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Physical activity in aging: Comparison among young, aged, and nonagenarian individuals

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[1]*Pennington Biomedical Research Center, Baton Rouge;* [2]*Louisiana State University, Department of Kinesiology, Baton Rouge;* [3]*Louisiana State University Health Sciences Center, New Orleans;* [6]*Tulane University, New Orleans, Louisiana;* [4]*University of Pittsburgh, Pittsburgh, Pennsylvania; and* [5]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia*

Johannsen DL, DeLany JP, Frisard MI, Welsch MA, Rowley CK, Fang X, Jazwinski SM, Ravussin E; The Louisiana Healthy Aging Study. Physical activity in aging: comparison among young, aged, and nonagenarian individuals. *J Appl Physiol* 105: 495–501, 2008. First published June 12, 2008; doi:10.1152/japplphysiol.90450.2008.— Physical activity (PA) is known to decline with age; however, there is a paucity of data on activity in persons who are in their nineties and beyond. We used objective and reliable methods to measure PA in nonagenarians ($\geq$90 yr; $n = 98$) and hypothesized that activity would be similar to that of aged (60–74 yr; $n = 58$) subjects but less than in young (20–34 yr; $n = 53$) volunteers. Total energy expenditure (TEE) was measured by doubly labeled water over 14 days and resting metabolic rate (RMR) by indirect calorimetry. Measures of PA included activity energy expenditure adjusted for body composition, TEE adjusted for RMR, physical activity level (PAL), and activity over 14 days by accelerometry expressed as average daily durations of light and moderate activity. RMR and TEE were lower with increasing age group ($P < 0.01$); however, RMR was not different between aged and nonagenarian subjects after adjusting for fat-free mass, fat mass, and sex. Nonagenarians had a lower PAL and were more sedentary than the aged and young groups ($P < 0.01$); however, the nonagenarians who were more active on a daily basis walked further during a timed test, indicating higher physical functionality. For all measures of activity, no differences were found between young and aged volunteers. PA was markedly lower in nonagenarians compared with young and aged adults. Interestingly, PA was similar between young volunteers and those who were in their 60s and 70s, likely due to the sedentary nature of our society, particularly in young adults.

total energy expenditure; doubly labeled water; accelerometers; physical functionality

ENERGY EXPENDITURE AND PHYSICAL activity decline with age (37) and are associated with detrimental changes in body composition (30) and decreased ability to perform activities of daily living such as eating, dressing, transferring, personal hygiene, and mobility (15). These impairments may lead to a loss of functional autonomy and independence. Low physical activity also contributes to a reduced health-related quality of life in older persons (12), and several studies have shown that older adults who report lower levels of physical activity are at greater risk for mortality than those reporting moderate or high activity (2, 4, 11, 13, 32).

Physical activity is most frequently assessed by self-report questionnaires, which are subject to errors and biases due to inadequate or inaccurate recall and failure to capture all physical activities, particularly free-living activity (29). The most accurate and precise method for measuring free-living energy expenditure is by doubly labeled water (DLW) (28). After one accounts for energy expended at rest and the thermic effect of food, the remaining energy can be assumed to be the energy expended in physical activity, both planned and spontaneous. The DLW technique allows for the objective determination of free-living activity in an individual's usual environment over a 1–2-wk period. This method is valid compared with energy expenditure in a metabolic chamber (28) in both lean and obese subjects (20), has excellent repeatability in younger and older adults (8), and is valid under adverse field conditions (7).

Several studies have used DLW to measure energy expenditure in older adults to compare against other measures of physical activity (31), to examine the relationship between activity energy expenditure and aerobic fitness (6) and activity intensity (17), and to describe energy requirements in the later years (5, 25). A recent summary of energy requirements of persons aged 20–96 yr (23) concluded that total energy expenditure (TEE) declines progressively and linearly with increasing age, at an approximate rate of 150 kcal/day per decade. Physical activity level (PAL) also decreases with age; however, whether PAL declines linearly is presently unknown. On the basis of available cross-sectional data (23), there is some suggestion that PAL remains relatively constant between ages 20 and 40 yr and then falls rapidly. However, data on objectively measured energy expenditure and physical activity in later decades is lacking, particularly in persons 90 yr old and older. There is also a paucity of data on how physical activity and activity energy expenditure relate to physical functionality in older adults (10).

