ORIGINAL ARTICLE

Current employment status, occupational category, occupational hazard exposure and job stress in relation to telomere length: the Multiethnic Study of Atherosclerosis (MESA)

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ABSTRACT

Objective Telomere length has been proposed as a biomarker of cell senescence, which is associated with a wide array of adverse health outcomes. While work is a major determinant of health, few studies have investigated the association of telomere length with various dimensions of occupation. Accelerated cellular aging could be a common pathway linking occupational exposure to several health outcomes.

Methods Leukocyte telomere length was assessed using quantitative PCR in a community-based sample of 981 individuals (age: 45–84 years). Questionnaires were used to collect information on current employment status, current or main occupation before retirement and job strain. The Occupational Resource Network (O*NET) database was linked to the questionnaire data to create five exposure measures: physical activity on the job, physical hazard exposure, interpersonal stressors, job control and job demands. Linear regression was used to estimate associations of occupational characteristics with telomere lengths after adjustment for age, sex, race, socioeconomic position and several behavioural risk factors.

Results There were no mean differences in telomere lengths across current employment status, occupational category, job strain categories or levels of most O*NET exposure measures. There was also no evidence that being in lower status occupational categories or being exposed to higher levels of adverse physical or psychosocial exposures accelerated the association between age and telomere shortening.

Conclusions Cellular aging as reflected by shorter telomeres does not appear to be an important pathway linking occupation to various health outcomes.

What this paper adds

- Telomere length has been proposed as a biomarker of cellular aging, and shorter telomeres have been linked to various adverse health outcomes.
- Although many of these health outcomes have also been associated with occupational exposure, the association of telomere length with occupational exposure has rarely been studied.
- In a large, racially diverse sample, we found no mean differences in telomere lengths across current employment status, occupational category, job strain categories or levels of occupational exposure measures derived from O*NET.

INTRODUCTION

Telomeres, the protective caps of the ends of chromosomes, become shorter during repeated DNA replication, and thus telomere length has been proposed as a biomarker of cell senescence.[1] Oxidative stress has also been shown to accelerate telomere shortening.[2] Thus shorter telomeres indicate cumulative history of oxidative stress, which accelerates cell senescence.[1] Shorter telomere length has been associated with a range of health outcomes including cardiovascular disease (CVD) and its risk factors,[3] incident cancer and cancer mortality,[4] chronic obstructive pulmonary disease (COPD),[5] decline in immune function,[6] and mortality.[7] Identifying environmental factors that shorten telomere length may shed light on aetiologies of these adverse health conditions as well as on the causes of disparities in these conditions.

Many adverse health outcomes associated with shortening of telomere length are also linked to working conditions. For example, occupational exposure accounts for a substantial proportion (15%) of COPD cases, second only to cigarette smoking.[8] A sizeable body of literature supports the link between CVD and job stress.[9] Some occupational exposures have been linked to specific types of cancer,[10] and different rates of mortality by occupation have been documented in many countries.[11–14] Occupational exposures, which are patterned by social class and race, may be important contributors to health disparities.[15] An effect of occupation on the general process of cellular aging, as reflected in telomere length, would provide evidence of a common pathway through which occupation could affect many different health outcomes.

While evidence has started to accumulate for a link between telomere length and life stress, such as caregiving[6 16] and childhood hardship or maltreatment,[17 18] little is known about the association of telomere length with job stress and other occupational exposures. To date, very few studies have examined associations of occupational exposures with telomere length.[19 20] Among 144 battery plant workers, Wu *et al*[20] found that elevated lead levels in urine and blood were associated with shorter telomeres. Parks *et al*[19] investigated various work schedule characteristics among 608 women and reported that working full-time was associated with shorter telomeres compared with working part-time. They found no associations between telomere length and irregular work hours or working at night. While lead and work schedule are important occupational exposures, a wider range of occupational characteristics and exposures need to be examined. Although several studies have examined telomere length and the more general construct of socioeconomic position, which is partly determined by occupation, results have been inconclusive.[21–23]

We used detailed data on multiple dimensions of occupation and occupational exposures available in the Multi-Ethnic Study of Atherosclerosis (MESA) to examine associations of telomere length with employment status, occupational category and selected occupational exposures (ie, physical activity on the job, physical hazard exposure, job strain, job control and job demands). In addition to cross-sectional associations, we also examined whether occupational exposures modified the association between age and telomere length. Because telomere length is a marker of cellular senescence which could manifest in various forms of diseases,[1] investigating its relationship with various dimensions of occupation may help us understand the role of occupation in disease aetiology and potentially the cause of health disparities across occupations.

