Adapting Fitness Age Calculations to Suit a Modern North American Female Population, Regardless of Age, Race, or Ability Level

Gerontology & Geriatric Medicine
Volume 6: 1–8

DOI: 10.1177/2333721420979815
journals.sagepub.com/home/ggm

Tara L. Diesbourg, PhD[1,2] and Geneviève A. Dumas, PhD[2]

Abstract

Objectives: Fitness Age (FA) has been reported in Japan and South Korea as one way to assess an individual's overall health. To date, this method has not been used in North America. The objective of the current study was to assess the applicability of existing Fitness Age calculations for North American women. **Methods:** Thirty-seven North American working women aged 18 to 67 years completed a fitness test battery, as described by previous studies. The fitness test results were used with published regression equations to estimate each woman's FA which was subsequently adjusted to correct for biases in the data. **Results:** The data from the fitness tests were similar to those presented in the previously published literature with the exception of grip strength, trunk flexion, and body fat percentage which differed significantly compared to the populations assessed previously. These population differences appear to have impacted the applicability of the published methods for this population. **Discussion:** Because the FA estimates must be corrected according to a theoretical "ideal" to address population biases before they can be used, the authors propose using the deviation from this theoretical ideal rather than raw FA in future aging studies, as this is where the interesting inter-personal differences lay.

Keywords

Healthy aging, age estimation, overall health

Manuscript received: August 11, 2020; **final revision received:** October 26, 2020; **accepted:** November 9, 2020.

Introduction

The aging process is subject to variability from a multitude of sources. Factors such as nutrition, sleep, stress level, and exercise can all affect the aging process (Rose, 1991). This is an important consideration because the process of aging involves changes in all of the systems of the body and individuals could age at different rates (Jylhava et al., 2017).

In the present study, the concept of age was examined from two perspectives, the first, is the standard definition of age, measured based on the year of birth (Chronological Age). This is the most functionally relevant definition as regulations surrounding age (e.g. retirement age, the age for old-age pensions and discounts, the age for driver's license renewal, and the age for certain medical tests) use this definition. The second perspective adopted for the current study is that of Fitness Age, which is thought to be an indication of the physical health of an individual (Lee et al., 1996; Nakamura et al., 1990, 1998).

Numerous papers have been published using physiological measures such as blood serum concentrations, intraocular pressure, lung capacity, and dental health to quantify biological age (Levine, 2012; Nakamura & Miyao, 2007; Nakamura et al., 1990, 1998). Unfortunately, these methods are highly invasive and expensive, requiring blood draws, specialized equipment, and trained professionals. An alternative to these invasive and costly tests assess fitness decline as an indirect estimate of the physiological effects of aging. "Fitness Age" is a term used to quantify the age of an individual based on their performance on a battery of fitness tests such as vertical jump height, standing

[1]Oakland University, Rochester, MI, USA
[2]Queen's University, Kingston, ON, Canada

Corresponding Author:
Tara L. Diesbourg, Department of Public and Environmental Wellness, School of Health Sciences, Oakland University, 3110–433 Meadow Brook Rd., Rochester, MI 48309, USA.
Email: tdiesbourg@oakland.edu

Table 1. Regression Coefficients Presented in the Literature for Calculating Fitness Age from Fitness Test Scores for Women.

Author	Back strength	Grip strength	Vertical jump	PWC 170	VO_2max	Trunk flexion	Side step	% Body fat	Correction factor
Nakamura et al. (1990)	0.012		0.047	0.376		0.031	0.058		5.5
Lee et al. (1996)[†]		0.047			0.047	0.049		0.069	2.81*
Nakamura et al. (1998)	0.014		0.041	0.466		0.032	0.047		5.4

[†]This equation was presented for males and females and did not use female-specific coefficients, while the other two papers presented coefficients for female populations.
*This paper used two correction factors in the calculation, the first is provided in the table, the second (a z-score) was calculated using the following equation: z-score = (0.18 · age)–8.76.

