AGE (2016) 38: 32
DOI 10.1007/s11357-016-9899-9

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Lower extremity muscular strength, sedentary behavior, and mortality

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Received: 28 December 2015 / Accepted: 23 February 2016 / Published online: 1 March 2016
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Abstract To examine whether lower extremity strength (LES) is predictive of all-cause mortality, independent of physical activity and among those with vary levels of sedentary behavior. Data from the 1999–2002 National Health and Nutrition Examination Survey was used ($N = 2768$; 50–85 years). Peak isokinetic knee extensor strength was objectively measured, sedentary behavior and physical activity were self-reported, and mortality was assessed via the National Death Index, with follow-up through 2011. Participants were followed for up to 12.6 years with the weighted average follow-up period lasting 9.9 years (standard error, 1.13). In the sample, 321,996 person-months occurred with a mortality rate of 2.1 deaths per 1000 person-months. After adjustments (including physical activity), for every 15 N increase in LES, participants had a 7 % reduced risk of all-cause mortality (HR = 0.93; 95 % CI 0.91–0.95; $P < 0.001$). When adding a three-level sedentary behavior variable (< 2, 2–4, 5+ h/day) as a covariate in this model, results were unchanged (HR = 0.93; 95 % CI 0.92–0.96; $P < 0.001$). Similarly, when sedentary behavior was included as a continuous covariate in the model, results regarding the relationship between LES and mortality were unchanged (HR = 0.94; 95 % CI 0.91–0.96; $P < 0.001$). There was no evidence of statistical interaction between LES and sedentary behavior on all-cause mortality ($HR_{interaction} = 1.01$; 95 % CI 0.92–1.10; $P = 0.88$). LES was inversely associated with all-cause mortality, and this association was unchanged when considering the participant's sedentary behavior.

Keywords Epidemiology · Morbidity · Health

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Introduction

Previous work has demonstrated that lower extremity strength (LES) is an independent predictor of mortality (Artero et al., 2011; Buckner, Loenneke, & Loprinzi, 2015; Katzmarzyk & Craig, 2002; Ruiz et al., 2008; Swallow et al., 2007). Emerging work also demonstrates that sedentary behavior is predictive of early mortality, even independent of moderate-to-vigorous physical activity (Katzmarzyk, Church, Craig, & Bouchard, 2009; Matthews et al., 2012; Patel et al., 2010). The mechanism through which sedentary behavior may influence health are not well established but may, for example, be through modulation of inflammation and/or increases in the enzyme lipoprotein lipase, which favors increased accumulation of triglycerides and decreased high-density lipoprotein cholesterol (Hamilton, Hamilton, & Zderic, 2007; Tremblay, Colley, Saunders, Healy, & Owen, 2010). Whether LES is predictive of mortality independent of physical activity and while considering the participant's sedentary behavior is unknown. Therefore, the specific purpose of this brief report was to examine whether LES was predictive of all-cause mortality and whether this relationship was moderated by sedentary behavior.

Methods

Design and participants

The 1999–2002 National Health and Nutrition Examination Survey (NHANES) data was used to analyze 2768 participants at baseline; 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 Center for Disease Control and Prevention designed to evaluate the health status of US adults through a complex, multi-stage, stratified clustered probability design. Participants in this study were followed (through 2011) for up to 12.6 years with the weighted average follow-up period lasting 9.9 years (standard error, 1.13). In the sample, 321,996 person-months occurred with a mortality rate of 2.1 deaths per 1000 person-months. Written informed consent was obtained from all participants.

All-cause mortality

The number of individuals deceased during the follow-up period was determined from the National Death Index (NDI). Specifically, mortality assessment was based on a probabilistic match between NHANES identification and NDI certificate records. To help minimize missing mortality status information from the NDI, other sources of information to determine mortality status included information from the Social Security Administration and the Centers for Medicare and Medicaid Services.

Muscle strength

Lower extremity strength of the knee extensors was evaluated using a Kin Kom MP isokinetic dynamometer (Chattanooga Group, Inc.). Following three warm-up repetitions, participants performed three 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. The specific isokinetic knee extensor test performed at 60° per second on the Kin Kom dynamometer has an interclass correlation coefficient (ICC) of 0.89 (Tredinnick & Duncan, 1988).

