance was represented by the amount of time spent in locomotion (as % from daily monitoring time), the longest continuous locomotion period (in steps), and the most frequent/usual cadence estimated as the mode of cadence distribution for all detected locomotion periods (in steps/min).

Performance was characterized by the cadence of the longest locomotion period, and the number of locomotion bouts longer than 30 steps with cadence equal or superior to 100 steps/min, that may correspond to outdoor purposeful activity [21–23] (expressed as % of the total number of locomotion bouts).

The definition of temporal PA patterns is intended to illustrate and quantify the individual's physical behavior over the course of the day [6, 12, 13, 24]. Based on the methodology developed in [6], refined and adapted to single-sensor configuration, a comprehensive representation was obtained by combining the parameters related to the type, duration, and intensity into multivariate PA states, as described in Figure 1a. The possible range of values

Table 1. Sociodemographics, health, and mobility-related characteristics of study participants and their comparisons across levels of concern about falling

Characteristics	All (n = 40)	Fully confident (n = 25)	Less confident (n = 15)	p value
Age, years	74±6	72±4	75±6	0.200
Gender (female), n	26	15	11	0.300
BMI	25±4	24±4	26±3	0.100
Living condition (alone), n	16	9	7	0.370
Very good/good self-assessed health, n	36	21	15	0.500
Comorbidities (yes = 1, no = 0), n	31	19	12	0.920
Depression (yes = 1, no = 0), n	5	2	3	0.310
Walking aids (yes = 1, no = 0), n	1	0	1	0.900
Pre-frail (yes = 1, no = 0), n	17	8	9	0.300
Faller (yes = 1, no = 0), n	11	5	6	0.350
TUG, s	10.5±2.4	9.5±1.5	12.2±2.8	0.001

spanned by each parameter was partitioned into several intervals, and combinations across intervals were related to 25 PA states. The fine-grained PA states corresponded to different levels of movement intensity during non-locomotion, classified according to the values of dynamic component of trunk acceleration, and to different locomotion intensity categorized according to the duration and cadence of each detected period [22, 25–27] (see online suppl. material for detailed description). Each state was assigned a number/color (e.g., non-locomotion with moderate trunk acceleration corresponds to state "3" and a cold color, whereas long locomotion periods at moderate cadence correspond to state "23" and a warm color).

By classifying on a second-to-second basis the recorded raw acceleration data into the defined states, PA pattern emerges as the temporal sequence of various states; this sequence can be visualized as a color barcode (Fig. 1b), and can be represented as a numerical sequence for subsequent complexity analysis. The complexity attribute, postulated to arise from diversity of states and dynamics of change between states, was quantified with measures derived from Lempel-Ziv complexity (LZC) theory [6, 28]. Basically, LZC determines the number of distinct temporal subsequences of PA states, as well as the rate of their recurrence, with larger values indicating higher complexity of the given PA pattern [6]. Analysis included the classical LZC and an improved version named permutation LZC (PLZC), devised to increase performances of LZC in terms of sensitivity for complexity assessment and robustness to possible signal artefacts [29].

Endurance, performance, and complexity metrics were estimated from data recorded on each day and average values over the 2 days were reported for statistical comparisons.

Statistical Analysis

Subject characteristics were summarized descriptively using means and standard deviations. Fully confident (not concerned about fall) and less confident (concerned) participants were compared in terms of demographics, clinical, functional, and daily PA measures using the Wilcoxon-Mann-Whitney rank test for continuous variables, and the Fisher's exact test for categorical variables. The effect size or the magnitude of difference was estimated using the non-parametric Cliff's delta measure [30]. All possible values of Cliff's delta measures are in the closed interval (−1, +1). An effect size of +1.0 or −1.0 indicates the absence of overlap between the two groups, whereas a value equal to zero indicates that group distributions overlap completely.

Correlations between parameters were quantified using Spearman rank-correlation test. Statistical significance was set at $p < 0.05$. The whole analysis was performed using MATLAB computing software (vR2013a, MathWorks, Natick, MA, USA).

Results

Subject Characteristics

Descriptive statistics of participants including demographics, health, and functional variables are presented in Table 1. The sample (n = 40) ranged in age from 65 to 86 years, 26 were women, 13 had BMI >25 (categorized as overweight), 16 were living alone, 36 reported good or very good health, 31 had at least one comorbidity, 5 reported some depressive symptoms, and only 1 participant used a walking aid. According to Fried's phenotype criteria, 23 participants were classified as non-frail and 17 as pre-frail (15 with one and 2 with two Fried's criteria). Eleven participants reported one or more falls in the previous year (3 reported two or more falls). However, the TUG score (in seconds) indicated good functional mobility (mean ± SD: 10.5 ± 2.4) according to the age-related normative values described in the literature [31].

