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Human Kinetics
ORIGINAL RESEARCH

Physical Activity and Sedentary Behavior at the End of the Human Lifespan

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To objectively assess physical activity levels and sedentary behavior in a cohort of Spanish centenarians and their nonagenarian peers. Physical activity and sedentary behavior patterns were objectively measured by an ActiGraph GT3X accelerometer in centenarians ($n = 18$; 83% women; 100.8 ± 0.8 [100–103] years) and nonagenarians ($n = 11$; 91% women; 93.3 ± 2.5 [90–98] years). Centenarians showed less counts per minute (17.6 ± 7.1 vs. 46.1 ± 23.7, $p = .003$, $d = 1.851$) and steps per day (455 ± 237 vs. $1{,}249 \pm 776$, $p = .007$, $d = 1.587$) than nonagenarians. The daily number of sedentary breaks was also lower in the former (5.0 ± 1.5 vs. 6.7 ± 2.0, $p = .019$, $d = 0.971$). When observing time distribution, the most active day period in both groups was the morning, with a peak between 10:00 and 11:59. This data suggest that the decline in physical activity levels continues to worsen until the end of the human lifespan.

Q1 ***Keywords**:* accelerometry, centenarian, longevity, sedentary lifestyle

The population of centenarians (≥100 years) is steadily increasing globally (Byass, 2008) being the paradigm of human extreme longevity and healthy aging because they have postponed, if not avoided, major age-related diseases, for example, cancer, cardiovascular disease, or neurodegeneration (Salvioli et al., 2008), as well as the onset of disability (Christensen, McGue, Petersen, Jeune, & Vaupel, 2008; Terry, Sebastiani, Andersen, & Perls, 2008). Despite this global demographic development, very old individuals (i.e., centenarians) remain an understudied and underserved population and little is known about their physical activity (PA) and sedentary behavior (SB) patterns, both factors contributing to healthy aging and longevity (Hall et al., 2014).

It is well known that PA levels decline with age, being older adults (65 years and older) the most physically inactive population (Troiano et al., 2008). It has also been reported that older adults spend 8.5–9.6 hr per waking daytime in SB (usually defined as the length of time spent sitting or lying, i.e., energy expenditure of 1–1.5 metabolic equivalents; Sedentary Behaviour Research Network, 2013; Wullems, Verschueren, Degens, Morse, & Onambélé, 2016). Furthermore, "oldest-old" individuals (85 years and older), who account for the fastest growing population segment in western societies, seem to be more sedentary than their younger older adults peers (Harvey, Chastin, & Skelton, 2015).

Despite this trend, the older adults including centenarians, do not routinely receive counseling by health care professionals on lifestyle habits linked to an improved quality of life and prolonged survival, particularly PA (Berra, Rippe, & Manson, 2015). The current PA recommendations of the World Health Organization for adults aged 65 years and above, that are the same than those proposed for younger adults from 18- to 64-years old, include to do at least 150 min of moderate-intensity aerobic PA throughout the week or do at least 75 min of vigorous-intensity aerobic PA throughout the week or an equivalent combination of both. However, due to the common health and physical conditions of this older population, the World Health Organization recommends to be as physically active as their abilities and conditions allow. World Health Organization emphasizes the importance of adjusting the PA for each individual, based on their exercise capacity and specific health risks or limitations (World Health Organization, 2010). For this reason, PA levels and SB patterns and indicators need to be accurately assessed in the different population subsets with the aim of conducting knowledge-based counseling.

Although the exceptional longevity is partially conditioned genetically (Santos-Lozano, Santamarina, et al., 2016), being physically active has demonstrated to delay and even prevent the pathophysiology of several noncommunicable disease and alterations associated with aging including Alzheimer's disease, metabolic syndrome-related disorders, hypertension and cardiovascular disease, some types of cancers, sarcopenia, and skeletal muscle dysfunction (Garatachea et al., 2015; Pareja-Galeano, Garatachea, & Lucia, 2015; Santos-Lozano, Pareja-Galeano, et al., 2016).

