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Analysis of Physical Activity Among Free–Living Nonagenarians From a Sardinian Longevous Population

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Physical activity was identified as a major determinant of longevity. Using wearable accelerometers, we evaluated energy expenditure (EE), including resting- (REE) and total-energy expenditure (TEE), physical activity level (PAL), percentage of PAL ≥ 3 metabolic equivalent tasks (METs), number of steps, resting index (RI%) and sleep patterns in 44 free-living nonagenarians (27 men) residing in a Sardinian village famous for its longevous population. The average REE and TEE recorded were 1275 ± 163 kcal/day and 2284 ± 543 in the men and 952 ± 108 kcal/day and 1810 ± 302 in the women, respectively. The average PAL was 1.8, and the percentage of physical activity >3 METs was greater than 40%. A significant negative correlation ($p < 0.05$) between disability and PAL was found among the women. This study provides evidence that nonagenarians from the longevous population of Sardinia show excellent physical functionality indexes. Their longevity might result, at least in part, from their ability to stay physically fit during aging.

Keywords: longevity, Longevity Blue Zone, physical activity, Villagrande Strisaili

Human longevity is a multifaceted trait likely due to numerous interacting causes (Christensen & Vaupel, 1996). Among the modifiable factors that have been associated with longer survival, persistent physical activity plays an important role (Lissner, Bengtsson, Björkelund, & Wedel, 1996). Previously, several epidemiological studies provided evidence that regular physical exercise in adult life was able to reduce mortality and extend lifespan (Paffenbarger, Hyde, Hsieh, & Wing, 1986). Among these, the Physicians' Health Study (Yates, Djoussé, Kurth, Buring, & Gaziano, 2008), the study of British twins (Cherkas et al., 2008) and the Louisiana Healthy Aging Study (Frisard et al., 2007; Johannsen et al., 2008) showed that, in addition to a significant decrease in mortality, regular exercise was associated with improved late-life physical function. The association between moderate levels of physical activity and maintenance of physical functionality and independence is currently recognized; however, to our knowledge, studies specifically addressing the relationship between physical activity and exceptional longevity are scarce (Frisard et al., 2007; Tiainen, Raitanen, Vaara, Hervonen, & Jylhä, 2015).

The population living in central Sardinia is particularly suitable to this type of research for two main reasons: (i) this population resides in an inland area considered a *Longevity Blue Zone* (LBZ) where an exceptional life expectancy among men was described more than a decade ago (Poulain et al., 2004); (ii) until recently, this population practiced agriculture or animal husbandry, occupations both entailing high levels of outdoor physical activity up to an advanced age (Pes et al., 2013). An ongoing survey is being performed in one LBZ village (Villagrande Strisaili, herewith called Villagrande) aimed at investigating genetic and non-genetic determinants of exceptional longevity in all subjects aged 90 years and older, which facilitates the quantitative evaluation of the daily physical activity of the oldest subjects.

For the quantification of physical activity, several tools have been developed including a diary of motor activity and similar individual questionnaires (self-reported or interviewer-administered) and proxy interviews (Aguilar-Farías, Brown, Olds, & Geeske Peeters, 2015; Saris et al., 2003). Although these methods have been largely employed in the past, their accuracy has been questioned as poor (Sallis, King, Sirard, & Albright, 2007). More objective methods to quantify physical activity include direct observation, the use of double-labeled water, monitoring of cardiac frequency and movement sensors (Arnardottir et al., 2013; Colbert et al., 2011). However, all these methods except the last are time-consuming and require specific training by the operators. Among the portable movement sensors able to record energy expenditure (EE) under free-living conditions, the Sensewear™ Armband (BodyMedia Inc., Pittsburg, PA, USA) has gained popularity because it can provide complete and accurate motor analysis (Malavolti et al., 2007). Such a device, equipped with a biaxial accelerometer, is able to continuously monitor the following: (i) the total energy expenditure (TEE) associated with physical activity; (ii) the duration and intensity of physical activity, expressed as metabolic equivalent tasks (METs) and the number of steps; and (iii) the alternation of periods of activity and rest/sleep. Recently, the Cronolife® software (SensorMed Inc., Rome, Italy) has made available algorithms allowing the calculation of various motor indexes.

In this study, daily physical activity and its relationships with functional status were assessed in free-living nonagenarians from the village of Villagrande (Sardinia), a well-known longevity area. The study may contribute to the planning of activity programs able to improve physical performance in advanced age.