METHODS

Study settings and participants

The data came from a subsample of the MESA, an ongoing cohort study designed to examine the prevalence and progression of subclinical CVD.[24] Between 2000 and 2002, MESA recruited 6814 adults, aged between 45 years and 84 years, free of clinical CVD in six US communities. The original MESA sample consisted of 38% white, 28% African American, 23% Hispanic, and 11% Asian (mainly Chinese) American participants. Of the 6814 MESA participants, about 1000 from the New York and Los Angeles study sites were randomly selected to participate in an ancillary study focusing on stress as a CVD risk factor. Telomere length was assessed for 981 participants in this ancillary study.

Telomere length

Leukocyte telomere length was measured from the blood sample taken during the first MESA exam (2000–2002) using quantitative PCR.[25] Each sample was amplified for telomeric DNA and for 36B4, a single-copy control gene that provided an internal control to normalise the starting amount of DNA. A 4-point standard curve (twofold serial dilutions from 10 ng to 1.25 ng DNA) was used to transform cycle threshold into nanograms of DNA. Baseline background subtraction was performed by aligning amplification plots to a baseline height of 2% in the first five cycles. The cycle threshold was set at 20% of maximum product. All samples were run in triplicate and the median was used for calculations. The amount of telomeric DNA (T) was divided by the amount of single-copy control gene DNA (S), producing a relative measurement of the telomere length (T/S ratio). Two control samples were run in each experiment to allow for normalisation between experiments, and periodical reproducibility experiments were performed to guarantee correct measurements. The introassay and interassay variability (coefficient of variation) for quantitative PCR was 6% and 7%, respectively.

Occupation

During their visit to the field centre, participants completed a questionnaire on their occupation and, job characteristics. The questionnaire was self-administered in their preferred language (English or Spanish).

Occupation was assessed with four open-ended questions modelled after the US Census (eg, 'What is/was your main job tasks?' 'What is/was your job title'). Participants who were no longer working at the time of the MESA exam (approximately 55% of the sample) reported their main occupation before they stopped working. For those who were still working at the time of data collection, we asked about their current occupation. Experienced coders at the National Institute for Occupational Safety and Health assigned the Census 2000 Occupation Codes to the responses, which were then converted to the Census 2002 Occupation Codes in order to facilitate the use of Occupational Resource Network (O*NET) data (see below for details). The coded occupation was categorised in five groups: management, professional, service, sales/office and blue-collar jobs. Current employment status was categorised in five groups: working full-time, working part-time, on-leave or unemployed, retired and not working (including homemakers), and retired but still working or volunteering.

Self-report measures of job control and job demands

For those who were current workers at the time of data collection (n=435), the Job Content Questionnaire (JCQ)[26] was used to obtain information about job control and job demands. These are two components of the demand-control model,[27] one of the most extensively studied job stress models. According to the demand-control model, high levels of job demands combined with low levels of job control (ie, job strain) negatively impact health.[28–30] Job control was measured with the JCQ's original nine items (eg, 'My job allows me to make a lot of decisions on my own'), and job demands with five items (eg, 'My job requires working very hard').[26] Each item had a 4-point response scale ('never/almost never (=1)' to 'often (=4)'), and the scale scores were calculated based on the original JCQ formula.[27] The score ranges from 12 to 48 for job demands, and from 24 to 96 for job control. Chronbach's α was 0.82 for the job control scale, and 0.72 for the job demands scale. More detailed psychometric properties of the scales and comparisons across languages in the MESA sample are reported elsewhere.[31] Following the most commonly used formulation of job quadrant,[32] job strain categories were created by dichotomising demands and control at their sex specific median (job control cut-off was 76 for men, 72 for women; job demands cut-off was 26 for men, 31 for women). Categories were low strain (low demands+high control), active jobs (high demands+high control), passive jobs (low demands+low control) and high strain (high demands+low control).

Occupational exposure measures from O*NET

We derived job characteristics measures from the O*NET, developed by the US Department of Labor.[33] O*NET provides detailed descriptive information for each of over 900 occupations in the US Standard Occupational Classification system.[34] The original intent of the US Department of Labor was to help job seekers identify jobs that fit their skills and interests; however, O*NET's comprehensive descriptions of the wide array of occupations attracted researchers' interest in using it as an occupational exposure matrix.[33 35] In their review, Cifuentes *et al*[35] observed that despite several methodological problems in earlier studies, O*NET is a promising source of job characteristics that may impact workers' health.