The FES-I score was highly skewed: for 25 subjects rsFES-I = 100 (fully confident group), and for 15 subjects rsFES-I was between 95 and 99 (mean ± SD: 96.5 ± 1.2) (less confident group).

Comparison between Groups: Fully Confident versus Less Confident

Demographics, Health, and Functional Mobility Variables

No significant difference was observed in age, gender, body mass index (BMI), living condition, self-assessed health status, the presence of comorbidities, depressive symptoms, pre-frail condition, and previous fall experience (Table 1). However, TUG score was significantly increased in the less confident group as compared to the fully confident group, indicating an association of the decrease in functional mobility and the mere presence of concern about falling.

Free-Living PA Measures

A first insight about potential differences in daily PA behavior between fully confident and less confident participants was obtained from the distribution plots illustrated in Figure 2a–d. Although the shape of distribution appeared similar, some differences were noticeable in the tail (i.e., how much probability is distributed over the largest values) and location (i.e., typical or central values such as mean/median/mode) parameters. For instance, the dynamic component of trunk acceleration (Fig. 2a), estimated as the mean value in consecutive time windows of 1-s length, showed an asymmetric distribution, with highest probabilities corresponding to very low/low movement intensity (right/positive skewed). The duration of locomotion periods also had a distribution skewed to the right, with high probabilities for very short/short durations and low probabilities for long duration of periods (Fig. 2b). In contrast, cadence displayed a normal distribution with peaks around 100 steps/min (Fig. 2c), a value corresponding to moderate PA intensity according to several studies [27, 32, 33]. The distribution of cadence by duration of locomotion periods (Fig. 2d) indicated a higher prevalence of locomotion periods combining long