The conventional method of obtaining self-reported PA data through questionnaires is inexpensive and generally well accepted by study participants. However, the validity of such data is questionable (Tucker, Welk, & Beyler, 2011) because of biases arising from different levels of social desirability and the cognitive challenge of quantifying both the intensity and duration of PA (Adams et al., 2005; Hills, Mokhtar, & Byrne, 2014; Welk, 2002).

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Such biases have prompted an interest in finding a less subjective way of monitoring PA. Accelerometers provide minute by minute recordings of PA and have been shown to be a reliable method for assessing both PA and SB in older adults (Gorman et al., 2014; Prince et al., 2008). Although PA and SB have been assessed by accelerometers during free living in older adults from 70 to 90 years (Chase, Lockhart, Ashe, & Madden, 2014; Johannsen et al., 2008; Simmonds et al., 2014), there is no accelerometry data available, to our knowledge, for centenarians until now. Therefore, the purpose of this study was to objectively assess PA and SB in Spanish centenarians and their nonagenarian peers.

Methods

Experimental Design

The study participants were of the same European American (Spanish) descent for ≥3 generations and lived in different areas of Spain. Inclusion criteria were to be a woman or a man, aged ≥90 years in the group of nonagenarians and ≥100 years in the case of centenarians. With regard to the exclusion criteria, the bedridden older adults were excluded; however, patients with reduced mobility were included, and also if they were helped by the caregivers, they used walking stick or walker. Likewise, older adults who were going through an acute disease process were excluded; nevertheless, the presence of chronic diseases or mental disorders such as dementia was not considered an exclusion criterion given the high prevalence in the last decades of life. Table 1 shows the descriptive characteristics of both groups. Almost all were women (83% of centenarians and 91% of nonagenarians). The most frequent chronic diseases were arterial hypertension, osteoarthritis, and cardiopathy. The number of diseases (2.4 vs. 5.5) and number of drugs consumed (2.1 vs. 9.9) by nonagenarians was greater. Although nonagenarians
Q4 showed greater independence in the activities of daily living.

Accelerometry was recorded for 7 days. The subjects and their caregivers were received written and verbal instructions to wear the accelerometer from the moment they woke up in the morning until bedtime at night. Also, they were asked to note in a provided diary the time when they wore the devices, when they were removed at the end of the day, and any time when the devices were removed and reattached during the day.

The study was approved by the ethical committee for clinical
Q5 research of the region (ID of the approval: PI17/0082) and was conducted adhering to the tenets of the declaration of Helsinki. Signed informed consent was obtained from all participants or their caregivers.

Measures

The PA was objectively measured by an ActiGraph GT3X accelerometer (ActiGraph, LLC, Pensacola, FL). The device was mounted on the right hip with an adjusted elastic belt to ensure close contact with the body. Monitors were set to record PA in a 15-s epoch, and the "Step Count" mode was selected. This device is lightweight (27 g), compact (3.8 × 3.7 × 1.8 cm), and has a
Q6 rechargeable lithium polymer battery. The GT3X collects movement in three axes with a range of ~0.05 to 2.5 Gs, then the accelerometer output is digitized, each sample is summed over an "epoch," and the output is given in an arbitrary unit called "counts." The value of the counts will vary based on the frequency and intensity of the raw acceleration. ActiGraph GT3X accelerometer has been validated for the assessment of PA and SB in older adults (Aguilar-Farías, Brown, & Peeters, 2014; Santos-Lozano et al., 2013) with a high classification accuracy (ROC-AUC of 0.81, 0.85, and 0.82 for 1-, 15-, and 60-s epochs, respectively; Aguilar-Farías et al., 2014) and an intrainstrument coefficient of variation of ≤2.5% (Santos-Lozano et al., 2012).