Methods

Study Population

Subjects aged 90 years and older from the village of Villagrande were enrolled in this study. After obtaining informed consent, a structured questionnaire was administered to collect demographic and functional data.

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Assessment of Functional Independence

The level of self-care and functional independence was determined through the 6-item Activity of Daily Living (ADL) questionnaire (feeding, bathing, dressing, bowel and bladder control, toilet use, transfers from bed to chair and back, and grooming). Performance in such tasks was expressed by a score ranging from 0 to 6, with a higher score indicating a better performance.

Assessment of Movement Pattern

Individual motor activity during a three-day interval was measured by the Sensewear™ Armband, positioned in the tricipital area of the non-dominant arm. Estimates of resting energy expenditure (REE) and total energy expenditure (TEE) were directly provided by the device; the active energy expenditure of each subject was calculated as the TEE / REE ratio, defined as the Physical Activity Level (PAL). The REE was estimated by selecting a two-hour nighttime interval (from 4:00 to 6:00) when the subject was supposedly in deep sleep. Single activities were converted into energy equivalents through the calculation of METs. By definition, one MET is the amount of oxygen consumed at rest for every kg of body weight (3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$). The Armband-recorded data were further analyzed by the Cronolife® software, which calculated seven parameters of motor activity, thus providing a snapshot of the motor style of the subject being investigated. The analysis of resting time was performed by calculating the time in which subjects remained in the supine position (Resting Time, RT), the actual time devoted to sleep (Sleep Time, ST), and the Resting Index (RI%), calculated by the formula (RT / ST × 100).

Statistical Analysis

Comparisons between groups were performed using the non-parametric Mann-Whitney U-test for continuous and ordinal variables, and Pearson's χ^2 test for categorical variables. Correlation was assessed by the non-parametric Spearman coefficient. The significance level was set at $p < 0.05$ for all calculations. Statistical analysis was performed using SPSS 16.0 for Windows (Chicago, IL).

Results

A total of 27 men and 17 women > 90 years old from the village of Villagrande agreed to participate in the study. All individuals were born between 1918 and 1926 and represented 50% of all nonagenarians living in the village. This cohort is a subset of an ongoing multidisciplinary study targeting elderly subjects living in the Sardinia Longevity Blue Zone. Table 1 shows the main features of all participants examined. Interestingly, all subjects lived in independent apartments, except for one living in a nursing home. The physical functionality score measured by the activities of daily living (ADL) was quite high in both genders. Relatively poor scores were reported during the assessment of cognitive performance, owing to the influence of a low educational level. Self-reported health was high in both genders. Curiously, the percentage of subjects never married was significantly higher among the women (29.4 vs 14.8, $p < 0.0001$).

Table 2 shows the indexes of motor activity. Most of the subjects fell within the category of "moderate" activity with PAL values of approximately 1.8 in both genders, suggesting an active lifestyle. None of the subjects displayed a "hypokinetic style" usually associated with poor health, defined by a PAL value lower than 1.4. The percentage of energy expenditure exceeding 3 METs (the threshold value corresponding to moderate physical activity) was 42.5% among the men and 46.3% among the women. The proportion of time spent in "light" activity (MAL ≥ 3 METs) was 2.41 among the men and 2.04 among the women. Energy expenditure associated with steps, a complementary parameter to assess the quality of daily activity, was quite high in both genders (Table 2).

Table 1 Main Features of Nonagenarians From Villagrande Participating in the Study

Variable	Men ($n = 27$)	Women ($n = 17$)
Age (years)	92.3 ± 2.9	92.0 ± 2.7
Body mass index (kg/m^2)	23.8 ± 16.4	25.5 ± 18.4
Housing (in apartments)	100%	94.1%
Never married (%)	14.8	29.4
Married (%)	59.2	23.5
Widower (%)	29.6	47.0
Household size	2.71 ± 0.80	2.48 ± 0.11
Standardized MMSE[§]	19.7 ± 6.5	19.2 ± 6.3
Self-reported health[#]	3.34 ± 0.74	3.48 ± 0.77
Activity of Daily Living*	4.9 ± 1.5	4.8 ± 1.4

*Number of disabilities among a total of 6.
§MMSE: Mini–Mental State Examination (range from 0 to 30).
#Score from 1 very bad to 5 very good.