O*NET data describe characteristics of more than 900 Standard Occupational Classification jobs through ratings obtained from randomly selected current job holders and occupational analysts. They assessed each job using a standardised rating system, which consisted of 277 items describing various aspects of the job (eg, 'In your current job, how much freedom do you have to make decisions without supervision? (for current job holders),' 'To what extent does this occupation allow workers to make decisions on their own? (for occupational analysts)'). O*NET provides the raw mean value of each item as well as scaled mean values ranging from 0 to 100. The scaled mean values are useful because the 277 items have various response scales (eg, a 7-point importance scale, a 5-point frequency scale). We linked each participant's reported occupation to the O*NET measures using the 2002 Census Occupation Codes.

For this study, five occupational exposure measures were derived from the O*NET16 database: physical activity on the job, physical hazard exposure, interpersonal stressors, job control and job demands. For *physical activity on the job*, we used three items: time spent on sitting (reverse item), the importance of using arms and legs and moving the whole body in performing the job, and the level of general physical activities needed to perform the job. We calculated the mean of O*NET scaled means for the three variables. Cronbach's α was 0.86.

For *physical hazard exposure*, we calculated the mean of seven items that address common physical hazards traditionally studied in occupational safety and health. These seven items asked the frequency of exposure to the following conditions: sounds and noise levels that are distracting and uncomfortable, very hot (above 90°F) or very cold (under 32°F) temperatures, extremely bright or inadequate lighting conditions, high places (eg, working on poles, scaffolding, catwalks or ladders), an environment that is not controlled (ie, without air-conditioning), outdoors under cover and outdoors exposed to all weather conditions. Cronbach's α for the seven items was 0.96.

For *interpersonal stressors*, we calculated the mean of six items: the importance of resolving conflicts and negotiating with others; frequency of conflict situations as part of the job; dealing with unpleasant, angry or discourteous people; dealing with physically aggressive people; the importance of maintaining composure and keeping emotions in check; and the importance of accepting criticisms and dealing calmly with high-stress situations. Cronbach's α was 0.88.

For *psychological job demands* and *job control*, we used the same items used by Cifuentes *et al*.[36] Psychological job demands included four items addressing the ability to shift back and forth between tasks, the ability to concentrate on a task, the seriousness of error and the importance of being accurate. We calculated the mean of the four items. Cronbach's α was 0.68. As for *job control*, we used four O*NET items asking the extent to which the job makes use of workers' abilities and allows workers to try out their own ideas, to make decisions on their own, and to plan their work. Cronbach's α was 0.97.

Covariates

For all participants, the following information was collected in a questionnaire conducted during MESA Exam 1: age, self-identified race/ethnicity, educational attainment, household income, current smoking status, and pack-years for current and former smokers. Height and weight were measured at the study site and used to calculate the body mass index (kg/m^2). Because a significant association between current sleep quality and telomere length has been reported,[37] we included it in all analyses (ie, 'During the past week, my sleep was restless' with four response options: >1 day, 1–2 days, 3–4 days and 5–7 days). For current workers, the number of years worked on the current job was asked in the questionnaire.

Statistical analyses

First, descriptive statistics of selected characteristics were calculated for all participants (n=981) and for the current worker subsample (n=435). Linear regression was used to estimate mean differences in telomere length associated with each of the following occupational characteristics: current employment status, occupational category, O*NET physical activity, O*NET physical hazard exposure and O*NET interpersonal stressors.

We also investigated telomere length in relation to job control and job demands among current workers (n=435). For the full sample and current worker subsample analyses, we tested the interaction term between age and each of the occupational characteristic variables in order to examine whether occupational characteristics modified the extent to which higher age was associated with shorter telomeres. Age, sex and race variables were all grand-mean centred so that the effect of age would reflect the aging effect adjusted for the sex and race distribution of the sample. We compared regression coefficients as we added sets of covariates. Model 1 was adjusted only for age, sex, race/ethnicity, and the interaction between age and race/ethnicity as well as age and sex.[38] In Model 2 we added the interaction term between age and occupational characteristics. Then in Model 3, we assessed if the coefficients for occupational characteristics were affected by including current working status (still working vs retired), job tenure (for the current worker subsample analyses only), indicators of socioeconomic position (ie, household income, education, occupational categories), body mass index, current smoking status, pack-years and sleep quality.