Results were processed with ActiLife software (version 6.5.4; ActiGraph). The classification of wear and nonwear intervals was done using an algorithm based on ≥90 min of consecutive counts per minute (CPM) equal to zero, without allowing for interruptions (Peeters, van Gellecum, Ryde, Farías, & Brown, 2013). Also, 10 hr was established as the minimum necessary to be considered a valid day (Matthews, Hagströmer, Pober, & Bowles, 2012), with at least five valid days (Hart, Swartz, Cashin, & Strath, 2011), including one weekend day (Mâsse et al., 2005; Trost, Mciver, & Pate, 2005), to include the subject in the analysis. Moreover, only hours with ≥45 valid wear minutes were included (Sartini et al., 2015). The previously reported cut points proposed by Aguilar-Farías et al.

Table 1 Descriptive Characteristics of Centenarians and Nonagenarians Group

Outcome	Centenarians	Nonagenarians
Age (years)	100.8 ± 0.8 (100–103)	93.3 ± 2.5 (90–98)
Sex (%)		
Women	83	91
Chronic diseases (%)		
Dementia	11	9
CVD	11	0
Osteoarthritis	22	64
Cardiopathy	33	64
Cancer	22	18
Diabetes	6	18
AHT	56	45
COPD	0	9
Others	50	82
Total number	2.4 ± 1.3 (0–5)	5.5 ± 1.7 (3–9)
Number of drugs	2.1 ± 1.2 (0–4)	9.9 ± 3.5 (2–14)
Activities of daily living (%)		
Dressing		
Independent	0	36
Needs help	21	0
Dependent	79	64
Bed to chair and back		
Independent	7	36
Needs help	14	18
Dependent	79	46
Walk more than 50 m		
Independent	7	36
Needs help	22	19
Dependent	71	45
Bath or shower		
Independent	0	27
Needs help	0	0
Dependent	100	73

Note. Scale values are mean ± *SD* and min–max. CVD = cardiovascular disease; AHT = arterial hypertension; COPD = chronic obstructive pulmonary disease.

(2014) for older individuals in free-living environments were used to estimate the time spent in SB (<10 counts/15 s for the vertical axis) and active time (≥10 counts/15 s); in this way, the definition achieved when registering in 15-s epoch was not lost. Finally, bouts analysis was performed using counts relative to 60 s because the ActiLife software does not allow different units of 1 min, ≥25 CPM at vertical axis was defined for 10-min activity bouts, and the sedentary bouts were calculated for 30 min (<25 CPM at vertical axis; Aguilar-Farías et al., 2014), these durations are not random; the international PA guidelines recommend that aerobic activity should be performed in bouts of at least 10-min duration, and 30 min is a commonly used duration in the scientific literature to describe "prolonged sedentary time" (Thorp et al., 2012; World Health Organization, 2010). Breaks in SB were defined as an activity above 25 CMP after having been more than 30 min below this threshold, in other words, the end of a sedentary bout.

In addition, an analysis of time of day effect was also carried out. For this purpose, all outcomes were also calculated during three different periods of a day: morning (7:00–12:59), afternoon (13:00–18:59), and night (19:00–6:59) (Davis et al., 2011; Garriguet & Colley, 2012; Sartini et al., 2015).

Statistics

Data are presented as mean ± *SD* values. The normality of data was checked with the Shapiro–Wilk test. Unpaired Student *t* test was used to analyze significant differences in variables between groups (or its nonparametric equivalent, the Mann–Whitney *U* test). To test if there was an interaction between group and period of the day, two-way analysis of variance was carried out. Statistical analyses were performed using IBM SPSS (version 20 for Windows; Chicago, IL), and the significance level was set at $p \le .05$.