The purpose of this study was to use objective and reliable methods to measure energy expenditure and physical activity in a large group of nonagenarians ($\geq$90 yr) and compare values to those obtained from a group of aged (60–74 yr) and young (20–34 yr) volunteers. Maintaining or increasing physical activity in late middle age is reported to be associated with reduced rates of mortality (18). A recent longitudinal study (14) showed that elderly, community-dwelling persons who were physically active for at least 2 h/wk were significantly less likely to die over a 10-mo follow-up period than persons

with no or very low levels of physical activity. This inverse relationship persisted even in a group of very old subjects (>80 yr), even after controlling for disability and mortality risk factors (i.e., heart disease, stroke, diabetes, cancer, etc.). Thus it is possible that persons who live to be in their nineties and beyond do so partially because they maintain an active life-style. We therefore posed the following question: do relatively healthy nonagenarians have levels of physical activity that are comparable to subjects in their sixties and seventies, and is daily activity level related to physical functionality? Accordingly, we hypothesized that physical activity would be similar between nonagenarians and aged subjects; however, both groups would be less active than a group of young volunteers. Additionally, we hypothesized that older adults who are more active on a daily basis have higher physical functionality as assessed by a 6-min walk test.

MATERIALS AND METHODS

Participant sampling and recruitment. Participants in this study represent a subset from an ongoing study known as the Louisiana Healthy Aging Study (LHAS). The overarching aim of LHAS is to determine whether characteristics of an individual's metabolism predispose to longevity with the retention of physical and cognitive functionality that is associated with healthy aging. Participant sampling was performed via random selection on the basis of voter registration lists and the Medicare Beneficiary Enrollment Data File from the Center of Medicare and Medicaid Services. Methods of recruitment included mail outs, follow-up phone calls, and, in the case of the nonagenarians, a home visit by members of the investigative team to explain the study in detail. For this study, 206 men and women (171 Caucasian, 23 Black, 12 Other) were grouped according to age into three categories: young (20–34 yr, 20 M/33 W), aged (60–74 yr, 29 M/29 W), and nonagenarian (≥90 yr, 46 M/49 W; one male was 101 yr old). Subjects were excluded if they had been diagnosed with diabetes or had elevated fasting blood sugar (≥126 mg/dl), thyroid disease, unstable cardiovascular disease, or mental health problems requiring drug treatment. Furthermore, nonagenarians were excluded if they had a heart attack or stroke within 3 mo before testing, severe high blood pressure, blood vessel aneurysm, taking medications for myasthenia gravis, or had uncontrolled asthma or chronic obstructive pulmonary disease. The study was approved by the Institutional Review Boards of the involved institutions and subjects provided written informed consent.

Anthropometrics and body composition. Anthropometric measurements were taken while the subject was in a hospital gown. Weight was measured to the nearest ± 0.1 kg with an electronic scale (Detecto, Webb City, MO), and height was measured to the nearest ± 0.5 cm with a wall-mounted stadiometer (Holtain; Crymych, Dyfed, UK). Body mass index was calculated as weight divided by height squared (kg/m^2). Body composition was measured with dual energy X-ray absorptiometry (QDA 4500A; Hologics, Bedford, MA) and fat-free mass (FFM) and fat mass (FM) were calculated from weight and percent body fat.

Daily energy expenditure. Total daily energy expenditure was determined by DLW. Upon arrival to the inpatient unit of the Pennington Biomedical Research Center, two baseline (*day 1*) urine samples were collected, and participants were then dosed with a mixture of 2.0 g of 10% enriched H$_2$^{18}O and 0.12 g of 99% enriched ^{2}H$_2$O (Cambridge Isotopes; Cambridge, MA) per kg of estimated total body water (55% of body wt). The dose was followed by a 100-ml tap water rinse. The first two urine samples after dosing (~1.5 and 3 h postdose) were discarded, followed by two urine samples collected at 4.5 h and 6.0 h after dosing. On the mornings of *days 13* and *14*, subjects were instructed to discard their first urine void and collect the second void of the day. Samples were kept refrigerated in airtight