The study protocol was approved by the institutional review board at each study site as well as the National Heart, Lung, and Blood Institute. The analysis for this study was approved by the institutional review board at the National Institute for Occupational Safety and Health.

RESULTS

Characteristics of study participants are presented in table 1. Mean age was 61.4 years for the full sample and 55.7 years for the current worker sample. The full sample was 47% male and 53% Hispanic; the current worker subsample was 51% male and 48% Hispanic. Compared with the full sample, the current workers had higher household income and more education, and a lower proportion of blue-collar workers. The average job tenure for the current workers was 14 years. Even though nearly half of the sample consisted of immigrants, the mean job tenure did not differ significantly between immigrants and non-immigrants (13.2 years and 15.1 years, respectively; χ^2=1.52, p=0.218).

The participants were nearly evenly distributed across occupational categories, except for a smaller proportion for management jobs. The sample included a wide range of occupations: 231 jobs were represented by the 981 participants in the full sample, and the 435 current workers held 155 jobs. Most common occupations included nurses' aide (n=47), room cleaner (n=35), administrative assistant (n=29) and janitor (n=23). The level of physical activity on the job, physical

Table 1 Characteristics of the full sample included in telomere analyses and the current worker subsample, the Multi-Ethnic Study of Atherosclerosis

Characteristic	Full sample (n=981)	Current worker subsample for job strain analyses (n=435)
Mean age (SD) in years	61.4 (9.93)	55.4 (7.63)
Per cent male	47.6	50.6
Race/ethnicity (% distribution)		
White	18.6	20.9
African American	28.3	34.9
Hispanic	53.1	44.1
Per cent foreign-born	49.3	47.6
Income (% distribution)		
<$20000	29.6	15.9
$20000–$39499	27.7	27.5
$35000–$49999	16.5	18.9
$50000–$74499	13.0	18.2
≥$75000	13.1	19.4
Education (% distribution)		
Less than high school	27.1	18.4
Complete high school	20.3	16.6
Some college, vocational/associate degree	29.9	34.7
Bachelor's degree	11.1	14.3
Graduate or professional degree	11.6	16.1
Occupation (% distribution)		
Management	11.2	13.0
Professional	21.0	25.4
Service	23.6	25.6
Sales, office, admin. support	20.2	20.2
Blue-collar	24.1	15.8
Current employment (% distribution)		
Working full-time	36.7	79.7
Working part-time	6.9	15.0
On-leave or unemployed	5.6	–
Retired, not working or volunteering	41.0	–
Retired, but working/volunteering	9.8	5.4
Current job tenure in years, mean (SD)	–	14.0 (11.4)
Mean O*NET physical activity (SD)	46.6 (21.2)	44.8 (21.2)
Mean O*NET physical hazard exposure (SD)	26.8 (15.7)	25.2 (14.9)
Mean O*NET interpersonal stressors (SD)	55.1 (11.3)	56.2 (11.3)
Mean O*NET job demands (SD)	–	52.2 (8.2)
Mean O*NET job control (SD)	–	51.9 (16.2)
Mean self-report job demands (SD)*	–	28.1 (8.3)
Mean self-report job control (SD)†	–	71.1 (15.8)
Job strain quadrant (% distribution)		
Low strain jobs	–	24.1
Active jobs	–	22.5
Passive jobs	–	25.6
High strain jobs	–	28.0
BMI (% distribution)		
<25 kg/m^2	23.5	25.3
25–29.9 kg/m^2	39.7	37.5
30–39.9 kg/m^2	32.3	31.3
≥40 kg/m^2	4.6	6.0
Smoking status (% distribution)		
Never smoker	52.4	51.7
Former smoker	36.1	34.5
Current smoker	11.5	13.8

Continued

Table 1 Continued

Characteristic	Full sample (n=981)	Current worker subsample for job strain analyses (n=435)
Mean pack-years among ever smokers (SD)‡	17.4 (19.0)	15.2 (16.0)
Per cent restless sleep >1 day/week	41.6	41.6
Telomere length (T/S ratio)		
10th percentile	0.634	0.663
25th percentile	0.719	0.758
50th percentile	0.832	0.872
75th percentile	0.952	0.994
90th percentile	1.092	1.123
mean (SD)	0.845 (0.176)	0.885 (0.181)

*Range from 12 to 48.
†Range from 24 to 96.
‡Mean pack years was calculated only for current and former smokers.
O*NET, Occupational Resource Network.

hazard exposure, and interpersonal stressors were similar for the full sample and the current worker subsample. The mean telomere length was longer for the current worker subsample than for the full sample.