trunk flexion, Modified Ishida Side-Step test, isometric low back strength, grip strength, and Physical Working Capacity test, among others (for a full list of the fitness tests used, please see Lee et al., 1996; Meshizuka, 1967; Nakamura et al., 1990, 1998). These researchers developed regression equations by weeding out only those tests that were found to be the strongest-associated with age-related decline and determine the equation coefficients needed to relate these fitness variables to age. Essentially, the equations serve to adjust the average age of the population upward or downward based on a person's weak or strong performance in the aforementioned fitness tests (Lee et al., 1996; Nakamura et al., 1990, 1998).

Unfortunately, there has been very little research in this area outside of Japan and South Korea so it is unclear whether these equations have been used on any population other than the ones on which the equations were developed. Studies suggest that older Chinese men are less healthy than older Canadian men (Chappell, 2003) and that healthy life expectancy differs significantly between Asian and North American populations (Murray & Lopez, 1997; Salomon et al., 2012). For these reasons, we sought to investigate whether these published methods would be robust enough to account for the large variability inherent in the heterogeneous nature of a modern, North American population.

Materials and Methodology

Materials

Participant description. Recruitment strategies targeted all healthy women 18 to 27 years, 38 to 47 years, and 58 to 67 years old in Kingston, Ontario, and the surrounding areas who were working a sedentary job, or who spent a minimum of 4 hours per day seated for work. This included students and individuals working part-time. Volunteers were excluded from participating if their responses on the Physical Activity Readiness Questionnaire (PAR-Q+: Warburton et al., 2015) suggested that they were not medically cleared to exercise. As these participants would also be completing testing for another study protocol, exclusion criteria also included current low back pain, or experiencing debilitating low back pain in the past 12 months that resulted in medical treatment or missed school/work. Participants who weighed in excess of 250 lbs were also excluded from participation as this was the weight capacity of some of the testing devices.

Fitness testing. Participants were instructed not to complete any strength training exercises within 24 hours of their scheduled participation.

The fitness testing protocol followed that described by Meshizuka (1967) and later adopted by Nakamura et al. (1990). The protocol also included tests used by Lee et al. (1996) to cover a wider range of age-related human performance and physiological decline. The full protocol is explained in detail in the supplementary resources. Briefly, the fitness testing protocol included the following tests, each completed three times with 30 to 60 seconds of rest between trials: vertical jump height, standing trunk flexion, Modified Ishida Side-Step test, isometric low back strength, grip strength, and Physical Working Capacity test.

Fitness age calculations. Two different regression equations were used to estimate Fitness Age in this study because together, they were thought to provide a better picture of the individual's overall health. One equation uses functional tests of strength, power, and flexibility and relates to how the individual's health might affect their ability to complete their activities of daily life. The second equation uses a more direct assessment of health by including factors such as body composition, estimated VO_2max, and grip strength. These two equations were derived from three different papers presented in the literature. The Fitness Age used for subsequent analyses is the average of the two Fitness Ages obtained from the equations. The coefficients for the presented regression equations are provided in Table 1.

Nakamura and colleagues presented a regression equation for calculating Fitness Age from fitness tests in 1990 and revised this equation in 1998. This latter paper offered some changes to the original proposed equation after examining the fitness of 249 physically fit women. Because the population examined in the current study is not exclusively fit women but rather women from a vast range of fitness levels, an average of the regression coefficients from the two studies (Nakamura et al., 1990, 1998) were used for this analysis. The resulting equation (Equation 1) is as follows:

$$FS_1 = Age + SD \cdot 0.013 \cdot BS - 0.044 \cdot VJ - 0.421 \cdot PWC - 0.0315 \cdot TF - 0.0525 \cdot SS + CF) \quad (1)$$

where,

- FS_1 is the calculated Fitness Score (the precursor to Fitness Age_1).
- Age is the average age for the population (in years).
- SD is the standard deviation for the population (in years).
- BS is the result of the isometric deadlift test (in kilograms).
- VJ is the result of the vertical jump test (in centimeters).
- PWC is the result of the PWC 170 test (in W/kg).
- TF is the result of the trunk flexion test (in centimeters).
- SS is the result of the side-step (agility) test (in the number of lines crossed in 20 seconds).
- CF is the correction factor (a constant) presented in the paper. In this case, the average between the two papers (5.45) was used.

