Determining the Importance of Meeting Muscle-Strengthening Activity Guidelines: Is the Behavior or the Outcome of the Behavior (Strength) a More Important Determinant of All-cause Mortality?

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Abstract

Objective: To determine whether the behavioral participation in muscle-strengthening activity (MSA) or the strength outcome produces the largest reduction in all-cause mortality risk.

Patients and Methods: The 1999-2002 National Health and Nutritional Examination Survey was used, with follow-up of up to 12.6 years (mean, 9.9 years) (N = 2773 adults aged ≥50 years). Participants were placed into 4 groups based on 2 dichotomously categorized variables: lower-extremity strength (LES) of the knee extensors (top quartile) and adherence to MSA guidelines (≥2 MSA sessions per week). Approximately 21% of the population died during follow-up.

Results: Compared with individuals not meeting MSA guidelines and not in top quartile for LES, the adjusted hazard ratios (HRs) and 95% CIs were as follows: (1) meets MSA guidelines but not in top quartile for LES (HR = 0.96; 95% CI, 0.63-1.45; P = .84), (2) in top quartile for LES but does not meet MSA guidelines (HR = 0.54; 95% CI, 0.42-0.71; P < .001), and (3) in top quartile for LES and meets MSA guidelines (HR = 0.28; 95% CI, 0.12-0.66; P = .005). Further analyses revealed that individuals in the top quartile for LES who also met MSA and moderate to vigorous physical activity guidelines were at even further reduced risk for premature all-cause mortality (HR = 0.23; 95% CI, 0.08-0.61; P = .005).

Conclusion: These results demonstrate that muscle strength seems to be more important than the behavioral participation in MSA for reducing the risk of premature all-cause mortality.

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The US Department of Health and Human Services (USDHHS) recommends that aerobic physical activity (PA) be performed for at least 150 minutes per week consisting of moderate to vigorous PA (MVPA), 75 min/wk of vigorous PA, or some combination of the two.1 In addition, the USDHHS recommends that muscle-strengthening activities (MSAs) be performed at least twice per week, concurrently with aerobic PA, as part of a comprehensive exercise program.1 Although 51% of Americans report meeting the recommended MVPA guidelines, less than 5% of adults actually meet these guidelines when bouts of MVPA (ie, MVPA lasting ≥10 minutes) are estimated using accelerometer data.2 Furthermore, a nationally representative survey conducted in 2008 revealed that only 29.3% of American adults reported meeting the guidelines for MSA, and only 20.6% reported meeting the guidelines for aerobic PA and MSA.3 The lack of participation in aerobic PA and MSA is alarming considering the wide range of health benefits associated with each individual mode of training, including improved quality of life,4,5 cognitive function,6,7 and mobility,8,9 as well as their preventive or attenuating effects on a plethora of individual chronic diseases, such as diabetes,10,11 chronic obstructive pulmonary disorder,12,13 stroke,14,15 and obesity.16 Unlike the aerobic PA and mortality studies that emphasize the behavioral participation in
aerobic PA,17–22 studies investigating the relationship between muscle strength and mortality have, almost exclusively, focused on actual strength and mortality as opposed to the behavioral participation in MSA. Two published studies were found examining the association between MSA and all-cause mortality; one study reported no preventive effect of MSA on mortality,18 and the other reported a 13% reduced risk in individuals meeting MSA guidelines after adjusting for covariates, including aerobic PA.17

An inverse association between muscle strength and all-cause mortality has been consistently demonstrated19–35; however, most of these studies were centered on handgrip strength,28–36 which has been shown to be unaffected by full-body MSA interventions lasting up to a full year.37,38 In addition, other studies assessing strength through commonly trained muscles, such as the chest or legs,23–27 are still not entirely reflective of participation in MSA due to the high degree of variability in individual responses to MSA, whereas some individuals see less than a 5% increase in strength of the trained muscles.39 One study reported that of 330 individuals in the top quartile for muscle strength (bench press and leg press), only 65% reported meeting MSA guidelines.40 Individuals who perform MSAs but see little increase in muscle strength are still likely to benefit from other positive adaptations occurring through MSA participation that may help reduce the risks of premature all-cause mortality (eg, glucose metabolism41). It, therefore, seems beneficial to evaluate strength and MSA participation individually to determine which is playing a larger role in the potential reduced risk of all-cause mortality.