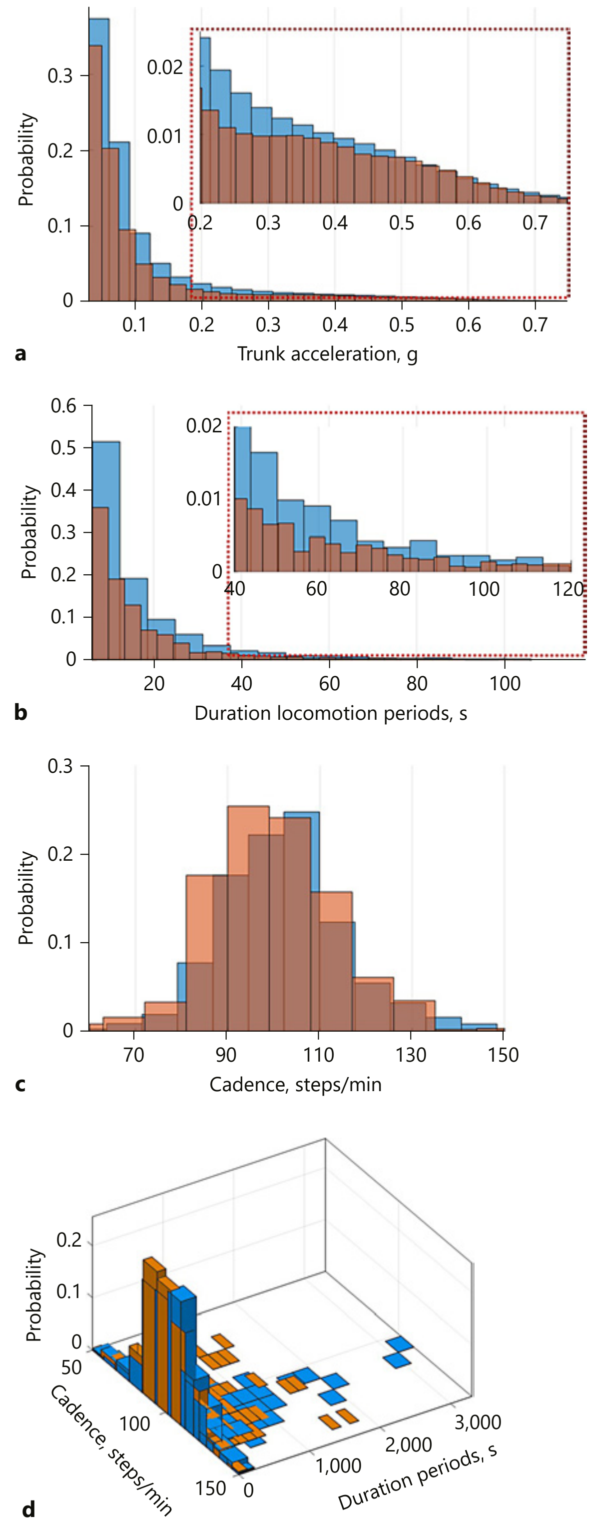

Fig. 2. Distribution plot of PA parameters in fully confident (rsFES-I score = 100, blue color) and less confident (rsFES-I score < 100, brown color) participants. **a** Dynamic component of trunk acceleration norm (in gravity units, g) (see Supplementary material) estimated as mean values in consecutive 1 second epoch length. **b** Duration of locomotion periods (in seconds). **c** Cadence of locomotion periods (in steps/min). **d** Bivariate distribution plot showing the duration of locomotion periods by their cadence. The height of each bar (probability) is the relative number of observations (i.e., the number of observations in bin divided by the total number of observations). **a**, **b** Graphs contain a zoomed-up inset plot to improve visibility of the long right tail of distribution.

Table 2. Physical activity metrics of study participants and their comparisons across levels of concern about falling

	All (n = 40)	Fully confident (n = 25)	Less confident (n = 15)	p value	Effect size
Endurance					
Time spent in locomotion, %	14.6±7.1	14.8±6.5	14.0±8.0	0.700	0.07
Longest locomotion period, steps	860±790	937±903	743±591	0.700	0.07
Usual cadence, mode, steps/min	99±11	100±9	97±8	0.600	0.10
Performance					
Cadence of longest locomotion period, steps/min	111±4	115±6	106±14	0.030	0.40
Locomotion periods with at least 30 steps and 100 steps/min, % of total n	64±20	69±20	57±18	0.020	0.42
Complexity					
LZC metric	0.26±0.04	0.28±0.04	0.23±0.03	0.003	0.57
PLZC metric	0.22±0.05	0.40±0.07	0.30±0.06	0.001	0.63

duration and high cadence in the fully confident than in the less confident participants.

Endurance and Performance Metrics. As shown in Table 2, fully confident and less confident subjects did not differ significantly on the endurance metrics, reflected by the time spent in locomotion per day, the duration of the longest locomotion period, and the usual locomotion cadence. However, the performance metrics represented by the cadence of longest locomotion period and the number of bouts with at least 30 steps at a cadence of 100 steps/min or more, were significantly lower in less confident compared to fully confident participants.

Complexity of PA Pattern. The complexity measures used to comprehensively characterize PA patterns in daily life were significantly lower in the less confident participants. Among all the metrics compared in Table 2, complexity measures appeared the most discriminative between fully confident and less confident participants, as indicated by their larger effect size (see also online suppl. Fig. 1S).

Correlations between Variables

Weak to moderate significant correlations were observed between the rsFES-I score and the TUG ($r = -0.50$, $p < 0.001$), the cadence of longest locomotion period ($r = 0.33$, $p = 0.030$), the number of locomotion periods with at least 30 steps and 100 steps/min ($r = 0.4$, $p = 0.008$), and both measures of complexity of PA patterns ($r = 0.46$, $p < 0.002$ and $r = 0.52$, $p < 0.001$ for LZC and PLZC, respectively).

Similarly, the TUG score appeared correlated with some of PA metrics, i.e. the usual locomotion cadence ($r = -0.38$, $p = 0.010$), the number of locomotion periods with at least 30 steps and 100 steps/min ($r = -0.50$, $p = 0.001$), and PA complexity (PLZC metric, $p = -0.35$, $p = 0.040$). These weak to moderate correlations are in line with accumulated evidence suggesting that functional mobility assessed in the lab/clinic does not entirely reflect an individual's functioning in everyday life [34, 35].

Discussion

This study demonstrates that data collected with a single accelerometer-based device attached to the trunk and appropriate analysis tools can provide a set of meaningful metrics related to various dimensions of daily PA behavior in older persons, such as endurance, performance, and complexity of the temporal patterns. This contribution is especially important at a time when unobtrusive wearable devices allow the long-term monitoring of PA in real-life conditions. The resulting large amount of recorded raw data makes it of utmost importance to enhance its interpretation and clinical applicability by providing a more accurate and integrated picture of a person's PA behavior. The current understanding of PA as a multidimensional construct implies that data analysis tools should provide at the same time a detailed characterization of each of the various dimensions as well as a more integrative representation. The methodology and results presented here indicate that these aims can be achieved successfully through the development of several specific descriptive metrics.