The second equation used was developed by Lee et al. (1996). The authors presented one single equation to use for males and females Invalid source specified. and is presented below (equation (2)):

$$FS_2 = Age + z\,score + SD \cdot \begin{pmatrix} 0.069 \cdot BF - 0.047 \cdot VO_2max \\ -0.047 \cdot GS - 0.049 \cdot TF + CF \end{pmatrix} \quad (2)$$

where,

- FS_2 is the calculated Fitness Score (the precursor to Fitness Age_2).
- Age is the average age for the population (in years).
- z score is a correction factor to adjust the Fitness Age for older individuals upward, and the Fitness Age for younger individuals downward where

$$z\,score = \left(0.18 \cdot age_{ind}\right) - 8.76$$

- SD is the standard deviation for the population (in years).
- BF is the percent body fat (in %).
- VO_2max is the cardiorespiratory fitness estimate, normalized to body weight (in ml/minute/kg), estimated from the PWC test
- GS is the grip strength (in kg).
- TF is the result of the trunk flexion test (in centimeters).
- CF is the correction factor (2.81) presented in the paper.

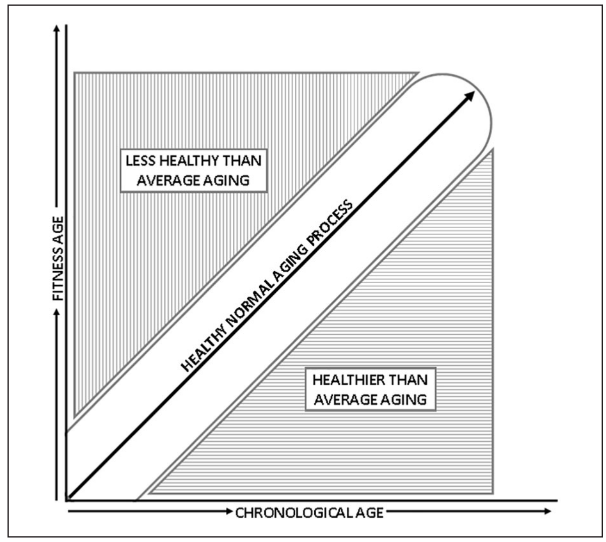

Figure 1. Theoretical representation of the normal relationship between Fitness Age and Chronological Age.

Methodology

The Fitness Age estimates obtained for this analysis provided an overestimation of up to 20 years for younger individuals and an underestimation of up to 10 years for older individuals. Nakamura et al. (1990, 1998) and Lee et al. (1996) described observing a bias in their estimates as well and proposed the implementation of a correction presented by Dubina et al. (1984). This correction assumes that on average, Fitness Age should correspond to Chronological Age on a one-to-one ratio, where for every year of chronological age, Fitness Age also increases by 1 year (Dubina et al., 1984). Any deviation from this ideal line would represent aberrations in the ideal aging process, in either the healthier or less healthy direction (Figure 1).

In the original paper by Dubina et al. (1984), the correction was in the form of a calculation, whereby the age estimate was shifted upward or downward using the standard deviation for the age group (equation (3)).

$$z = \left(y_i - \bar{y}\right) \cdot \left(1 - b\right)$$
$$Y_i = BA_i + z \quad (3)$$

where z is the calculated correction factor used to adjust the Fitness Age estimate, y_i is the Chronological Age of the individual, $\bar{y}$ is the group mean for the Chronological Age, and b is the slope of the regression equation between the biological and chronological ages. Y_i is the adjusted Fitness Age and is calculated by adding the correction factor (z) to the individual's Fitness Age estimate (BA_i).