In addition to no studies examining the potential individual and combined effects of MSA and strength on mortality risk, we are aware of no studies examining whether engagement in aerobic PA may further augment the potential combined effects of MSA and lower-extremity strength (LES) on mortality risk. This is plausible because aerobic PA and MSA, for example, may result in unique physiologic adaptations (eg, aerobic PA may provide greater cardiovascular adaptations, whereas MSA will provide greater increases in strength and lean body mass), ultimately complementing each other in promoting survival. Therefore, to bridge these gaps in the literature, the purposes of this study were twofold: (1) to examine the potential individual and combined associations of LES and MSA with all-cause mortality risk and (2) to examine whether meeting MSA guidelines, being in the top quartile for LES, and meeting MVPA guidelines may augment the reduced risk that each individual criterion has on premature all-cause mortality. To maximize the generalizability of these results, we studied these questions using a nationally representative sample.

**METHODS**

**Design and Participants**

The 1999–2002 National Health and Nutrition Examination Survey (NHANES) data were used to analyze 2773 participants at baseline (Table 1); these cycles were chosen because at the time of this writing they are the only current NHANES cycles with LES data. The NHANES is an ongoing survey conducted by the Centers for Disease Control and Prevention designed to evaluate the health status of US adults through a complex, multistage, stratified clustered probability design. Participants in this study were followed (through 2011) for up to 12.6 years, with weighted mean ± SE follow-up lasting 9.9 ± 1.13 years. In the sample, 322,489 person-months occurred, with an incidence rate of 2.1 deaths per 1000 person-months (95% CI, 2.0–2.32 per 1000 person-months). Written informed consent was obtained from all the participants.

**Muscle-Strengthening Activities**

Individuals self-reported their involvement in MSAs by answering 2 questions: “During the past 30 days, did you do any PAs specifically designed to strengthen your muscles, such as weight lifting, push-ups, or sit-ups?” Those who answered yes to question 1 were then asked, “During the past 30 days, how many times did you do these MSAs (eg, weight lifting, push-ups, or sit-ups)?” Individuals who reported involvement in at least 8 MSA sessions in the past 30 days were recorded as meeting MSA guidelines in adherence with the USDHHS guideline of performing at least 2 MSA sessions per week.1 The self-reported participation in MSAs has been shown to have evidence of construct validity.40

**Muscle Strength**

The LES of the knee extensors was evaluated using a Kin Kom MP isokinetic dynamometer.
(Chattanooga Group Inc). After 3 warm-up repetitions, participants performed 3 maximal isokinetic contractions with the right leg at 60° per second. The strength values were corrected to account for gravity, limb weight, and lever arm weight. The peak force recorded was used for analysis. Individuals in the top quartile (75th percentile) for knee extensor muscle strength were classified as strong (>428 N) based on previous findings demonstrating that the highest quartile for muscle strength is inversely associated with all-cause mortality. The specific isokinetic knee extensor test performed at 60° per second on the dynamometer has an interclass correlation coefficient of 0.893 using the Shrout and Fleiss equation.

**Aerobic PA**

Participants were asked open-ended questions about participation in leisure-time PA during