Table 2 presents the mean differences in telomere length by current employment status and occupational category, as well as mean difference associated with 1 SD difference in three O*NET job characteristic measures for the full sample. The mean telomere length did not differ across current employment status or by occupational category, and the association of age with telomere length did not differ by current employment status or occupational category (all interaction p values>0.05). There were also no statistically significant associations between telomere length and O*NET-derived physical activity on the job, physical hazard exposure, or interpersonal stressors, either as the main effect or in interaction with age.

Associations of telomere length with job strain, job control and job demands (self-report and O*NET) among current workers are shown in table 3. The mean telomere length did not differ by job strain category, and the association of greater age and shorter telomere did not differ by job strain category (p for interaction=0.096). O*NET job demands had a statistically significant interaction with age (p for interaction=0.041) such that the association of greater age with shorter telomeres became weaker as job demands increased. This interaction was attenuated after all covariates were included in the model (p for interaction=0.078).

DISCUSSION

This cross-sectional study of a multiethnic community sample explored associations of telomere length with several dimensions of occupation, including current employment status, occupational category, occupational exposure measures from O*NET and self-reported job strain. We found no evidence that occupational category, employment status or various features of occupation were associated with differences in telomere length. We examined the occupation-telomere relationship with sociodemographic characteristics and some behavioural risk factors accounted for, but these covariates did not influence the association (or lack thereof) between telomere length and various dimensions of occupation. There was also no consistent

Table 2 Mean difference in telomere length (T/S ratio) associated with current employment status, occupational category, and a 1 SD difference in three O*NET characteristics after adjustments for sets of covariates (n=981)

	Model 1: Main effect			Model 2: Main effect+Age interaction			Model 3: Main effect+Age interaction+other covariates		
Occupational characteristics	**Mean difference**	**(95% CI)**	**p Value**	**Mean difference**	**(95% CI)**	**p Value**	**Mean difference**	**(95% CI)**	**p Value**
Age	−0.0055	(−0.0070 to −0.0040)	<0.001	−0.0050	(−0.0076 to −0.0025)	<0.001	−0.0052	(−0.0077 to −0.0026)	<0.001
Current employment status			0.934			0.985			0.928
Working full-time	Reference			Reference			Reference		
Working part-time	0.0107	(−0.0329 to 0.0543)		−0.0048	(−0.0545 to 0.0448)		−0.0115	(−0.0609 to 0.0380)	