While this correction may have been appropriate for the population used in the published Fitness Age studies, it was not sufficient to adjust the current dataset to achieve the desired relationship and therefore may not apply to all populations. This is thought to have been a result of the larger variability in the age estimates for the

Table 2. Demographic Information Including Average Chronological Age, Body Weight, and Height. Standard Deviations are Provided in Brackets Beside Each Average Value.

	n	Age (years)	Body mass (kg)	Height (cm)
Younger (18–27 years old)	13	23.5 (1.6)	51.5 (9.5)	166.5 (9.7)
Middle age (38–47 years old)	11	41.8 (1.4)	73.8 (13.5)	171.1 (10.9)
Older (58–67 years old)	13	61.6 (2.4)	68.2 (9.8)	163.3 (6.5)

Table 3. Average (SD) for Each of the Fitness Tests Used in the Calculation of Fitness Age by Either Equation.

Study	Back strength (kg)	Vertical jump (cm)	PWC170 (W/kg)	Trunk flexion (cm)	Side step (# of lines)	Grip strength (kg)	VO_2max (ml/min/kg)	Percent body fat (%)
Nakamura et al. (1990)	82.6 (23.2)	33.7 (7.1)	2.4 (0.5)	13.7 (6.6)	34.6 (6.4)			
Nakamura et al. (1998)	79.8 (20.1)	32.2 (8.1)	2.2 (0.5)	12.6 (6.7)	34.6 (7.2)			
Lee et al. (1996)*				5.6 (7.6)		43.9 (7.4)	40.8 (12.0)	16.0 (4.9)
Current Study	77.7 (28.2)	31.9 (8.0)	2.1 (0.5)	8.3 (7.9)	36.3 (5.6)	33.5 (7.8)	43.9 (8.9)	32.2 (7.0)

*Average values for males only.

present population as compared to the cited works of Nakamura et al. (1990, 1998) and Lee et al. (1996), which relied on a more homogenous population than that described here. In the current study, rather than applying the correction factor from Equation 3, a two-dimensional rotation matrix was applied to the data using a custom MATLAB script (R2018a: Mathworks, Natick, MA). This script essentially rotated the average Fitness Age for each age group such that the angle of the regression line between Fitness Age and Chronological Age matched the line that represents this one-to-one relationship between the two age variables and shifted the y-intercept such that it passed through the zero mark. This calculation was repeated for each age group.

Results

In total, 37 women volunteered and satisfied the inclusion criteria. Their demographic information is presented in Table 2.

On average, the results from the fitness tests in the current study aligned well with the average values presented in the original studies (Table 3). All of the test scores were within the same average and standard deviation ranges, with the largest discrepancies seen in the Trunk Flexion, Grip Strength, and Body Composition results. On average, the participants in the present study presented with twice as much body fat as those described in the Lee et al. (1996) paper. This discrepancy could have been due in part to the Lee et al study focusing on males, who are known to have a lower body fat percentage than females (Mott et al., 1999), on average. An increase in body fat percentage, whether due to sex or to ethnicity, could have been responsible for the reductions seen in Trunk Flexibility (Minck et al., 2000) compared to the Nakamura et al studies, and Grip Strength (Nevill & Holder, 2000; Sayer et al., 2007) when compared to the Lee et al study. Similarly, males are known to have 60% to 70% stronger grip strength than females (Härkönen et al., 1993), and the decrease in grip strength seen in the current analysis could have been due to the difference in the sexes of the sample populations.

Of the eight fitness tests used, five of them were significantly correlated with increasing age, with a strength of the correlation from moderate to strong (Table 4, Figure 2). The three variables not correlated with Chronological Age included the PWC, estimated VO_2max, and Trunk Flexion tests. On average, all tests trended in the direction that was expected based on published data, except for the PWC and VO_2max test results, which showed a slight but non-significant increase with age, although a decrease in cardiorespiratory fitness with increasing age was expected Invalid source specified.