The analysis of resting time showed that the total daily sleep time (including nighttime sleep and naps) averaged 6.3 hours among the men and 5.6 hours among the women; it was adequate for 57% of the surveyed nonagenarians (6–7 hours daily). In addition, Table 2 shows the correlation of motor indexes with ADL. A high and significant coefficient of correlation was observed only among the women for the PAL and the energy expenditure corresponding to activities greater than 3 METs.

The CronoLife software allowed the expression of the parameters calculated in the form of a "motor polygon", i.e., a polar diagram providing an immediate visualization of the subject's physical activity. The polygon for men and women is displayed in Figure 1. The area inside the polygon was wider in the men compared to the women. Interestingly, in none of the subjects studied did the average values of the motor indexes fall within the central blue area of reduced motility.

Discussion

Engaging in regular physical activity is essential for maintaining long-term good health and functionality (Buchman, Yu, Boyle, Shah, & Bennett, 2012; Gremeaux et al., 2012; Huffman, 2010; Paffenbarger et al., 1986; Rajpathak et al., 2011; Venturelli, Schena, & Richardson, 2012). The determination of the level of physical activity in an individual is not always an easy task because of the multifaceted nature of motor activity. Although several methods have been developed recently that enable an acceptable estimation of energy expenditure during the activity (indirect calorimetry, double-labeled water turnover), they require the use of time-consuming procedures and expensive equipment difficult to apply in nonagenarians. Such methods may be used only under standardized motor activities and for this reason are not suitable to record daily "free-living" activities. It has been demonstrated that

Table 2 Parameters of Energy Expenditure Measured in Nonagenarians From Villagrande and Their Correlation (Spearman rho) With Activities of Daily Living

	Men ($n = 27$)		Women ($n = 17$)	
Motor parameters	**Mean ± SD**	**Correlation with 6–item ADL**	**Mean ± SD**	**Correlation with 6–item ADL**
Body mass index (kg/m^2)	23.3 ± 16.4	–	25.5 ± 18.3	–
REE (kcal/d)	1275 ± 163	0.301	952 ± 108	–0.323
TEE (kcal/d)	2284 ± 543	0.272	1810 ± 302	0.421
PAL	1.78 ± 0.26	0.090	1.84 ± 0.25	0.565*
EEAM (kcal)	1003 ± 421	0.133	857 ± 254	0.621*
% EE-A ≥ 3 METs	42.54 ± 7.90	0.068	46.31 ± 6.80	0.565
STEPS	12110 ± 5141	0.027	12799 ± 6420	0.329
% STEPS ≥ 3 METs	29.10 ± 11.61	0.107	23.01 ± 10.73	–0.058
MAL ≥ 3 METs	2.41 ± 1.95	–0.067	2.04 ± 1.71	–0.315
PAD ≥ 3 METs (hrs)	2.2 ± 0.6	0.121	1.4 ± 0.5	0.134
SAL < 3 METs	1.4 ± 0.4	0.088	1.5 ± 0.4	0.167
Resting time (hrs)	8.5 ± 1.7	0.098	7.4 ± 1.1	0.198
Sleeping time (hrs)	6.3 ± 1.6	0.012	5.6 ± 0.6	0.056
%RI	75.5 ± 7.9	0.023	81.3 ± 11.1	0.082

Abbreviations: REE = resting energy expenditure; TEE = total energy expenditure; PAL = physical activity levels; EE–A = energy expenditure; MAL = motor activity level; SAL = sedentary activity level.
*$p < 0.05$.