containers and were picked up by study staff. Abundance of ^{18}O was measured in duplicate on a Finnigan MAT 252 dual inlet gas isotope ratio mass spectrometer (IRMS), and ^{2}H$_2$ abundance was measured in duplicate on the same IRMS using a Finnigan H/D equilibration device (7). The ^{2}H and ^{18}O isotope elimination rates (k$_D$ and k$_O$) were calculated using linear regression following a log transformation. Total body water (N) was determined at time zero, obtained from the regression line of the H$_2$^{18}O isotope. The rate of CO$_2$ production was calculated using the equations of Schoeller et al. (27) and later modified (19) as follows: rCO$_2$ (mol/d) = (N/2.078) (1.007k$_O$ − 1.041k$_D$) − 0.0246r$_{GF}$, where rCO$_2$ is the rate of carbon dioxide production; N is total body water calculated from N$_O$/1.007, where N$_O$ is the ^{18}O dilution space; k$_O$ and k$_D$ represent the fractional elimination rates of ^{18}O and ^{2}H$_2$, respectively; and r$_{GF}$ is the rate of fractionated gaseous evaporative water loss, which is estimated to be 1.05*N (1.007k$_O$ − 1.041k$_D$). TEE was calculated as follows: TEE (kcal/d) = 22.4 rCO$_2$ (3.9/RQ + 1.10), where RQ represents the respiratory quotient estimated to be 0.86, equal to a healthy, rather low fat diet. Accordingly, the energy equivalent of CO$_2$ (Eeq$_{CO2}$) was 5.637 kcal/l CO$_2$.

Resting metabolic rate. Resting metabolic rate (RMR) was measured using a Deltatrac II metabolic cart (Sensormedics, Yorba Linda, CA) and was determined by measuring O$_2$ consumption and CO$_2$ production. The cart was calibrated before each use with room air and a known calibration gas concentration with 4% CO$_2$-96% O$_2$. Subjects were fasted overnight for 12 h before measurement and were required to rest in a reclined position for 30 min before starting the test. Metabolic rate was then measured for 30 min with the last 20 min used to calculate resting energy expenditure.

Physical activity. Activity energy expenditure (AEE) was determined by the following equation (21): AEE = TEE − (RMR + 0.1*TEE). This approach assumes that the thermic effect of food is 10% of TEE (33). The level of physical activity commonly referred to as PAL was calculated as TEE/(RMR + 0.1 × TEE). To avoid the confounding effect of using a ratio (1), physical activity level was also calculated using linear regression analysis to adjust TEE for RMR.

Participants wore an activity monitor (Actigraph; LLC, Pensacola, FL) for 14 consecutive days simultaneously to the measurement of TEE by DLW. Subjects were instructed to wear the monitor at the mid-axillary line of the right hip and to remove the monitor only when bathing. The monitor uses a single axis accelerometer designed to detect normal human motion to record activity counts that reflect the summation of accelerations during a 1-min interval. Data were categorized as follows according to metabolic equivalents (METs; 1 MET = 1 kcal·kg^{-1}·h^{-1}): <574 counts/min (cpm) was considered light (low-intensity) activity (1 to ≤3 METs) such as lying, sitting, and standing; 574–4,945 cpm was considered moderate activity (>3 to ≤6 METs) such as walking and light household or work-related tasks; 4,946–9,317 cpm was considered high activity or >6 to ≤9 METs; and >9,317 cpm was considered very high activity (≥9 METs). To be included in the analysis, subjects must have worn the monitor for at least 1,375 min per day for a minimum of 7 out of the 14 days. Data were averaged across all days to reflect one 24-h average. The Actigraph monitor is the most widely used and accepted accelerometer for field-based monitoring (36), and an extensive body of research supports the valid use of the Actigraph as an objective indicator of physical activity (35).

Functionality. Functional data were collected in the aged and nonagenarian subjects by completion of a 6-min walk test. The test involved subjects walking at a self-selected pace, without motivational encouragement, in a long hallway between two cones spaced 40 m apart. They were instructed to walk as quickly and safely as possible without running. The total distance walked in 6 min was recorded and used as an indicator of physical functionality. The 6-min walk test has been established as a measure of functional status in elderly adults (9), and the reliability of the test in healthy elderly persons is high (intraclass correlation = 0.93) (2a).