The main contribution of the presented study is to extend our understanding of the interplay between low concern about falling and PA behavior of well-functioning older persons in their everyday life context. Results show that even a very low concern about falling was associated with significantly decreased measures of performance and complexity of PA patterns, but not endurance. Indeed, measures devised to comprehensively characterize PA behavior using the concept of multivariate pattern and complexity, like LZC and PLZC, were those most strongly associated with the presence of some concern about falling. Furthermore, both measures appear to best discriminate between fully confident and less confident groups, as suggested by their largest effect size (Table 2). These results can be explained by the capacity of complexity metrics to integrate multiple aspects of individuals' physical behavior over the course of the day. Indeed, the variety of states defining on a second-to-second basis the temporal pattern of PA (Fig. 1) can describe in great detail the body movements and activities a person performs in the daily-life context. For example, the five states during non-locomotion periods ("1" to "5"), characterized by different intensity of trunk acceleration, may correspond to mobility-related tasks such as standing up, turning around to sit down, bending/flexion for reaching, or turning. For older persons, these are demanding tasks/movements that challenge their static balance. Similarly, the twenty states during locomotion periods ("6" to "25") describe locomotion in different contexts: for instance, short bouts at different cadences are more likely to be part of various indoor tasks, whereas long periods at higher cadence are more likely to correspond to outdoor activity. Moreover, some of these multivariate states ("12" to "15," "17" to "20," and "22" to "25") are related to locomotion performance (i.e., are assigned to locomotion periods with at least 30 steps and 100 steps/min). In this context, the complexity of the multivariate PA patterns appears as an appropriate measure to assess objectively the relationship between concern about falling, as formulated by the items of FES-I, and PA behavior in everyday life.

Overall, this study provides evidence supporting the hypothesis that well-functioning older adults without concern about falling (i.e. fully confident group) can span a wider range of movements/activities and therefore have more complex PA patterns (as assessed by LZC/PLZC metrics) than those with even very low concern. Although these individuals with very low concern about falling may be physically active, they might adopt a more cautious behavior (e.g., slowing down or avoiding challenging body movements and activities) resulting in a paucity of variations of PA states and consequently a less complex PA pattern.

From a theoretical standpoint, these results appear in line with the concept of physiological and movement (gait, postural control, PA patterns) complexity loss with ageing-/disease-/fall-related functional decline [6, 8, 10, 11, 13]. A preliminary study conducted in a sample of community-dwelling adults, aged 38–98 years, indicated an abrupt decrease in the complexity of PA patterns with aging, starting around 75 years [13]. The present study is, to our knowledge, the first attempt to quantify and understand changes/decrease in movement complexity with increased levels of concern about falling. Concern about falling may result from the interplay between factors that cover the entire spectrum of physical, cognitive, psychological, environmental, and behavioral dimensions [36]. Decline in one or more of these multiple factors potentially triggers an imbalance in their delicate interplay that, in turn, negatively influences an older person's participation in and performance of daily activity, reduces his/her capacity to adapt to task demands and environmental conditions, and consequently, reduces the complexity and dynamics of PA patterns.

The homogeneous sampling of well-functioning study participants has led to a ceiling effect for the rsFES-I score. The investigation of the relationship between concern about falling and PA behavior in a sample with a narrow range of concern is a limitation, and further studies are necessary to verify the reproducibility on a broader range, and on groups stratified according to the consensus in literature [37]. Nevertheless, the significant decrease in PA performance and complexity observed in the current study, despite the very low level of concern about falling, further strengthen the proposed approach.

Another limitation is the relatively small sample size in each group that may have led to underpowered statistical comparisons. However, despite the modest number of participants, the large effect size observed for complexity metrics as compared to usual PA metrics such as the time spent in locomotion (see illustrative non-overlap between groups in online suppl. Fig. 1S) indicates that the results obtained are robust and worth to be applied/replicated in future studies. The methodology described (see online suppl. material) can be applied to acceleration data recorded on any location on the trunk segment, e.g. low back or waist, which are frequently used for ambulatory monitoring in large cohort studies. Analysis of such datasets may allow to better understand the concept of complexity of daily-life PA behavior and its relationship with various clinical conditions.

Conclusion

In this sample of well-functioning community-dwelling older persons, low concern about falling was associated with decreased performance and complexity of daily PA patterns, but not with endurance. These results could be informative to design and evaluate improved personalized interventions programs. In fact, since PA endurance seems unaffected by very low concern about falling, further studies should investigate whether interventions specifically tailored to modify PA performance and complexity in daily life have a stronger effect than standard exercise programs [38].

Disclosure Statement

The authors declare no conflict of interest.

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