| TABLE 1. Weighted Baseline Characteristics, 1999-2002 NHANES (N=2773) |
|-----------------------------|-----------------------------|-----------------------------|
| Characteristic              | Value (95% CI)              | Sample (No.) | Deaths (No. [% of total]) |
| Demographic features       |                             |               |                            |
| Age (y)                     | 62.5 (62.1-63.0)            | 2773          | NA                         |
| BMI (mean)                  | 28.1 (27.8-28.4)            | 2773          | NA                         |
| Female sex (%)              | 52.6 (51.2-54.0)            | 1370          | 298 (43)                   |
| Race/ethnicity (%)          |                             |               |                            |
| Mexican American            | 3.3 (2.0-4.5)               | 533           | 100 (14)                   |
| Other Hispanic              | 5.1 (1.7-8.5)               | 122           | 14 (2)                     |
| Non-Hispanic white          | 81.3 (77.4-85.3)            | 1621          | 455 (65)                   |
| Non-Hispanic black          | 7.2 (5.0-9.4)               | 431           | 116 (17)                   |
| Other                       | 2.9 (1.7-4.2)               | 66            | 13 (2)                     |
| Health status               |                             |               |                            |
| Ambulatory device (%)       | 5.8 (4.6-7.0)               | 2013          | 95 (13)                    |
| Mean arterial pressure (mm Hg), mean | 93.0 (92.1-93.8) | 2773          | NA                         |
| Statin medication use (%)   | 16.5 (14.9-18.0)            | 457           | 110 (16)                   |
| Total cholesterol level (mg/dL), mean | 215.6 (213.5-217.7) | 2773          | NA                         |
| Smoking behavior (%)        |                             |               |                            |
| Current                     | 16.0 (14.0-18.1)            | 421           | 127 (18)                   |
| Former                      | 38.7 (36.0-41.4)            | 1081          | 298 (43)                   |
| Never                       | 45.1 (42.4-47.8)            | 1271          | 273 (39)                   |
| Disease (%)                 |                             |               |                            |
| Arthritis                   | 37.5 (34.7-40.3)            | 1058          | 295 (42)                   |
| Cardiovascular disease      | 6.7 (5.5-7.9)               | 196           | 83 (12)                    |
| Diabetes                    | 9.8 (8.6-11.1)              | 372           | 123 (18)                   |
| Stroke                      | 0.6 (0.2-0.9)               | 25            | 12 (2)                     |
| Mortalities (%)             | 20.6 (18.2-22.9)            | 698           | 698 (100)                  |
| Physical fitness status     |                             |               |                            |
| Aerobic-based physical activity |                        |               |                            |
| MVPA (MET-min/week), mean   | 947.6 (812.7-1082.4)        | 2773          | NA                         |
| Meets MVPA guidelines (%)   | 41.3 (37.0-45.5)            | 1145          | NA                         |
| MSA and LES                 |                             |               |                            |
| MSA sessions in past 30 d (No.), mean | 2.8 (2.2-3.4) | 2773          | NA                         |
| Meets MSA guidelines (%)    | 14.7 (12.0-17.4)            | 407           | NA                         |
| LES (N), mean               | 366.1 (360.7-371.5)         | 2773          | NA                         |
| Does not meet MSA guidelines, not in top quartile for LES (%) | 61.7 (59.2-64.2) | 1824          | 551 (79)                   |
| Meets MSA guidelines, but not in top quartile for LES (%) | 9.2 (7.5-10.8)          | 253           | 62 (9)                     |
| In top quartile for LES but does not meet MSA guidelines (%) | 23.5 (21.8-25.1) | 563           | 75 (11)                    |
| Meets MSA guidelines and in top quartile for LES (%) | 5.6 (4.0-7.1)       | 133           | 10 (1)                     |

*BMI = body mass index; LES = lower-extremity strength (of the knee extensors); MET = metabolic equivalent; MSA = muscle-strengthening activity; MSA guidelines = 2 or more MSA sessions per week; MVPA = moderate to vigorous physical activity; MVPA guidelines = at least 150 min/wk of MVPA; NA = not available; NHANES = National Health and Nutrition Examination Survey.

**SI conversion factor**: To convert total cholesterol values to mmol/L, multiply by 0.0259.

*The percentage of total deaths was calculated by using the total number of deaths (n=698) as the denominator.*


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the past 30 days. Data were coded into 48 activities, including 16 sports-related activities, 14 exercise-related activities, and 18 recreation-related activities; these individual PAs are published elsewhere.44 For each of the 48 activities where participants reported moderate or vigorous intensity for the respective activity, they were asked to report the number of times they engaged in that activity during the past 30 days and the mean duration they engaged in that activity. For each of the 48 PAs, metabolic equivalent (MET)-min-month was calculated by multiplying the number of days by the mean duration by the respective MET level (MET-min-month = days × duration × MET level). The MET levels for each activity are provided elsewhere.45 Participants were defined as meeting MVPA guidelines if they self-reported at least 2000 MVPA MET-min/month, which is equivalent to the USDHHS guideline of 500 MVPA MET-min/week.1 The self-reported aerobic PA variable has been shown to have evidence of construct validity.46

All-cause Mortality
The number of individuals who died during follow-up was determined by comparing the participant’s personal identification information with the National Center for Health Statistics’ National Death Index. Positive matches were then examined manually for further validation, whereas individuals who had no signs of mortality were considered living at the time of census.