Sedentary time

Participants were asked, "Over the past 30 days, on a typical day how much time altogether did you spend on a typical day sitting and watching TV or videos or using a computer outside of work?" The following are the response options: none, less than 1, 1, 2, 3, 4, or 5+ h. Participants were subsequently classified into the following sedentary behavior groups: <2 h/day, 2–4 h/day, and 5+ hrs/day. This screen-based sedentary behavior item has demonstrated some evidence of convergent validity by correlating with body mass index categories. (McDowell, Hughes, & Borrud 2006). Using data from the 2003–2006 NHANES (cycles with objective "overall" sedentary data), the author computed the correlation between this self-report screen-based sedentary behavior item and identical categories (h/day) of accelerometer-determined sedentary behavior (counts/min <100); a weak statistically significant association ($r = 0.10$, $P < 0.0001$) was observed, which is not unexpected as this self-report screen-based sedentary item only assessed non-occupational sedentary behavior, whereas accelerometry assesses overall daily sedentary behavior. This observed correlation is within the range ($r = -0.19$ to 0.80) of a review paper documenting the concurrent validity of television viewing time and other non-occupational sedentary behaviors (referent measures included heart rate monitoring, behavioral logs, and accelerometry combined with behavioral logs) (Clark et al., 2009); notably, only three of the evaluated studies from this review examined the validity of self-reported television viewing time and other non-occupational sedentary behaviors. This review did, however, demonstrate moderate-to-high reliability of these measures (the majority of the ICCs were >0.5).

Covariates

Covariates included age (years; continuous), sex, body mass index (BMI; kg/m^2), race/ethnicity, self-reported moderate-to-vigorous physical activity (MET-min-month) (Loprinzi, 2015), use of an ambulatory device (e.g., cane), self-reported smoking status (never, former or current smoker), total cholesterol (continuous; mg/dL), statin medication (yes/no), measured mean arterial blood pressure (continuous; mm Hg), and the following physician diagnosed conditions: arthritis, diabetes, cardiovascular disease, and stroke.

Statistical analyses

Analyses were performed using Stata (version 12.0) and accounted for the complex survey design employed in the NHANES. To examine the associations between LES and all-cause mortality, a weighted multivariable Cox proportional hazard model was employed. Schoenfeld's residuals were used to verify the proportional hazards assumption. In the Cox models, results are expressed as a 15-N increase in LES. Multiplicative interaction was assessed by creating a cross-product term of sedentary behavior and LES, and including this cross-product term, along with their main effects and covariates, in a weighted Cox proportional hazard model. Significance was set at $P < 0.05$.

Results

Characteristics of the study variables are shown in Table 1, with results stratified by sedentary behavior. Generally, participants who had higher levels of sedentary behavior were older; had a higher BMI; engaged in less moderate-to-vigorous physical activity; and were more likely to be diabetic and arthritic, have coronary

Table 1 Weighted characteristics of the analyzed sample ($N = 2768$)

Variable	Mean/proportion (SE)				
	<2 h/day of sedentary (n = 653)	2–4 h/day of sedentary (n = 1711)	5+ h/day of sedentary (n = 404)	Below median strength (≤263 N)	Above median strength (>263 N)
Age, mean years	60.5 (0.3)	62.9 (0.2)	64.2 (0.6)	66.2 (0.4)	59.5 (0.2)
% Female	50.7	53.4	52.5	75.6	33.7
Race-ethnicity, %					
Mexican American	4.6	3.0	2.3	3.4	3.2
Other Hispanic	6.3	5.3	2.1	6.1	4.3
Non-Hispanic White	78.9	82.6	80.3	79.5	82.9
Non-Hispanic Black	6.2	6.5	12.1	7.4	7.1
Other	3.9	2.6	3.2	3.6	2.4
Body mass index, mean kg/m^2	27.2 (0.2)	28.3 (0.1)	28.8 (0.3)	27.3 (0.2)	28.8 (0.2)
MVPA MET-min-month, mean	5491.3 (723.8)	3829.4 (292.8)	2876.4 (450.2)	2881.9 (431.0)	5119.0 (371.5)
Total cholesterol, mean mg/dL	216.4 (1.6)	215.9 (1.1)	212.4 (2.6)	217.5 (1.2)	213.8 (1.3)
Mean arterial pressure, mmHg	93.6 (0.8)	92.9 (0.4)	92.2 (0.7)	92.2 (0.6)	93.6 (0.3)
Diabetes, %	8.2	9.8	13.6	11.8	8.4
Arthritis, %	31.9	38.3	44.7	45.0	31.5
Coronary artery disease, %	6.2	5.9	11.7	6.9	6.6
Stroke, %	0.6	0.4	1.4	0.8	0.4
Ambulatory device, %	4.5	5.6	9.4	8.5	3.6
Statin medication, %	14.2	17.3	17.4	16.3	16.7
Smoking status, %					
Current smoker	12.9	15.6	24.0	15.3	16.8
Former smoker	36.9	39.7	37.8	32.5	43.9
Never smoked	50.2	44.7	38.2	52.2	39.3
Deaths at follow-up, %	18.2	19.1	31.5	29.4	13.2
Person-months of follow-up	76,851	201,289	43,856	168,276	153,720
Strength, mean N	295.8 (4.1)	287.6 (3.9)	265.9 (4.8)	200.2 (1.5)	358.1 (2.7)
Sedentary, h/day	0.5 (0.01)	2.7 (0.02)	5	2.6 (0.1)	2.4 (0.1)