Results

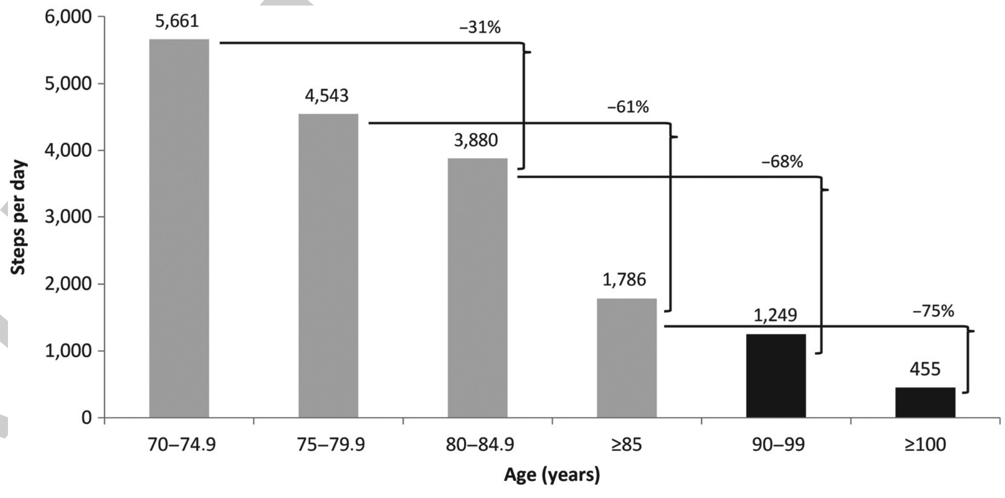
Eighteen centenarians (83% women; mean ± *SD* [range]: 100.8 ± 0.8 [100–103] years)] and 11 nonagenarians (91% women; 93.3 ± 2.5 [90–98] years) (Table 1) met inclusion criteria of the accelerometry analysis (i.e., five valid days with at least 10-hr recorded, including one weekend day). Table 2 shows the results obtained by accelerometry. Centenarians had significantly lower CPM values ($p = .003$, $d = 1.851$) and steps per day ($p = .007$, $d = 1.587$) than their nonagenarian peers. The number of daily sedentary bouts ($p = .018$, $d = 0.914$) and breaks ($p = .019$, $d = 0.971$) was also lower in the former.

Figure 1 represents the number of steps per day during the last decades of life. As our study begins in nonagenarians, data from Davis et al. (2011) are showed for adults aged from 70 to 85 years. As can be seen, when the age increases, the decrease in the number of steps was more and more accentuated: –31% (70–74 vs. 80–84 years), –61% (75–79 vs. ≥85 years), –68% (80–84 vs. 90–99 years), and –75% (≥85 vs. ≥100 years).

Table 2 Physical Activity and Sedentary Behavior in Centenarians and Nonagenarians Group

Outcome	Centenarians	Nonagenarians	*p* value*	*d*
Counts per minute for *y*-axis	17.6 ± 7.1	46.1 ± 23.7	**.003**	1.851
Activity time (min/day)	63 ± 38	98 ± 59	.061	0.722
Activity bouts (times/day)	0.55 ± 0.71	1.17 ± 1.16	.130	0.663
Steps/day	455 ± 237	1.249 ± 776	**.007**	1.587
Sedentary time (min/day)	920 ± 193	1.007 ± 167	.225	0.483
Sedentary bouts (times/day)	5.2 ± 1.5	6.8 ± 2.0	**.018**	0.914
Sedentary breaks (times/day)	5.0 ± 1.5	6.7 ± 2.0	**.019**	0.971

Note. Values are mean ± *SD*. Significant *p* values are in bold. *d* = Cohen *d* size effect. *Unpaired Student *t* test.