Covariates
Unless otherwise noted, the covariates included age (continuous), sex, body mass index, race/ethnicity, MVPA, use of an ambulatory device (eg, cane), self-reported smoking status (never, former, or current smoker), total cholesterol level (continuous), statin medication use (yes/no), measured mean arterial blood pressure (continuous), and the following physician-diagnosed conditions: arthritis, diabetes, cardiovascular disease, and stroke.

Statistical Analyses
Analyses were performed using Stata software (version 12.0; StataCorp LP) and accounted for the complex survey design used in the NHANES. To examine the associations between LES and all-cause mortality and between participation in MSA and all-cause mortality, a weighted multivariable Cox proportional hazard model was used (Table 2). The Harrell C concordance statistic for this model was 0.78, and the test of proportional hazards assumption was not violated (global $\chi^2$=29.46, $P=.11$). Further supplemental analyses were performed to assess the hazard ratio (HR) for individuals meeting 1, 2, or all of the following criteria: (1) top LES quartile, (2) meets MSA guidelines, and (3) meets MVPA guidelines. Significance was set at $P<.05$.

RESULTS
The baseline characteristics of the study participants are detailed in Table 1. Of the 4 groups (<75th LES percentile and not meeting MSA guidelines [group 1], <75th LES percentile but meeting MSA guidelines [group 2], ≥75th LES percentile but not meeting MSA guidelines [group 3], and ≥75th LES percentile and meeting MSA guidelines [group 4]), the greatest risk reduction in all-cause mortality was in those in the top quartile for LES and also meeting MSA guidelines (Table 2). Although group 4 (strong and meets MSA guidelines) had the greatest risk reduction, there was no significant difference between groups 3 and 4 ($P=.12$). When recomputing the analyses comparing individuals in the lowest quartile for LES with those in the upper 3 quartiles (as opposed to the upper quartile vs the lower 3), the results were unchanged. That is, compared with group 1 (<25th percentile for LES and not meeting MSA guidelines), the HR and 95% CI for groups 2 through 4 were as follows: group 2 (<25th percentile for LES but meeting MSA guidelines) (HR=0.94; 95% CI, 0.61-1.44; $P=.77$), group 3 (≥25th percentile for LES but not meeting MSA guidelines) (HR=0.47; 95% CI, 0.37-0.59; $P<.001$), and group 4 (≥25th percentile for LES and meeting MSA guidelines) (HR=0.40; 95% CI, 0.26-0.63; $P<.001$).

We provided further analysis assessing LES in terms of relative strength (ie, strength/body mass) rather than absolute strength (excluding body mass index as a covariate); however, this did not alter any of the results. Results of the relative LES analyses compared with individuals in group 1 were as follows: group 2 (HR=0.91; 95% CI, 0.58-1.43; $P=.69$), group 3 (HR=0.58; 95% CI, 0.41-0.82; $P=.003$), and group 4
In addition, when excluding those with diabetes, stroke, or coronary artery disease (n = 545), the HRs (95% CIs) for groups 2, 3, and 4 vs 1 remained unchanged: 0.95 (0.62-1.45), 0.54 (0.42-0.71), and 0.29 (0.11-0.81), respectively. In a single hazard model examining the independent associations of being in the top quartile for strength, meeting MSA guidelines, and meeting MVPA guidelines, we found that after adjustments, meeting MSA guidelines did not produce a significant reduction in all-cause mortality risk whereas meeting MVPA guidelines and being in the top quartile for LES did (Figure 1). When evaluating the potential additive effects of being in the top quartile for LES and meeting MSA and MVPA guidelines, we observed a clear dose-response relationship with all-cause mortality (Figure 2). Although there was a 34% greater reduction in all-cause mortality comparing those who met all 3 criteria with those meeting 2 criteria, this difference was not significant (P = .08).

**DISCUSSION**

Most studies attempting to assess the importance of participating in MSAs have done so through an outcome measure of muscle strength, which is not directly indicative of MSA participation, as, for example, 62.5% of individuals meeting MSA guidelines in this sample were not in the top quartile for LES.
To our knowledge, no previous studies have assessed whether participation in MSA or the outcome measure of muscle strength plays a larger role in reducing the risk of premature all-cause mortality. To answer this question, we analyzed a nationally representative sample of 2773 US adults followed for an average of 9.9 years.

