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

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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 (≥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

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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 lifestyle. 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 (Holttain; Crymych, Dyfed, UK). Body mass index was calculated as weight divided by height squared (kg/m²). 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 H318O and 0.12 g of 99% enriched H218O (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 18O was measured in duplicate on a Finnigan MAT 252 dual inlet gas isotope ratio mass spectrometer (IRMS), and H2 abundance was measured in duplicate on the same IRMS using a Finnigan H/D equilibration device (7). The H2 and 18O isotope elimination rates (kH and kO) 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 H218O isotope. The rate of CO2 production was calculated using the equations of Schoeller et al. (27) and later modified (19) as follows: rCO2 (mol/d) = (N/2.078) (1.007kO - 1.041kH) - 0.0246rQF, where rCO2 is the rate of carbon dioxide production; N is total body water calculated from N0/1.007, where N0 is the 18O dilution space; kO and kH represent the fractional elimination rates of 18O and H2, respectively; and rQF is the rate of fractionated gaseous evaporative water loss, which is estimated to be 1.05*N (1.007kO - 1.041kH). TEE was calculated as follows: TEE (kcal/d) = 22.4 rCO2 (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 CO2 (EeqCO2) was 5.67 kcal/l CO2.

**Resting metabolic rate.** Resting metabolic rate (RMR) was measured using a Deltrac II metabolic cart (Sensormedics, Yorba Linda, CA) and was determined by measuring O2 consumption and CO2 production. The cart was calibrated before each use with room air and a known calibration gas concentration with 4% CO2-96% O2. 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 + O.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 simultaneous to the measurement of TEE by DLW. Subjects were instructed to wear the monitor at the midaxillary 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): ≤544 counts/min (cpm) was considered light (low-intensity) activity (1 to ≤3 METs) such as lying, sitting, and standing; 544–9,495 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 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 validity use of the Actigraph as an objective indicator of physical activity (35). 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 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

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**Table 1. Participant characteristics**

<table>
<thead>
<tr>
<th>Statistic Mean (SE)</th>
<th>Young, 20–34 yr</th>
<th>Young vs. Aged</th>
<th>Aged, 60–74 yr</th>
<th>Aged vs. Non.</th>
<th>Nonagenarian, ≥90 yr</th>
<th>Young vs. Non.</th>
<th>Statistical Significance of Difference Between Means</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>27 ± 1</td>
<td>28 ± 1</td>
<td>69 ± 1</td>
<td>69 ± 1</td>
<td>&lt;0.001</td>
<td>170 ± 1</td>
<td>156 ± 1</td>
</tr>
<tr>
<td>Height, cm</td>
<td>177 ± 1</td>
<td>164 ± 1</td>
<td>0.12</td>
<td>167 ± 1</td>
<td>161 ± 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>88 ± 4</td>
<td>73 ± 4</td>
<td>0.49</td>
<td>90 ± 2</td>
<td>78 ± 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>28 ± 1</td>
<td>27 ± 1</td>
<td>0.09</td>
<td>29 ± 1</td>
<td>30 ± 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body fat, %</td>
<td>22 ± 2</td>
<td>35 ± 1b</td>
<td>&lt;0.001</td>
<td>28 ± 1</td>
<td>41 ± 1d</td>
<td>0.005</td>
<td>27 ± 1c</td>
</tr>
<tr>
<td>Fat-free mass, kg</td>
<td>68 ± 2</td>
<td>47 ± 1b</td>
<td>0.28</td>
<td>65 ± 1c</td>
<td>46 ± 1b</td>
<td>&lt;0.001</td>
<td>52 ± 1c</td>
</tr>
<tr>
<td>Fat mass, kg</td>
<td>20 ± 3</td>
<td>26 ± 2</td>
<td>0.01</td>
<td>25 ± 2</td>
<td>32 ± 2</td>
<td>&lt;0.001</td>
<td>19 ± 1</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Age group</th>
<th>Sex</th>
<th>PAL (TEE/(RMR + 0.1 × TEE))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young vs. Non.</td>
<td>Men</td>
<td>20.0 ± 2.1</td>
</tr>
<tr>
<td>Nonagenarian, ≥90 yr</td>
<td>Men</td>
<td>16.0 ± 1.2</td>
</tr>
<tr>
<td>Aged vs. Non.</td>
<td>Men</td>
<td>18.0 ± 1.4</td>
</tr>
<tr>
<td>Young vs. Aged</td>
<td>Men</td>
<td>17.0 ± 1.3</td>
</tr>
</tbody>
</table>

Fig. 2. Top: physical activity level (PAL) in the 3 groups. PAL is a ratio of 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 ± 8 min/day and 1,298 ± 12 min/day and were moderately active for 126 ± 8 min/day and 141 ± 12 min/day, respectively. Physical activity by activity monitors is 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 intensity 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
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 as well as in 60–74-yr-old subjects. Data in older individuals suggest that maintaining a higher level of daily physical activity in 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 associated with a reduced risk of becoming disabled (15).

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REFERENCES


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