The Fitness Age estimates obtained using the published equations were skewed where younger participants were generally estimated to be older than their Chronological Age and older participants were estimated to be younger than their Chronological Age (Figure 2). While the data showed a reasonable fit ($R^2 = 52.6\%, p < .001$), the overestimation in the younger group could be as high as 33.5 years older, and the underestimation in the older group could be as low as 17.3 years younger. The resulting distribution was left with a bias at the y-intercept whereby on average, someone with a Chronological Age of 0 years would be estimated to have a Fitness Age of approximately 18 years.

After applying the correction matrix and rotating the trendline to match the one-to-one ideal relationship between Chronological Age and Fitness Age, the data showed a strong fit ($R^2 = 80.5\%, p < .001$). The adjusted (rotated) Fitness Age values are displayed in Figure 3.

Table 4. Correlation Values and Corresponding Significance Levels for all Fitness Test Score with Chronological and Fitness Age.

	Chronological age		Fitness age	
	Pearson *r*	Sig	Pearson *r*	Sig
Chronological age	—	—	0.897*	0.000
Fitness age	0.897*	0.000	—	—
Back strength	−0.437*	0.008	−0.443*	0.007
Vertical jump	−0.711*	0.000	−0.790*	0.000
PWC	0.063	0.715	−0.175	0.309
Side step	−0.750*	0.000	−0.852*	0.000
Trunk flexion	−0.121	0.482	−0.303	0.72
Grip strength	−0.465*	0.004	−0.451*	0.006
VO2max	0.067	0.698	−0.197	0.250
Body fat percentage	0.515*	0.001	0.695*	0.000

*Significant at the 0.01 level (two-tailed).

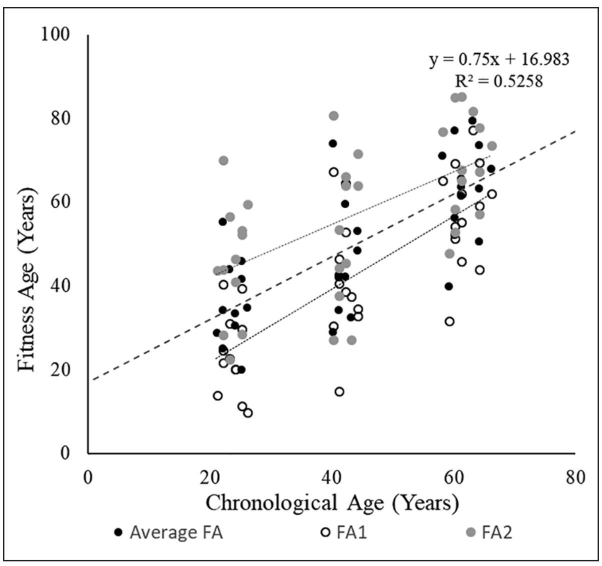

Figure 2. Graphical representation of the relationship between Chronological Age and Fitness Age (FA). The raw/unadjusted Fitness Age estimated by each of the two equations (FA1 and FA2, respectively) as well as the average are presented. The equation of the linear trendline and the R^2 for the fit of this line is also shown.

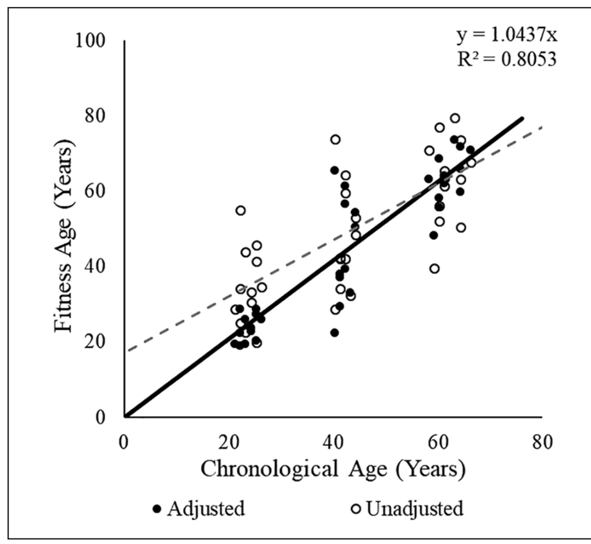

Figure 3. The relationship between Chronological Age and the new Adjusted Fitness Age (Black circles). The equation of the linear trendline as well as the R^2 for the fit of the adjusted age line are shown. The original data (open circles) is also provided for reference.