We found that individuals who did not meet MSA guidelines but were in the top quartile for LES were at a 46% significantly reduced risk for premature all-cause mortality; however, antithetical results demonstrated that individuals meeting MSA guidelines but not in the top quartile for LES were at a statistically nonsignificant 4% reduced risk (Table 2). These results suggest that muscle strength, rather than participation in MSA, may be more beneficial for reducing the risk of premature all-cause mortality, which seems to follow a similar pattern to that of aerobic PA. Two meta-analyses have reported that individuals meeting MVPA guidelines were at 20% to 40% reduced risk for premature all-cause mortality; however, studies assessing aerobic fitness through maximal exercise tests report the risk reduction to be approximately 50% to 60%.47-49

In our additional supplemental analysis comparing individuals in the lowest quartile with those in the upper three quartiles, the results remained unchanged. This suggests that as long as individuals possess adequate strength (≥25th percentile), they may be at reduced risk for all-cause mortality compared with those in the lowest quartile. A previous study demonstrated that only individuals in the lowest 20th percentile for LES were at increased risk for premature all-cause mortality.50 The importance of muscle strength to combat premature all-cause mortality may be due to the attenuation of dynapenia, or age-related strength loss, which likely contributes to the direct association between strength and balance,51 in addition to the inverse association between strength and risk of falls.49 Although MSAs are likely to help prevent age-related declines in muscle strength, it is likely that overall strength provides the greatest protective effect against premature all-cause mortality. In addition to the possibility of individuals overestimating their MSA participation, we were unable to determine the intensity with which individuals performed MSAs, which may be an important determinant of strength gains.52 Note, however, that, although not statistically significant, individuals in the top quartile for LES who also met MSA guidelines were at 26% further reduced risk for all-cause mortality compared with individuals who were in the top quartile for LES but did not meet MSA guidelines (72% − 46% = 26%) (Table 2). This may provide evidence that some of the adaptations occurring from MSA, which may help prevent the incidence of specific diseases known to be more prevalent with age, may be overlooked (eg, improved glycemic control to combat diabetes10).

We computed further analyses and determined that the individuals in the top quartile for LES who also met MSA guidelines were at 5% further reduced risk for premature all-cause mortality if they also met MVPA guidelines (77% total reduced risk). This can likely be attributed to the beneficial effect that each mode of exercise has on the body’s system as a
whole. To put this into perspective, there seems to be a dose-response relationship between participation in PA and reduced risk of all-cause mortality, demonstrating up to a 39% risk reduction. However, a threshold seems to exist in that once an individual performs 3 to 5 times the recommended MVPA, no further risk reduction for all-cause mortality seems to exist, even if the individual performs greater than 10 times the recommended MVPA. It seems reasonable to suggest that rather than increasing the participation in 1 modality of training, simply meeting guidelines for MSA and MVPA would provide a more complete stimulus, inherently protecting against a wider range of potential life-threatening conditions. To illustrate, MSAs are likely to provide a greater stimulus to protect against the risk of falls; however, without concurrent participation in PA, the individual may be at greater risk for cardiovascular disease compared with someone performing both modes of training. Furthermore, and particularly in older populations, adequate strength may also facilitate the ability to engage in ambulatory-based PAs.

When analyzing each of these 3 measures independently, we found that individuals in the top quartile for LES, those meeting MVPA guidelines, and those meeting MSA guidelines were at 49%, 27%, and 12% reduced risk for premature all-cause mortality, respectively, although the 12% reduced risk from MSA was not statistically significant (Figure 1). These results are in line with those of another study reporting that individuals meeting MSA guidelines were at 13% reduced risk and those meeting MVPA guidelines were at 36% reduced risk for premature all-cause mortality, respectively. The present findings support the idea that although both are important, meeting MVPA guidelines seems to be more important than meeting MSA guidelines for the prevention of premature all-cause mortality.