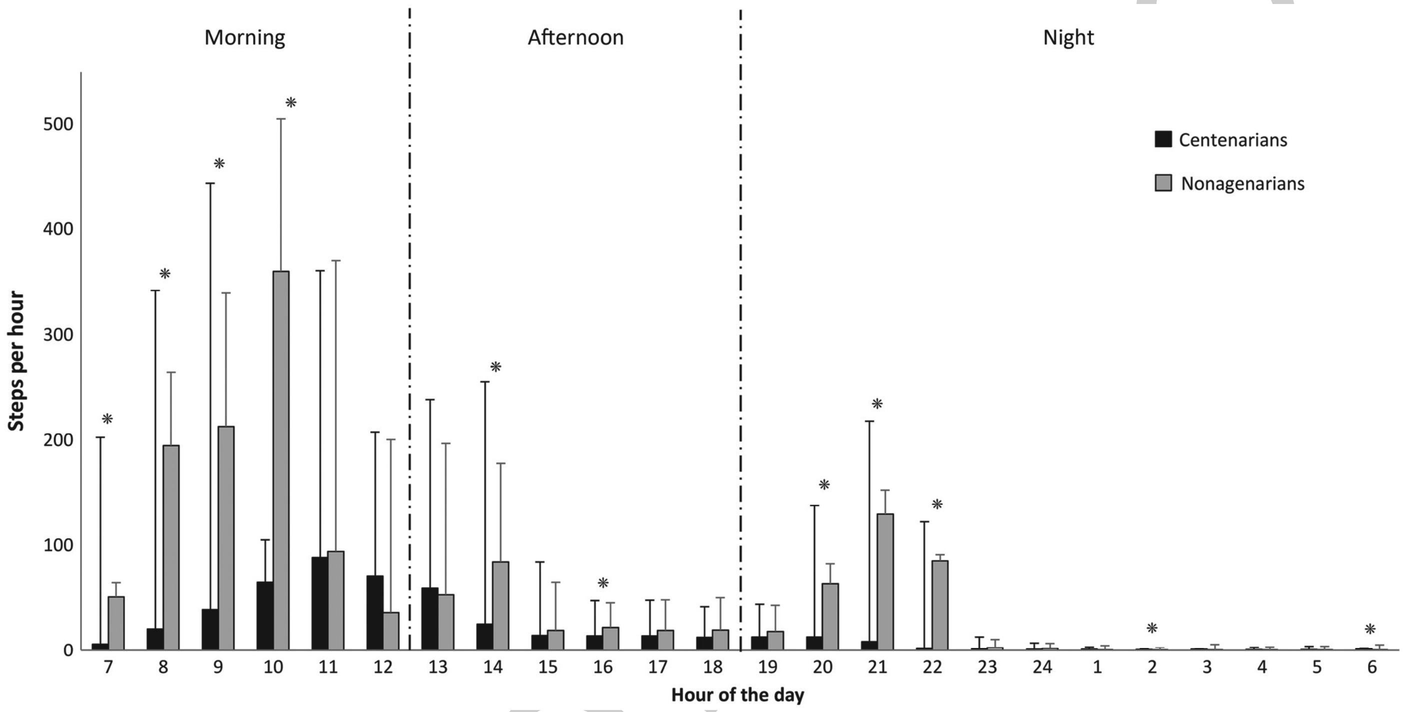


Q7 **Figure 1** — Number of steps per day during the last decades of life.

Table 3 Physical Activity Outcomes During Different Periods of the Day in Centenarians and Nonagenarians Group

	Centenarians			Nonagenarians		
Outcome	**Morning**	**Afternoon**	**Night**	**Morning**	**Afternoon**	**Night**
CPM	$38.0 \pm 90.3^{*,a,n}$	$20.0 \pm 57.2^{m,n}$	$4.6 \pm 17.3^{*,m,a}$	$113.3 \pm 258.7^{*,a,n}$	23.5 ± 72.3^{m}	$23.6 \pm 66.2^{*,m}$
Activity time (min/hr)	$4.5 \pm 7.3^{*,n}$	4.2 ± 6.6^{n}	$1.0 \pm 2.8^{*,m,a}$	$7.1 \pm 12.0^{*,a,n}$	$4.9 \pm 6.8^{m,n}$	$2.0 \pm 4.8^{*,m,a}$
Steps/hour	$49.5 \pm 160.4^{*,a,n}$	$23.8 \pm 78.7^{m,n}$	$3.8 \pm 12.9^{*,m,a}$	$123.8 \pm 303.0^{*,a,n}$	36.0 ± 126.1^{m}	$25.1 \pm 88.8^{*,m}$

Q8 *Note*. Values are mean ± *SD*. CPM = counts per minute for *y*-axis; η_p^2 = partial eta squared effect size. *Differences between centenarians and nonagenarians, same period of the day ($p < .05$). [m]Different to morning, same group ($p < .05$). [a]Different to afternoon, same group ($p < .05$). [n]Different to night, same group ($p < .05$).