This new, adjusted Fitness Age estimate showed an almost perfect correlation with Chronological Age ($r = 0.897$, $p < .001$).

Discussion

While originally, it was unclear whether the equations presented would be appropriate for the current population, it seems as though these methods were successful at estimating what would be a realistic semblance of Fitness Age. Anecdotally, those individuals that seemed more unfit while completing the tests were estimated to be older than individuals who were able to excel in the tests. However, the correction originally presented by Dubina et al. (1984) was not appropriate for addressing the calculation bias in the given population.

By combining two different equations to estimate Fitness Age, the current study provided a well-rounded estimate of overall health. Compared to the originally published datasets for these equations, on average the values obtained through the present analysis were quite similar (Table 3). Of particular interest, however, is the difference in body fat percentage between the current population and that reported in the Lee et al. (1996) paper. It is important to note that this original paper was based on men and as women are known to have higher proportions of body fat than men, weighting this factor into the Fitness Age estimate would skew the age estimate upward in the current study compared to that presented by Lee et al. (1996). The effects caused by differences between males and females were noted as well in the grip strength values measured in the current study compared to those presented by Lee et al. Men are known to have stronger grip strengths than women (Härkönen et al., 1993), and therefore the observed differences were to be expected in the present study. Nonetheless, the subsequent correction of the Fitness Age estimate to match the theoretical ideal would have addressed some of these population differences.

Therefore, it seems reasonable that these equations can be used to assess Fitness Age in the current population because the effect of age on the variables in question has been well-researched and the published trends with age seem to be present in the current dataset. In general, the fitness data collected coincided with what would have been expected, with some exceptions. Back strength and grip strength, the two tests used to assess muscle strength, were found to decrease significantly with age, which agrees with previous studies looking at the effect of age on muscle strength in these areas (Frederiksen et al., 2006; Kallman et al., 1990; Lawman et al., 2016; Sinaki et al., 2001; Syddall et al., 2003). Vertical jump height also decreased significantly with age. This trend agrees with previous research that noted similar relationships between age and vertical jump height (Izquierdo et al., 1999; Wang, 2008). It is thought that the decreased vertical jump height is an effect of a reduced ability to generate power with legs.

The results from the trunk flexion test for the current population were not significantly correlated with age, although previous research has noted that, to some degree flexibility and age exhibit a negative relationship (Chodzko-Zajko et al., 2009; Rikli & Jones, 1999; Shephard et al., 1990). Significant decreases in trunk flexibility with age have been noted primarily in populations older than 70 years, and, likely, the populations used in the current analysis were not old enough to display this age-related trend in trunk flexibility (Chodzko-Zajko et al., 2009; Rikli & Jones, 1999).

Percent body fat displayed the expected increase in magnitude with age (Chodzko-Zajko et al., 2009; Meeuwsen et al., 2010). Previous research has shown that percent body fat increases within the third, fourth, and fifth decades, with eventual declines in body fat percentage after approximately age 70 (Chodzko-Zajko et al., 2009).

Possibly the most confounding of these test results is that of the PWC 170 test, which was further used to estimate VO_2max. VO_2max has been shown to decrease with age (Chodzko-Zajko et al., 2009), while the results from the current analysis show a slight, non-significant increase in oxygen consumption with age. Because the PWC test result was extrapolated from a submaximal test, and this value was used to estimate VO_2max, there may have been some inherent error in the estimation methods that could have affected their relationship with age. Anecdotally however, these results may also be somewhat skewed by the lifestyles of the participants. In talking with them during the data collections, it seemed as though the middle-aged and older participants reported riding bikes and walking more frequently than the younger groups, who seemed to focus their attention more on strength and flexibility training.