Statistical analysis. SAS (version 9.1; SAS Institute, Cary, NC) was used for analysis. Data are expressed as means ± SE, and the level of significance for all statistical tests was set at $P < 0.05$. Differences among age groups and sex for all variables were analyzed by two-way ANOVA. Multiple regression analyses were used to adjust TEE, RMR, and AEE for FFM, FM, and sex, and a linear regression was used to adjust TEE for RMR, the true indicator of metabolic body size. ANOVA was used to assess differences in adjusted TEE, RMR, and AEE among groups. Statistical significance for all multiple comparisons was adjusted with respect to the Tukey-Kramer method to control for type I errors. Pearson correlation coefficients were calculated to determine the relationship between physical activity and physical functionality in the aged and nonagenarian groups.

RESULTS

Body composition. Participant characteristics are presented in Table 1. Nonagenarians (≥90 yr) weighed less and had less FFM (both, $P < 0.001$) than either the aged (60–74 yr) or young (20–34 yr) volunteers and had less FM ($P < 0.001$) than aged subjects. FFM was similar between the young and aged participants ($P = 0.28$). As expected, women weighed less and had lower FFM than men in all age groups ($P < 0.001$). For men and women, percent body fat was higher in aged subjects compared with young volunteers ($P < 0.001$). However, percent body fat was lower in nonagenarian women compared with both younger groups of women ($P = 0.004$), whereas no difference was observed in nonagenarian men compared with the younger groups of men ($P = 0.99$).

TEE. Nonagenarians had lower absolute RMR and TEE than aged ($P < 0.001$) and young ($P < 0.001$) subjects (Fig. 1). After adjusting for FFM, FM, and sex, however, there was no significant difference in RMR between the nonagenarian and aged groups ($P = 0.11$) (Table 2, presented as the deviation from the predicted RMR value), but the difference in TEE remained significant ($P = 0.02$, data not shown). Compared with the young group, both older groups had significantly lower adjusted RMR ($P < 0.001$ for both comparisons) and adjusted TEE ($P < 0.001$ and $P = 0.02$, respectively).

AEE and PAL. Absolute AEE was lower in nonagenarians compared with aged and young subjects ($P < 0.01$ for both), and there was a trend ($P = 0.06$) for differences to persist between the nonagenarian and aged groups after adjusting for FFM, FM, and sex. There were no differences in AEE either
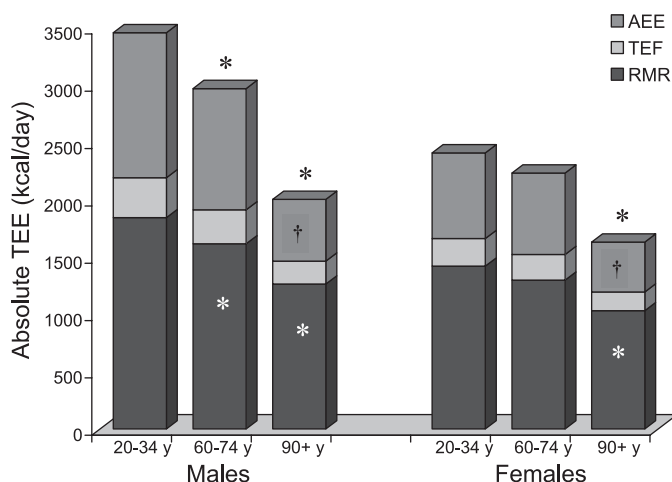

Fig. 1. Absolute total energy expenditure (TEE) and its components. *TEE and resting metabolic rate (RMR) measured by indirect calorimetry were significantly lower with age among all groups in men ($P < 0.01$) and lower in nonagenarian women compared with young and aged women ($P < 0.001$). †Activity energy expenditure (AEE), calculated as TEE − (RMR + TEF) was significantly lower in the nonagenarians compared with the young ($P < 0.01$) and aged groups ($P < 0.05$) for men and women. TEF = thermic effect of food estimated as 10% of TEE. Overall, women had lower TEE than men ($P < 0.001$); Table 2 shows that this sex effect was true in each category.

before or following adjustment for body composition between young and aged subjects ($P = 0.16$ and $P = 0.53$, respectively) (Table 2, adjusted AEE presented as the deviation from the predicted AEE value). Similarly, PAL was lower only in nonagenarians ($P < 0.001$) with no significant difference between young and aged subjects ($P = 0.98$) (Table 2 and Fig. 2, *top*). TEE adjusted for RMR (an indicator of metabolic body size) was lower in nonagenarians compared with aged subjects ($P = 0.02$) and was similar between aged and young subjects ($P = 0.96$), indicating lower physical activity in nonagenarian subjects (see TEE presented as the deviation from the predicted TEE value in Table 2 and Fig. 2, *bottom*).