On-leave or unemployed	−0.0121	(−0.0597 to 0.0355)		−0.0051	(−0.0743 to 0.0641)		−0.0026	(−0.0673 to 0.0725)	
Retired, not working/homemaker	−0.0004	(−0.0316 to 0.0309)		−0.0051	(−0.0381 to 0.0279)		−0.090	(−0.0429 to 0.0249)	
Retired, working or volunteering	0.0099	(−0.0340 to 0.0538)		0.0126	(−0.0498 to 0.0750)		0.0157	(−0.0464 to 0.0778)	
Age by employment interaction						0.689			0.430
Age×Working full time				Reference			Reference		
Age×Working part time				−0.0036	(−0.0089 to 0.0016)		−0.0046	(−0.0098 to 0.0006)	
Age×On-leave or unemployed				0.0009	(−0.0062 to 0.0080)		0.0009	(−0.0062 to 0.0080)	
Age×Retired, not working/homemaker				−0.0002	(−0.0035 to 0.0032)		0.0002	(−0.0032 to 0.0036)	
Age×Retired, working or volunteering				−0.0011	(−0.0071 to 0.0048)		−0.0008	(−0.0067 to 0.0051)	
Age	−0.0055	(−0.0066 to −0.0044)	<0.001	−0.0059	(−0.0090 to −0.0028)	<0.001	−0.0059	(−0.0090 to −0.0026)	<0.001
Occupational category			0.658			0.637			0.758
Management	Reference			Reference			Reference		
Professional	−0.0252	(−0.0652 to 0.0147)		−0.0251	(−0.0654 to 0.0152)		−0.0207	(−0.0613 to 0.0199)	
Service	−0.0205	(−0.0610 to 0.0200)		−0.0236	(−0.0645 to 0.0174)		−0.0296	(−0.0739 to 0.0147)	
Sales, Office, admin support	−0.0074	(−0.0480 to 0.0333)		−0.0085	(−0.0496 to 0.0325)		−0.0185	(−0.0610 to 0.0240)	
Blue-collar	−0.0085	(−0.0485 to 0.0315)		−0.0098	(−0.0505 to 0.0308)		−0.0188	(−0.0637 to 0.0262)	
Age by occupational category interaction						0.775			0.845
Age×Management				Reference			Reference		
Age×Professional				0.0012	(−0.0027 to 0.0051)		0.0008	(−0.0031 to 0.0047)	
Age×Service				−0.0009	(−0.0049 to 0.0031)		−0.0009	(−0.0048 to 0.0031)	
Age×Sales/Office				0.0008	(−0.0030 to 0.0047)		0.0004	(−0.0034 to 0.0042)	
Age×Blue-collar				0.0006	(−0.0033 to 0.0045)		0.0010	(−0.0029 to 0.0048)	
Age	−0.0053	(−0.0064 to −0.0042)	<0.001	−0.0053	(−0.0064 to −0.0042)	<0.001	−0.0055	(−0.0070 to −0.0040)	<0.001
O*NET Physical activity on the job	−0.0019	(−0.0134 to 0.0096)	0.751	−0.0020	(−0.0135 to 0.0095)	0.816	−0.0007	(−0.0169 to 0.0155)	0.933
Age×O*NET Physical activity on the job				0.0006	(−0.0005 to 0.0018)	0.163	0.0006	(−0.0006 to 0.0017)	0.315
Age	−0.0053	(−0.0064 to −0.0042)	<0.001	−0.0053	(−0.0064 to −0.0042)	<0.001	−0.0054	(−0.0070 to −0.0039)	<0.001
O*NET Physical hazard exposure	0.0085	(−0.0034 to 0.0205)	0.162	0.0080	(−0.0040 to 0.0199)	0.192	0.0105	(−0.0053 to 0.0262)	0.192
Age×O*NET physical hazard exposure				0.0010	(0.0003 to 0.0022)	0.125	0.0009	(−0.0003 to 0.0021)	0.163
Age	−0.0053	(−0.0064 to −0.0042)	<0.001	−0.0053	(−0.0064 to −0.0041)	<0.001	−0.0055	(−0.0071 to −0.0040)	<0.001
O*NET Interpersonal stressor exposure	−0.0007	(−0.0121 to 0.0107)	0.909	−0.0007	(−0.0121 to 0.0107)	0.902	0.0029	(−0.0099 to 0.0156)	0.659
Age×O*NET Interpersonal stressor exposure				−0.0001	(−0.0013 to 0.0011)	0.881	−0.0003	(−0.0014 to 0.0009)	0.665