Given that the corrections applied in the present analysis were aimed at adjusting the sample average in such a way that it matches the theoretical "ideal" of a one-to-one increase in age between Chronological Age and Fitness Age, it stands to reason that the interesting data lies in the areas above and below this ideal line (Figure 1). These are the areas that represent healthy aging (below the line) and unhealthy aging (above the line), and the factors that differentiate healthy aging from unhealthy aging within a subject would likely be the same factors that affect the dependent variable in any given study. Therefore, it stands to reason that perhaps a more functional use of this approach would be to use the difference between Fitness Age and Chronological Age for future aging research, where someone with an effective age that is higher than zero would be "aging" faster than is ideal, and someone with and effective age that is lower than zero would be "aging" slower than is the ideal. By using Fitness Age in this way, it might better represent the participant's health status regardless of their Chronological Age, and effectively normalizes this measure. As these assumptions have not been tested in the present study, the authors can only speculate at this time, however future research should seek to examine the applicability of such an approach.

The authors are confident that the findings presented here provide a useful approach to assessing changes associated with age in a diverse population, however given that this analysis was only completed with a small, stratified sample of women, these findings cannot yet be generalized to the North American population as a whole. The selection of age groups in this analysis was made to satisfy the requirements for a secondary collection using the same sample, and therefore represented a convenience sample in this analysis. Future research should aim to fill in the gaps between the recruited age groups in the present analysis and supplement these findings with a male sample. It is important to note, however, that if a male population is included in future analyses, body composition and grip strength must be controlled for before these values can be compared to the female data presented here.

Conclusion

In summary, it seems as though the equations for estimating Fitness Age are appropriate for the current North American female population despite their having been developed for a Japanese population upwards of 20 years ago. However, the correction applied previously did not have the same effect on the current data as it did in the cited research. The correction developed for the current analysis appears robust enough to overcome large variabilities in the population demographics such as that seen in a modern, North American, female working population and the heterogeneity therein. Future research using a similar methodology should consider that, given the corrections and assumptions that must be made in order to use such an approach, the Fitness Age may be most useful when presented as the difference between Chronological Age and the estimated age, rather than as a direct measure of age. This could help mitigate some of the variability inherent to the fitness testing methods and control for differences between populations.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the National Science and Engineering Research Council (NSERC) Discovery Grant [grant number #6858].

Ethical Approval

This study, including it recruitment practices and data collection protocols, was approved by the Health Sciences and Affiliated Teaching Hospitals Research Ethics Board (ID: PHE-150-14, #: 6013828) prior to beginning recruitment and collection.

ORCID iD

Tara L. Diesbourg https://orcid.org/0000-0003-2671-459X

Supplemental Material

Supplemental material for this article is available online.

References

Chappell, N. L. (2003). Correcting cross-cultural stereotypes: Aging in Shanghai and Canada. *Journal of Cross-Cultural Gerontology*, *18*, 127–147.

Chodzko-Zajko, W., Proctor, D., Fiatarone Singh, M., Minson, C., Nigg, C., Salem, G., & Skinner, J.; American College of Sports Medicine. (2009). American College of Sports Medicine position stand: Exercise and physical activity for older adults. *Medicine and Science in Sport and Exercise*, *41*, 1510–1530.

Dubina, T., Mints, A., & Zhuk, E. (1984). Biological age and its estimation. III. Introduction of a correction to the multiple regression model of biological age and assessment of biological age in cross-sectional and longitudinal studies. *Experimental Gerontology*, *19*, 133–143.

Frederiksen, H., Hjelmborg, J., Mortensen, J., McGue, M., Vaupel, J., & Christensen, K. (2006). Age trajectories of grip strength: Cross-sectional and longitudinal data among 8,342 Danes aged 46 to 102. *Annals of Epidemiology*, *16*, 554–562.