When analyzing the combined effects of being in the top quartile for LES and meeting MSA and MVPA guidelines, we observed a clear dose-response relationship with all-cause mortality (Figure 2). Although the HRs for individuals meeting 2 and 3 criteria were 0.57 (95% CI, 0.42-0.75) and 0.23 (95% CI, 0.08-0.61), respectively, the difference in all-cause mortality risk between those meeting 2 and 3 criteria was not statistically significant; compared with those meeting 2 criteria, those meeting 3 criteria had a 59% reduced risk of all-cause mortality (HR=0.41; 95% CI, 0.15-1.11; P=.08). This lack of statistical significance reflects this relatively large CI (95% CI, 0.15-1.11), likely a result of the relatively few (n=6) mortalities in those meeting all 3 criteria. Therefore, we should use caution when interpreting this specific finding. It was not possible to assess the aerobic fitness of each individual included in this study (NHANES cardiorespiratory fitness data are available only for those <50 years old); however, based on these findings, it seems as though the outcome measure of strength or aerobic fitness is more important than the behavioral participation in either MSA or aerobic PA, although the combination of meeting guidelines and possessing the adaptations of the corresponding behavior seems to provide the most

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**FIGURE 2.** Dose-response relationship between individuals meeting 1, 2, or 3 of the following criteria: (1) meets top 75th percentile for lower-extremity strength (LES), (2) meets muscle-strengthening activity (MSA) guidelines, and (3) meets moderate to vigorous physical activity (MVPA) guidelines, 1999-2002 National Health and Nutritional Examination Survey (N=2773). All the values are presented as hazard ratios and their corresponding 95% CIs. The following 3 criteria were used: (1) meets MSA guidelines of at least 2 sessions per week, (2) meets aerobic-based exercise guidelines of at least 2000 MVPA metabolic equivalent-min/month, and (3) classified as strong by being in the 75th percentile for LES of the knee extensors. Individuals meeting any 1, 2, or 3 of these criteria were compared with individuals meeting none of these. All the hazard ratios were adjusted for age, sex, body mass index, race/ethnicity, use of an ambulatory device, self-reported smoking status, total cholesterol level, statin medication use, mean arterial blood pressure, arthritis, diabetes, cardiovascular disease, and stroke. *Statistically significant (P<.05) from those not meeting any of the 3 criteria.
robust stimulus for attenuating the risk of premature all-cause mortality.

To assess participation in both aerobic PA and MSA we used self-reported data, which may be subject to social desirability and recall bias; however, our MSA and aerobic PA variables have been previously demonstrated to have some extent of construct validity. Regarding aerobic PA, the NHANES accelerometry data were not collected in the same cycles as the LES data, and there is no true way to objectively assess the volume of MSA performed in a large cohort of individuals. Previous research, however, demonstrates that objectively vs subjectively measured aerobic PA has a stronger association with various health outcomes, which suggests that our aerobic PA findings may be underestimated. In addition, we did not have a measure of aerobic fitness because this test was not used for NHANES adults aged 50 years and older (entry criteria for LES assessment). Furthermore, although some aerobic PAs (cycling, walking) may increase strength in elderly populations, the inclusion of aerobic PA as a covariate likely limited the influence of aerobic PA on strength. Last, the sample size and the number of cause-specific mortalities (ie, cardiovascular disease mortality) allowed for only the outcome measure of all-cause mortality. The strengths of this study included the national sample and its novelty, being the first to analyze the individual and combined associations of MVPA, MSA, and LES with all-cause mortality.

CONCLUSION

Individuals in the top quartile for LES were at greater reduced risk for premature all-cause mortality than were individuals who met MSA guidelines. Although these results suggest that the strength outcome measure is a more important predictor of mortality than the behavior, having high LES and meeting MSA guidelines produced an even greater reduction in premature all-cause mortality, with this reduction further enhanced when MVPA guidelines were also met. Future research is needed to determine whether muscle strength or aerobic fitness is a greater predictive measure against premature all-cause mortality. If these results are replicated and confirmed, clinicians should seek to assess at-risk patients through prognostic fitness testing, and, when appropriate, MSA and aerobic PA interventions with a focus on improving muscle strength and increasing aerobic capacity through higher-intensity exercise should be used.

Abbreviations and Acronyms. HR = hazard ratio; LES = lower-extremity strength; MET = metabolic equivalent; MSA = muscle-strengthening activity; MVPA = moderate to vigorous physical activity; NA = not available; NHANES = National Health and Nutrition Examination Survey; PA = physical activity; USDHHS = US Department of Health and Human Services

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REFERENCES

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