Each occupational characteristic was examined separately. Models 1 and 2 were adjusted for age, sex, race, as well as age by sex and age by race interactions. Model 3 had additional covariates of household income, education, nativity, current smoking status, pack-years, BMI and sleep quality. In addition, for current employment models, occupational category was adjusted, and for occupational category models, current employment was adjusted for. Both variables were included in the three O*NET characteristic models. Age was centred around the sample mean, and the O*NET variables were standardised to facilitate the interpretation of the regression coefficients. The mean differences for age and age interaction were estimated for 1 year of aging.
BMI, body mass index; O*NET, Occupational Resource Network.

Table 3 Mean difference in telomere length (T/S ratio) associated with job strain quadrant and a 1 SD difference in job control and job demands among current workers (n=435)

	Model 1: Main effect			Model 2: Main effect+Age interaction			Model 3: Main effect+Age interaction+other covariates		
Occupational characteristics	**Mean difference**	**(95% CI)**	**p Value**	**Mean difference**	**(95% CI)**	**p Value**	**Mean difference**	**(95% CI)**	**p Value**
Age	−0.0044	(−0.0068 to −0.0020)	0.003	−0.0076	(−0.0115 to −0.0038)	0.001	−0.0101	(−0.0143 to −0.0058)	<0.001
Job strain quadrant (self-report)			0.934			0.254			0.456
Low strain jobs	Reference			Reference			Reference		
High strain jobs	0.0034	(−0.0433 to 0.0501)		0.0130	(−0.0508 to 0.0767)		0.0142	(−0.0513 to 0.0797)	
Active jobs	0.0099	(−0.0379 to 0.0578)		0.0168	(−0.0445 to 0.0781)		0.0330	(−0.0299 to 0.0959)	
Passive jobs	0.0142	(−0.0322 to 0.0606)		0.0557	(0.0008 to 0.1106)		0.0442	(−0.0138 to 0.1021)	
Age by job strain (self-report)						0.063			0.096
Age×Low strain jobs				Reference			Reference		
Age×High strain jobs				0.0027	(−0.0040 to 0.0093)		0.0033	(−0.0034 to 0.0099)	
Age×Active jobs				0.0026	(−0.0037 to 0.0088)		0.0037	(−0.0027 to 0.0101)	
Age×Passive jobs				0.0078	(0.0021 to 0.0136)		0.0073	(0.0016 to 0.0130)	
Age	−0.0047	(−0.0069 to −0.0022)	0.001	−0.0047	(−0.0071 to −0.0023)	0.001	−0.0065	(−0.0092 to −0.0038)	<0.001
Job control (self-report)	−0.0029	(−0.0201 to 0.0147)	0.741	−0.0137	(−0.0352 to 0.0077)	0.210	−0.0043	(−0.0275 to 0.0189)	0.715
Job demands (self-report)	−0.0089	(−0.0262 to 0.0085)	0.315	−0.0083	(−0.0298 to 0.0133)	0.452	0.0057	(−0.0172 to 0.0285)	0.626
Age×Job control (self-report)				−0.0019	(−0.0041 to 0.0003)	0.097	−0.0020	(−0.0042 to 0.0002)	0.078
Age×Job demands (self-report)				−0.0001	(−0.0022 to 0.0023)	0.966	0.0010	(−0.0013 to 0.0034)	0.397
Age	−0.0043	(−0.0067 to −0.0019)	0.005	−0.0040	(−0.0064 to −0.0016)	0.001	−0.0063	(−0.0090 to −0.0035)	<0.001
O*NET Job control	−0.0004	(−0.0197 to 0.0189)	0.970	−0.0088	(−0.0319 to 0.0143)	0.455	0.0199	(−0.0093 to 0.0491)	0.182
O*NET Job demands	0.0051	(−0.0130 to 0.0232)	0.583	0.0203	(−0.0030 to 0.0446)	0.088	0.0217	(−0.0018 to 0.0452)	0.071
Age×O*NET Job Control				−0.0016	(−0.0040 to 0.0008)	0.188	−0.0013	(−0.0037 to 0.0011)	0.281
Age×O*NET Job demands				0.0026	(0.0001 to 0.0050)	0.041	0.0022	(−0.0002 to 0.0047)	0.078

Self-reported job strain, job control and job demands, and O*NET job control were examined separately. Models 1 and 2 were adjusted for age, sex, race, as well as age by sex and age by race interactions. Model 3 had additional covariates of household income, education, job tenure, nativity, occupational category, current smoking status, pack-years, BMI and sleep quality. Age was centred around the sample mean, and the O*NET variables were standardised to facilitate the interpretation of the regression coefficients. The mean differences for age and age interaction were estimated for 1 year of aging.
BMI, body mass index; O*NET, Occupational Resource Network.

evidence that occupational factors modified the association of age with shorter telomeres.

Our results regarding no differences in telomere length by occupational category are consistent with other reports showing no associations of telomere length with socioeconomic position based on occupation.[21 23 39 40] Equivocal results were reported regarding the association between telomere length and other measures of socioeconomic position as well. Batty *et al*[41] found no association between telomere length and educational attainment in a community-based sample of over 1500 men. Steptoe *et al*,[23] on the other hand, reported that higher educational attainment was associated with longer telomeres among healthy men and women. Telomere length was not associated with either residential area deprivation[41] or individuals' own sense of their socioeconomic position among women.[42] While Cherkas *et al*[22] did find shorter telomeres among women in manual jobs compared with those in non-manual jobs, all other studies as well as the current study suggest that telomere length may not reflect the increased disease risk associated with low socioeconomic position.

Our results are not consistent with some previous findings such as those reported by Parks *et al*.[19] They found that among women aged between 35 years and 74 years, full-time workers had shorter telomeres compared with part-time workers and those who were not in the workforce. Their sample was predominantly white (83%), with only 7% African American and 2% Hispanic participants. In our sample, white participants represented only about a fifth of the sample, and immigrants accounted for nearly half. Even though our sample is larger than the Parks study, we did not find differences in telomere lengths by occupational characteristics. Other studies have found that associations between socioeconomic status (for which occupational measures are often proxies) and health outcomes are not always similar across ethnic groups or between immigrants and non-immigrants.[43 44] This suggests that the heterogeneity in our sample may have made it difficult to identify differences in telomere length associated with occupational characteristics.