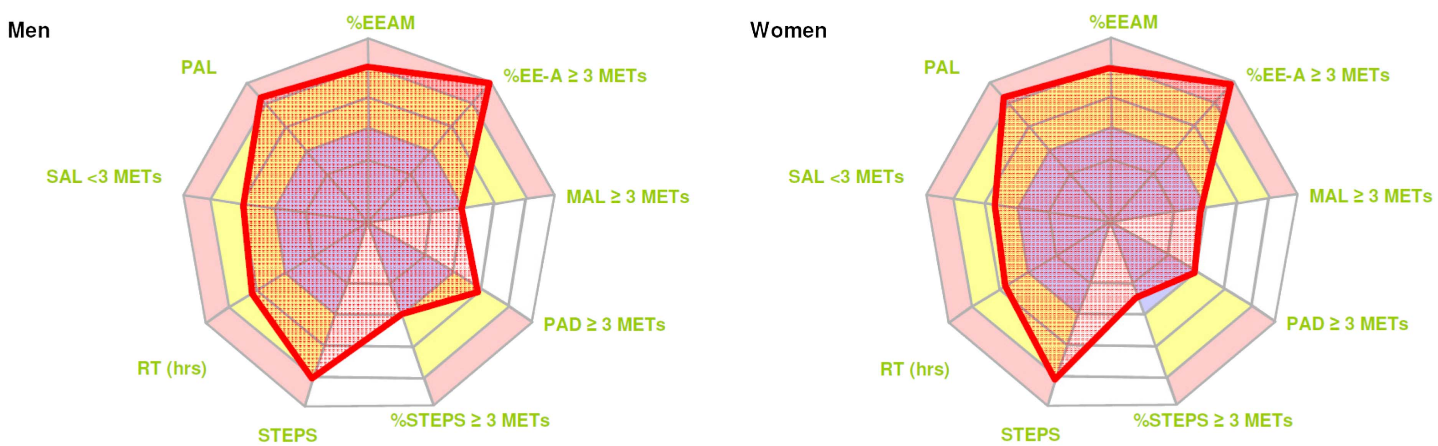

Figure 1 — Motor polygons of nonagenarian men and women from *Villagrande*. The area inside the polygon was wider in the men compared to the women. Interestingly, none of the subjects studied showed average motor index values falling within the central blue area of reduced motility.

the quantification of physical activity through diaries is dramatically affected by the subjective judgment of the interviewed (Aguilar-Farías et al., 2015; Prince et al., 2008; Sallis et al., 2007;). Moreover, completing a diary is a difficult commitment for the oldest individuals and may easily affect their routine activities.

Recently, wearable accelerometers have been developed to measure the displacements of the body's center of gravity during movements: they are devices capable of recording the motor activity in the subject completely free to move (Heiermann, Khalaj Hedayati, Müller, & Dittmar, 2011; Johannsen et al., 2010; Malavolti et al., 2007; St-Onge, Mignault, Allison, & Rabasa-Lhoret, 2007). Through special predictive algorithms, these devices provide an estimate of energy expenditure. Their effectiveness may be enhanced through the use of software (e.g., "CronoLife") designated to calculate specific motor indexes, thus representing the individual motor style similar to a "snapshot". The accuracy and versatility of such an approach might be valuable in geriatric research (Cawthon et al., 2013). Physical activity was studied for the first time through the use of this device in a cohort of persons aged 90 years and older from *Villagrande*, a population well known for its longevity (Poulain, Pes, & Salaris, 2011). The analysis of TEE, divided into two levels of activity as low (<3 METs) and moderate (≥3 METs), surprisingly showed that the amount of activity greater than 3 METs exceeded 40% in both genders. Overall, these indexes of physical activity are among the highest reported in the literature for nonagenarians (Frisard et al., 2007). In an Italian elderly cohort with good functionality (Venturelli et al., 2012), the reported average PAL values were 1.7. Similarly, the value observed in the Villagrande cohort qualifies the majority of the study participants as still physically active into advanced age. Notably, although the average TEE in the women was lower than that in the men, their average PAL was slightly superior, a finding in contrast to that typically found in both genders in advanced age. In addition, the significant correlation found between some motor indexes and ADL in the elderly women may suggest that their good motor functionality may have helped them maintain a low disability level. Finally, the finding concerning sleep was one of the most interesting observations, i.e., the duration of sleep exceeded 82% and 77% of the resting time in the men and women respectively, rarely reported in older cohorts (Gu, Sautter, Pipkin, & Zeng, 2010).

The reasons for this excellent physical performance among Sardinian nonagenarians remain unknown. In a previous ecological study, which analyzed historical data on the lifestyle of Sardinians, we found an association with increased physical activity (Pes et al., 2013, 2015). The longstanding practice of agriculture and animal husbandry, the most common occupations in this geographic area since childhood, might have become so grounded in the population as to prolong outdoor daily activities until the end of life and led to high levels of physical fitness.

Conclusion

This study provides evidence that nonagenarians from the Sardinian Longevity Blue Zone have excellent physical functionality indexes, comparable to those reported in other long-living populations. We speculate that the longevity of this population might result, at least in part, from the ability of aging individuals to stay physically fit. However, longitudinal studies are needed to better understand this complex relationship.

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