Physical activity. According to activity monitors, nonagenarians were sedentary or engaged in low-intensity activity for $1,390 ± 6$ min/day or more than 23 h a day including sleeping time and were moderately active for less than 1 h ($50 ± 6$ min) per day. These results were different from aged and young

Table 1. *Participant characteristics*

	Young, 20–34 yr		Young vs. Aged	Aged, 60–74 yr		Aged vs. Non.	Nonagenarian, ≥90 yr		Young vs. Non.	Statistical Significance of Difference Between Means		
										Age group	Sex	AXS
	Men	Women	*P* Value	Men	Women	*P* Value	Men	Women	*P* Value	*P* Value		
	n = 20	*n = 33*		*n = 29*	*n = 29*		*n = 46*	*n = 49*				
Age, yr	27±1	28±1		69±1	69±1		92±0.3	92±0.3				
Height, cm	177±1	164±1	0.12	176±1	161±2	<0.001	170±1	156±1	<0.001	<0.001	<0.001	0.82
Weight, kg	88±4	73±4	0.49	90±2	78±3	<0.001	71±1	60±2	<0.001	<0.001	<0.001	0.80
BMI, kg/m²	28±1	27±1	0.09	29±1	30±1	<0.001	25±0.4	25±1	0.003	<0.001	0.97	0.73
Body fat, %	22±2[a]	35±1[b]	<0.001	28±1[c]	41±1[d]	0.005	27±1[ce]	35±1[bf]	0.04	<0.001	<0.001	0.04
Fat-free mass, kg	68±2[a]	47±1[b]	0.28	65±1[ac]	46±1[bd]	<0.001	52±1[e]	38±1[f]	<0.001	<0.001	<0.001	0.007
Fat mass, kg	20±3	26±2	0.01	25±2	32±2	<0.001	19±1	22±1	0.17	<0.001	<0.001	0.25

Applicable values are means ± SE. [a,b,c,d,e,f]Mean values within a row not sharing a common superscript letter are significantly different ($P < 0.05$) for pair-wise comparisons by age group and sex when interaction is significant. Non., nonagenarian; BMI, body mass index. AXS, age group by sex interaction.

Table 2. *Energy expenditure by age group*

	Young, 20–34 yr		Young vs. Aged	Aged, 60–74 yr		Aged vs. Non.	Nonagenarian, ≥90 yr		Young vs. Non.	Statistical Significance of Difference Between Means		
	Men	Women	P Value	Men	Women	P Value	Men	Women	P Value	Age group	Sex	AXS
										P Value		
RMR, kcal/d												
Absolute	$n = 19$ 1844±68[a]	$n = 33$ 1421±38[b]	<0.001	$n = 29$ 1616±39[c]	$n = 29$ 1299±40[bd]	<0.001	$n = 46$ 1265±19[e]	$n = 48$ 1032±19[e]	<0.001	<0.001	<0.001	0.02
Deviation from predicted RMR*	112±39	99±23	<0.001	−12±25	−4±24	0.11	−36±18	−65±16	<0.001	<0.001	0.54	0.69
TEE, kcal/d												
Absolute	$n = 19$ 3476±202[a]	$n = 33$ 2409±100[b]	0.004	$n = 29$ 2970±85[c]	$n = 29$ 2233±75[bd]	<0.001	$n = 42$ 2002±48[e]	$n = 47$ 1626±32[f]	<0.001	<0.001	<0.001	<0.001
Deviation from predicted TEE‡	167±172	−34±76	0.96	143±64	33±63	0.02	−126±41	−37±36	0.08	0.02	0.19	0.08
AEE, kcal/d												
Absolute	$n = 18$ 1265±160[a]	$n = 33$ 747±71[b]	0.16	$n = 29$ 1057±57[ac]	$n = 29$ 711±51[bd]	<0.01	$n = 42$ 539±35[e]	$n = 46$ 436±26[e]	<0.001	<0.001	<0.001	0.002
Deviation from predicted AEE*	199±165	31±68	0.53	56±52	34±46	0.06	−119±35	−43±30	0.004	0.003	0.44	0.13
PAL	1.57±0.06	1.44±0.04	0.98	1.55±0.03	1.47±0.03	<0.001	1.37±0.02	1.37±0.02	<0.001	<0.001	0.01	0.12