Q9 **Figure 2** — Mean number of steps per hour throughout the day.

Table 3 shows PA outcomes in different periods of the day. There was a significant interaction effect between the age group and the period of the day, on the PA performed (CPM, activity time, and steps; $p \leq .001$, $\eta_p^2 = .018$), which indicates that the centenarians' and nonagenarians' PA were affected differently by period of the day. As can be seen in Table 3 and Figure 2, nonagenarians had greater activity than centenarians mainly because of the morning activity. Similarly, the younger group had a greater activity at night. On the other hand, the afternoon activity was similar in both groups.

Finally, Figure 2 shows the mean number of steps per hour throughout the day. There were observed three main peaks where nonagenarians' activity was significantly greater: early morning (7:00–10:59) at 14:00, and at the beginning of the night (20:00–22:59). Centenarians seem to increase their number of steps at the end of the morning while decrease progressively until night, although its activity was never significantly greater.

Discussion

To our knowledge, this is the first evidence in which PA levels have been objectively assessed by accelerometers in centenarians. Centenarians were less active (CPM and steps per day, −62% and −64%, respectively) and in consequence more sedentary (30' sedentary bouts; +29%) than nonagenarians. This results indicate that even in people aged >90 years, PA level continues decreasing with age. Davis et al. (2011) also reported lower values of steps per day (by −61%) in persons aged ≥85 years as compared with young-old adults (75–79.9 years; 1,786 vs. 4,543 steps/day, respectively), whereas the difference was smaller (−31%) when comparisons were made among younger age ranges 70–74.9 years (5,661 steps/day) versus 80–84.9 years (3,880 steps/day), as can be seen in Figure 1 (Davis et al., 2011), which represents a greater loss than the 7.5% decline per decade indicated by Doherty et al. (2017) in subjects aged from 45 to 79 years.

Although rare, there are cases of centenarians who not only avoid the usual fall of PA but who also continue participating in sports competitions, even improving their sports performance (+11%) and maximal oxygen uptake (+13%) between 101 and 103 years, which reflects the plasticity and ability of human tissues to favorably adapt to PA at any age (Billat et al., 2017). This could indicate that, although the decrease of PA seems to be higher during the last decades of life, it is never too late to start exercising given that “oldest-old” adults (≥90 years) who are more active have a greater functionality (indeed, the distance reached in a 6-min walk test is positively associated with PA levels; Johannsen et al., 2008). Functional independence is directly dependent on physical fitness, that is, “the ability to carry out daily tasks with vigor and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies” (Park, 1989). In turn, physical fitness is determined by several measurable health-related phenotypes, including mainly cardiorespiratory fitness and muscle function.

The SB has recently emerged as an independent risk factor for cardiovascular disease, diabetes, mental health problems, and some cancers, as well as all-cause cancer and cardiovascular disease mortality (Biswas et al., 2015; de Rezende, Rey-López, Matsudo, & do Carmo Luiz, 2014; Koster et al., 2012; Thorp, Owen, Neuhaus, & Dunstan, 2011). Some authors have pointed to PA decrement from youth to adulthood, and then PA and SB seem to be stable until retirement age when another decline occurs (Johannsen et al., 2008). Along this line, centenarians group spent more than 15 hr per day in SB, which is twofold higher than the levels usually found in young-old adults (Wullems et al., 2016). Thus, nonagenarians spent 91% of their waking time in SB, with this value reaching 94% in centenarians, who in addition also showed a more inactive pattern. This indicates that the most rapidly growing subgroup of the population (i.e., oldest old) is at the same time the most inactive.