The O*NET job characteristics and job strain were not associated with telomere length in our sample, either as a main effect or as an interaction with age. One interaction with age was marginally significant, but the association was in the unexpected direction and was attenuated once covariates were adjusted for. While O*NET has been recognised as a potentially valuable source of job exposure data,[35] it has rarely been used in investigating objectively measured health outcomes, and no other studies have examined telomere length in relation to O*NET-derived job characteristics. Until more studies with objective health measures become available, it is difficult to evaluate the utility of O*NET as a job exposure matrix.

This study has a few limitations. The participants were of older age (mean age=62 years), and about half of them were no longer working. The occupation data were either the person's current job or the main job before the person stopped working. O*NET information may not capture the job characteristics when the participants actually had the job, which could be many years ago as job exposure may have changed during that time. Also, job tenure was not available for former jobs reported by those who were no longer working. While this is a significant limitation, we are reasonably confident that these jobs were held for a substantial time period. In the 1980s and 1990s, when these participants were presumably working, median job tenure for middle-aged workers was about 10 years.[45] A large proportion of retired workers in our sample, however, may have affected results because the association between occupational exposures and health outcomes appears to weaken after retirement (ie, after occupational exposures end).[46] We conducted a sensitivity analysis by repeating the analyses in table 2 (except for employment status) in the subsample of currently employed workers. Similar results were observed in this subsample as in the full sample.

Our sample included a wide range of occupations, which is a strength; but the large proportion of service and blue-collar workers in this older sample may mean that we had especially healthy people (ie, healthy worker effect).[47] This could cause us to underestimate the association between occupation and telomere length. Also, nearly half of our participants were immigrants although the mean years spent in the USA was 32 years, and over 95% of them had lived in the USA more than 10 years prior to the data collection. If immigrant workers had a substantially shorter job tenure, estimates of job characteristics would be less accurate for immigrants than for non-immigrants, but job tenure did not differ by nativity among current workers. We have no reason to believe that job tenure among former workers differ considerably by nativity. The Current Population Survey from 1995 to 2008 showed that immigrants had on average 2.1 years shorter job tenure than non-immigrants.[48] Another large-scale study of immigrants from Mexico reported a 1.1 year difference in 1992.[49] Given over 10 years of likely job tenure among former workers, we assume that a 1–2-year difference by nativity would not alter our conclusions. However, the large proportion of immigrants in the sample may have affected our results some other way because immigrants' jobs could be different even within the same job title. For example, being a restaurant owner as a Chinese immigrant and as a native-born American may be different experiences. The work environment of a given job title could also be very different for recent immigrants and the native born. O*NET measures describe typical characteristics of a given job, which may not apply to immigrants. O*NET exposure measures, as all job exposure matrices that apply average exposure by job title to individuals, produce non-differential misclassification that usually bias the results towards the null value. The psychological job demands items derived from O*NET are not typical measures of psychological job demands. Thus, it is not known how valid this scale is in predicting ill health. In addition, other occupational stressors, such as effort-reward imbalance, long work hours and shiftwork need to be assessed in relation to telomere length.

Blood processing methods may not be consistent across studies, and different methods may potentially select for different subpopulations of leukocytes, in which telomere length may vary. In order to minimise any potential differences, we used well-documented blood processing methods carried out by trained and certified personnel.[24 50] However, we are unable to rule out confounding of results by differences in leucocyte distributions associated with the occupational characteristics. We had a single measurement of telomere length and measurement error may have limited our ability to detect small effects. Nevertheless, as reported by Kim *et al*[51], a single measurement of leukocyte telomere length is a reliable indicator of an individual's telomere length within a several-month time-span. Although our sample was large compared with other telomere studies, it may not have been large enough to detect small effects of job characteristics on telomere length or interactions between age and various occupational characteristics.

Nevertheless, our study has several significant strengths: a diverse population sample, a wide range of occupations, and a sample that includes current and former workers. Most importantly, this study examined various dimensions of occupation that have not been addressed in previous studies.

In conclusion, we did not find associations between telomere length and occupational characteristics. Even though occupation and telomere length are associated with the same diseases (eg, CVD, cancer), our results are not consistent with the notion that job characteristics examined in this study are antecedents of telomere shortening. Occupation is a complex phenomenon that can expose workers to various hazards, each of which may lead to adverse health conditions through unique pathways. Given the multiethnic nature of our sample and the older age of our participants, our findings must be confirmed in other studies. However, our preliminary conclusion is that the impact of occupation on multiple adverse health outcomes is not mediated by accelerated cellular aging.

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