Applicable values are means ± SE. *Expressed as residual values (measured value minus predicted value based on the entire group). Adjusted for fat-free mass, fat mass, and sex. These values could also be expressed as the residuals plus the mean for the entire population to represent an adjusted 24-h value. ‡Expressed as residual values (measured value minus predicted value based on the entire group). Adjusted for resting metabolic rate (RMR) only. These values could also be expressed as the residuals plus the mean for the entire population to represent an adjusted 24-h value. a,b,c,d,e,fMean values within a row not sharing a common superscript letter are significantly different (P < 0.01) for pair-wise comparisons by age group and sex when interaction is significant. TEE, total energy expenditure; AEE, activity energy expenditure; PAL, physical activity level, TEE/[RMR+(0.1× TEE)].
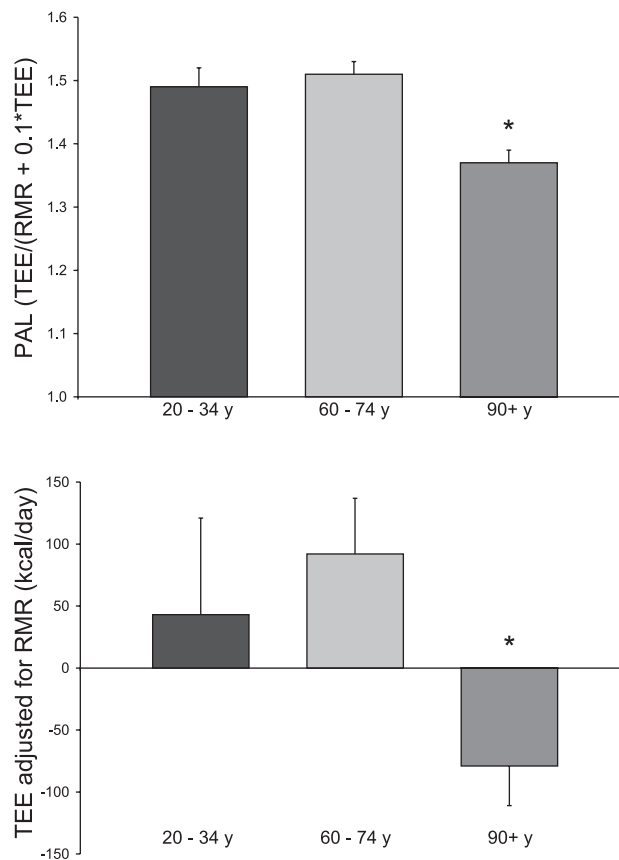

Fig. 2. *Top*: physical activity level (PAL) in the 3 groups. PAL is a ratio [TEE/(RMR + 0.1 × TEE)], and no units are assigned to it. *PAL was significantly lower in the nonagenarian group compared with the young and aged groups (P < 0.001). *Bottom*: residual of TEE after adjusting for RMR. Residual values represent the difference between predicted and measured values of adjusted TEE and indicate the amount of energy expended in activity. *Residuals were lower in the nonagenarian group compared with the aged group (P = 0.02) and young group (P = 0.08). Residuals were not different between the young and aged groups (P = 0.96).

subjects ($P < 0.001$ for both), who were sedentary or in low-intensity activity for $1,314 \pm 8$ min/day and $1,298 \pm 12$ min/day and were moderately active for 126 ± 8 min/day and 141 ± 12 min/day, respectively. Physical activity by activity monitors was not significantly different between young and aged subjects, consistent with data derived from TEE and RMR (Fig. 3). The average time spent in high and very high physical activity was 0 min/day for all age groups. For all subjects combined, the number of minutes of light activity was negatively associated with PAL, AEE, and TEE adjusted for RMR ($P < 0.001$ for all comparisons); likewise, the number of minutes of moderate activity was positively associated with each of those variables ($P < 0.001$ for all comparisons).