MVPA moderate-to-vigorous physical activity, *MET* metabolic equivalent of task artery disease, use an ambulatory device, and had lower levels of LES.

After adjustments, for every 15-N increase in LES, participants had a 7 % reduced risk of all-cause mortality (HR = 0.93; 95 % CI 0.91–0.95; $P < 0.001$). When adding the three-level leisure-time sedentary behavior variable as a covariate in this model, results were unchanged (HR = 0.93; 95 % CI 0.92–0.96; $P < 0.001$). Similarly, when leisure-time sedentary behavior was included as a continuous covariate in the model, results regarding the relationship between LES and mortality were unchanged (HR = 0.94; 95 % CI 0.91–0.96; $P < 0.001$). Additional [reverse causality] sensitivity analyses evaluated whether this relationship was altered when taking into consideration the duration of follow-up. After excluding those who died within the first 12 months of follow-up, results were unchanged (HR = 0.94; 95 % CI 0.92–0.96; $P < 0.001$); results were similar when excluding those who died within the first 24 months of follow-up (HR = 0.94; 95 % CI 0.92–0.96; $P < 0.001$), 36 months of follow-up (HR = 0.95; 95 % CI 0.93–0.97; $P < 0.001$), or 48 months of follow-up (HR = 0.95; 95 % CI 0.93–0.97; $P < 0.001$).

When considering leisure-time sedentary behavior as a continuous variable, there was no evidence of statistical interaction between LES and sedentary behavior on all-cause mortality ($HR_{interaction}$ = 1.01; 95 % CI 0.92–1.10; $P = 0.88$). Similarly, there was no evidence of statistical interaction between LES and leisure-time sedentary behavior on all-cause mortality when creating the cross-product term of the three-level leisure-time sedentary behavior variable ($HR_{interaction}$ = 1.00; 95 % CI 0.96–1.03; $P = 0.99$).

Discussion

This brief report is the first to examine whether LES is predictive of all-cause mortality among individuals with considerations by sedentary behavior. This is worthy of investigation as emerging work suggests that sedentary behavior is independently associated with early mortality. For example, several studies (Katzmarzyk et al., 2009; Matthews et al., 2012; Patel et al., 2010) have demonstrated that physical activity does not appear to negate the effects of sedentary behavior on mortality, suggesting that prolonged sedentary behavior, even among individuals who are relatively active, may still increase an individual's risk for premature mortality. Because of this emerging evidence, a new line of inquiry, named *sedentary physiology*, has emerged, which can be conceptualized as being on the opposite end of the movement continuum from *exercise physiology* (Tremblay et al., 2010). However, whether LES continues to demonstrate protective effects on mortality among those with higher levels of sedentary, is, at this point, unknown. Consistent with previous work on this topic (Buckner et al., 2015), LES was inversely associated with all-cause mortality among the entire sample, and this association was not attenuated when considering leisure-time sedentary behavior. Further, there was no evidence of a multiplicative interaction effect of LES and leisure-time sedentary behavior on all-cause mortality. Taken together, these findings suggest that leisure-time sedentary behavior does not appear to negate the beneficial effects of LES with regard to mortality risk.

Despite the notable strengths of this study, which include the national sample, objective measure of LES, and prospective design, limitations include the subjective assessment of physical activity and, in particular, sedentary behavior. Also, the sedentary behavior assessment was restricted to leisure time sedentary, which may not be representative of overall daily sedentary behavior. As such, future work on this topic, overcoming these limitations, is needed to confirm the present findings. Until future work on this topic is employed, at this point, it is not possible to definitely conclude whether or not sedentary behavior moderates the relationship between LES and mortality. However, based on these findings, it appears unlikely that it does. Again, however, the sedentary behavior measured employed herein was subjective, possibly underestimating the potential interaction effect of sedentary behavior on the LES-mortality relationship.

Acknowledgments No funding was used to prepare this manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interests.

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