On the other side, growing strong epidemiological evidence support that regular PA is an influencing factor for healthy aging and is associated with lower risk of all-cause mortality and major chronic diseases (Hallal et al., 2012). Centenarian group spent only 63 min a day actively, whereas nonagenarians spent 98 min. Several studies with mice have shown that voluntary wheel running decreases with age (Garcia-Valles et al., 2013; Holloszy, Smith, Vining, & Adams, 1985; Stolle et al., 2018). In addition, lifelong spontaneous exercise improves survival (more mice attain old age; Holloszy et al., 1985) and also ameliorates health span, that is, the portion of the life span during which function is sufficient to maintain autonomy, control, independence, productivity, and well-being (Garcia-Valles et al., 2013). Therefore, it could be hypothesized that although centenarians perform less PA now, the protective effect of lifelong PA could be a key factor that allowed them to achieve a long and healthy life. However, it should not be forgotten that exceptional longevity is a complex trait, some authors say that nongenetic factors, including diet, PA, health habits, and psychosocial factors contribute approximately 50% of the variability in human lifespan with another 25% explained by genetic differences (Rea, Dellet, & Mills, 2016).

In our study, both groups were more active during the morning than afternoon or night, and nonagenarians were more active than centenarians during morning and even during night ($p < .05$). Results during the afternoon were similar between groups, being physically active during the morning the main contributor to the difference between nonagenarians and centenarians, that is, 7 min versus 5 min of moderate to vigorous PA per hour ($p \leq .001$, $\eta_p^2 = .003$) or 124 versus 50 steps per hour ($p \leq .001$, $\eta_p^2 = .008$). In consonance, morning has already been pointed out by other authors as one of the moments of greatest variability in PA levels and therefore a great moment to implement PA enhancement programs (Sartini et al., 2015).

When the time of day effect was analyzed for number of steps (Figure 2), we found similar results to previous studies in older adults (71–91 years), the highest number during the morning (with a peak between 10:00 and 11:59), and a small increase at 14:00 (Doherty et al., 2017; Sartini et al., 2015). However, some slight Q10 differences deserve to be discussed. First, nonagenarians' showed another peak at the beginning of the night (20:00–22:59) that could be due to cultural differences, as in Spain this period corresponds with dinner time (Eurostat, 2007). Also PA levels during the Q11 morning were different between groups. Nonagenarians seem to be more active in the early morning (7:00–10:59) and centenarians at the end of the morning (9:00–13:59). This behavior could be related to the fact that older adults with high fatigability reach their peak of PA later in the morning (Wanigatunga et al., 2018), or it could also be because some participants were institutionalized and their schedules were more defined.

The identification of time patterns of behavior will allow making some recommendations that could be considered when proposing an intervention with the oldest-old adults. Some interventions ideas could be as follows: (a) the morning is the time of greatest variability in PA, whereby is a good time to try to extend the duration of bouts of PA and/or encourage to increase the intensity of PA in older adults with a level of functionality that allows it; (b) it is important to try to individualize the intervention: adults with greater fatigability seem to reach their peak of activity at the end of the morning, time patterns may depend on cultural differences as well as whether the older adults are institutionalized or not; and (c) the afternoon is the time of the day with the highest SB, as recent studies have shown (Nagai et al., 2018) replacing just 30 min of SB with light PA decreases the risk for frailty in older adults.

We believe that the main strength of this study comes from the elevated sample size, considering that exceptional longevity is a rare phenotype (≈1/10.000 individuals live to the age of 94–110 years; Martin, Bergman, & Barzilai, 2007), and this study is novel because this is the first study that PA and SB have been objectively assessed in centenarians. Another important strength of our study is the measurement of PA and SB in everyday life during a whole week, using a device and cut points validated in older adults, so there is a great ecological validity. On the other hand, although most of the long-lived older adults are women and suffer from chronic diseases, one of the main limitations is selection bias as we use a sample of convenience. Another limitation is that all the participants are Spanish and white, and the generalization of the results could be partly limited. In future research, and to replicate the results obtained with our cohort, future studies with more representative samples of exceptionally long-lived older adults are necessary.

Up to now, it has been shown that the level of PA decreases progressively in the older adults; the present study confirms that this trend continues to worsen until the end of the human lifespan. A progressive decrease in PA and exercise capacity leads to a downward spiral of reduced physical function and health, which translates into increased health costs. Thus, maintaining high levels of PA and reducing SB must be viewed as a main priority for health policymakers.

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