Functionality. Nonagenarians walked a shorter distance in a 6-min timed interval than did the aged subjects (282 ± 13 m vs. 467 ± 13 m, $P < 0.001$). Distance walked was positively associated with PAL and TEE adjusted for RMR for the entire sample of aged and nonagenarian volunteers ($P < 0.001$ for both comparisons). When separated by age group, these relationships remained significant in the nonagenarians ($P < 0.05$); however, only a trend persisted in the aged subjects ($P < 0.1$) (Fig. 4, results shown for PAL only). Distance walked was
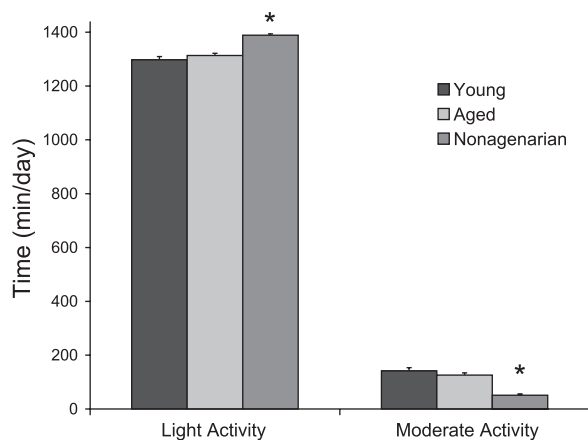
Fig. 3. Daily physical activity as recorded by an activity monitor (Actigraph) worn over 14 days. Data are presented as minutes per average 24-h day spent in light activity [<574 counts/min (cpm) or activity intensity of 1 to ≤3 metabolic equivalents (METs)] and moderate activity (574–4,945 cpm or activity intensity of >3 to ≤6 METs). Light activity included time spent sleeping. *Nonagenarians spent significantly more time being sedentary or in low-intensity activity than either the aged or young groups ($P < 0.001$) and less time in moderate-intensity activity ($P < 0.001$). Activity was not different between the young and aged groups ($P = 0.32$ and $P = 0.34$, respectively).

inversely associated with minutes of daily light activity ($r = -0.55$, $P < 0.001$) and positively with moderate activity ($r = 0.55$, $P < 0.001$) for the entire sample; however, after separation by age group, no significant associations were found.

DISCUSSION

The uniqueness of this study includes the large number of participants, particularly those in their tenth decade of life, the use of DLW to measure free-living energy expenditure, and the inclusion of objective measures of physical activity to determine differences in average daily activity among three distinct age groups. We found that absolute daily TEE and TEE adjusted for FFM, FM, and sex were lower in nonagenarians compared with individuals aged 60–74 yr and young subjects aged 20–34 yr. These findings are similar to previous research demonstrating a progressive decrease in TEE with age (3, 22) and lower TEE in elderly compared with middle age (24) and young (26) persons. However, and surprisingly, adjusted TEE was similar in young and aged subjects mostly due to similar levels of activity, which may be either quite low in our young participants or rather high in our aged volunteers.

Lower TEE in nonagenarians compared with young subjects was due to both lower RMR and lower AEE since they contributed 44% and 46% to lower TEE, respectively, whereas the remaining 10% was assumed to be thermic effect of food. Lower TEE in nonagenarians compared with aged subjects appeared to be driven primarily by less physical activity since we found no real difference in RMR after accounting for differences in body weight and body composition. Indeed, AEE tended to be lower in nonagenarians compared with aged individuals, even after accounting for differences in body composition (406 vs. 929 kcal/day expended in activity, respectively). Additionally, we found PAL to be lower only in the nonagenarian group compared with the young and aged groups. Since PAL is a ratio between TEE and RMR and subject to previously described artifacts (1), we also adjusted the data using

linear regression (regressing TEE on RMR) and found similar implication of reduced physical activity in nonagenarians. Supporting our findings, 24-h energy expenditure measured in a metabolic chamber with flexible activity requirements was lower in elderly compared with younger subjects (34).

Results from activity monitors provided confirmation of lower physical activity in nonagenarians. Nonagenarians were sedentary or in low-intensity activity (e.g., lying, sitting, or standing) for ~96% of the day. In comparison, aged and young subjects spent about 90% of the day being sedentary or in low-intensity activity. To our knowledge, this is the first study to report average daily physical activity as measured by activity monitors in a large group of nonagenarians; thus we are unable to draw comparisons from previous data. Meijer et al. (17) used a triaxial accelerometer to investigate physical activity in old compared with young individuals and found that older subjects (mean age of 61 ± 4 yr) spent significantly more time in low-intensity activity and less time in moderate-intensity activity than a group of younger subjects (mean age 27 ± 5 yr). The young volunteers in our study were similarly active to the young subjects of Meijer et al.; however, our aged volunteers, who were closest in age to the older subjects of Meijer et al., were more physically active according to PAL. Our aged subjects were, however, slightly older than those of Meijer et al. and all were retired, whereas approximately one-third of Meijer's older volunteers were still employed full time. We speculate that, on the basis of our PAL and activity-monitor results, our aged group of subjects may represent a rather physically active retired population.

We found positive relationships between distance walked during the 6-min walk test and PAL and TEE adjusted for RMR in the combined sample of aged and nonagenarian volunteers, and these relationships persisted in the nonagenarians after separating by age group. Our findings are similar to previous results (10) that showed positive associations between measures of physical functionality by the CS-PFP10 and PAL in nonagenarians as well as in 60–74-yr-old subjects. Data in older adults suggest that maintaining a higher level of daily
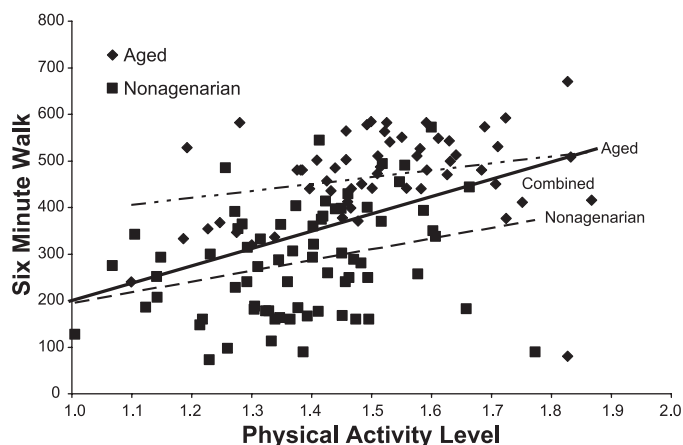

Fig. 4. Relationship between PAL and distance walked (m) during a 6-min test for nonagenarians and aged subjects. For the combined sample, distance walked was significantly related to PAL ($r = 0.44$, $P < 0.001$). When separated by age group, nonagenarians with a higher PAL were able to walk further during the timed test ($r = 0.29$, $P = 0.01$), and there was a trend for the same relationship in aged subjects ($r = 0.26$, $P = 0.06$).

physical activity is associated with a reduced risk of becoming disabled (15).

An interesting finding from this study was the similar physical activity between the young and aged subjects, and this was evident using independent measures of activity, i.e., DLW and activity monitors. Our results differ from those of several previous studies. For example, Black et al. (3) found that distributions of PAL and TEE were shifted downward for subjects aged ≥ 65 yr compared with a group including subjects up to age 64, implying a maintenance of physical activity until reaching retirement age. In the Black et al. study, multiple regression statistics showed that the effect of age was more pronounced for AEE than for RMR, suggesting that the reduction in TEE in people of retirement age was due mostly to lower levels of physical activity. Furthermore, Meijer and colleagues (17) showed reduced activity intensity in subjects in their sixties compared with subjects in their twenties; also Westerterp et al. (37) found lower levels of physical activity in subjects aged 60–74 yr than those between the ages of 20 and 49, and levels were further reduced in persons over the age of 75. The authors concluded that a significant drop in AEE can largely explain the decline in TEE with age. Our results support that conclusion in nonagenarian individuals but not in aged persons.

In summary, we found that physical activity was markedly lower in nonagenarian volunteers compared with a group of 60–74-yr-olds, which was contrary to our hypothesis. It is important to keep in mind that, since these data are cross sectional, we cannot imply changes over time in TEE and physical activity. Indeed, the low levels of physical activity found in our very old subjects may be a conservative estimate since it is possible that only the most fit and active people live to be 90+ years of age. Despite lower physical activity overall, our data suggest that nonagenarians who are more physically active on a daily basis are able to walk further during a timed test, indicating higher physical functionality. Another unexpected finding was the similar levels of physical activity between the young and aged subjects in our study. Taken together, our data are in agreement with previous work (23) showing the TEE declines significantly and progressively with age; however, PAL appears to be maintained from young adulthood until reaching upper-middle age. The similarity in levels of activity suggests that either our present environment is encouraging young people to be quite sedentary, or that physical activity is maintained throughout adulthood and during the retirement years before falling rapidly as age progresses.

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