Härkönen, R., Piirtomaa, M., & Alaranta, H. (1993). Grip strength and hand position of the dynamometer in 204 Finnish adults. *Journal of Hand Surgery (British and European Volume). 18B*, 129–132.

Izquierdo, M., Ibañez, J., Gorostiaga, E., Garrues, M., Zúñiga, A., Antón, A., Larrión, J. L., & Häkkinen, K. (1999). Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men. *Acta Physiologica Scandinavica*, *167*(1), 57–68.

Jylhava, J., Pedersen, N., & Hagg, S. (2017). Biological age predictors. *EBioMedicine*, *21*, 29–36.

Kallman, D., Plato, C., & Tobin, J. (1990). The role of muscle loss in the age-related decline of grip strength: Cross-sectional and longitudinal perspectives. *Journal of Gerontology: Medical Sciences*, *45*(3), M82–M88.

Lawman, H., Troiano, R., Perna, F., Wang, C.-Y., Fryar, C., & Ogden, C. (2016). Associations of relative handgrip strength and cardiovascular disease biomarkers in U.S. adults, 2011–2012. *American Journal of Preventive Medicine*, *50*(6), 677–683.

Lee, M., Tanaka, K., Nakagaichi, M., Nakadomo, F., Watanabe, K., Takeshima, N., Hiyama, T., & Chodzko-Zaiko, W. (1996). The relative utility of health-related fitness tests and skilled motor performance tests as measures of biological age in Japanese men. *Journal of Physiological Anthropology and Applied Human Science*, *15*(3), 97–104.

Levine, M. (2012). Modeling the rate of senescence: Can estimated biological age predict mortality more accurately than chronological age? *Journal of Gerontology Series A: Biological Sciences*, *68*(6), 667–674.

Meeuwsen, S., Horgan, G., & Elia, M. (2010). The relationship between BMI and percent body fat, measured by bioelectrical impedance, in a large adult sample is curvilinear and influenced by age and sex. *Clinical Nutrition*, *29*(5), 560–566.

Meshizuka, T. (1967). Adult physical fitness test and its application upon Japanese adults. *Japanese Society of Physical Education – Research Journal of Physical Education*, *11*(3), 177–182.

Minck, M., Ruiter, L., Van Mechelen, W., Kemper, H., & Twisk, J. (2000). Physical fitness, body fatness, and physical activity: The Amsterdam Growth and Health Study. *American Journal of Human Biology*, *12*, 593–599.

Mott, J. W., Wang, J., Thornton, J. C., Allison, D. B., Heymsfield, S. B., & Pierson, R. N. (1999). Relation between body fat and age in 4 ethnic groups. *The American Journal of Clinical Nutrition*, *69*(5), 1007–1013.

Murray, C. J. L., & Lopez, A. D. (1997). Regional patterns of disability-free life expectancy and disability-adjusted life expectancy: Global Burden of Disease Study. *The Lancet*, *349*(9062), 1347–1352.

Nakamura, E., & Miyao, K. (2007). A method for identifying biomarkers of aging and constructing an index of biological age in humans. *Journal of Gerontology Series A: Biological Sciences*, *62A*(10), 1096–1105.

Nakamura, E., Moritani, T., & Kanetaka, A. (1990). Biological age versus physical Fitness Age in women. *European Journal of Applied Physiology and Occupational Physiology*, *61*, 202–208.

Nakamura, E., Moritani, T., & Kanetaka, A. (1998). Further evaluation of physical Fitness Age versus physiological age in women. *European Journal of Applied Physiology*, *78*, 195–200.

Nevill, A. M., & Holder, R. L. (2000) Modelling handgrip strength in the presence of confounding variables: Results from the Allied Dunbar National Fitness Survey. *Ergonomics*, *43*(10), 1547–1558.

Rikli, R., & Jones, C. (1999). Development and validation of a functional fitness test for community-residing older adults. *Journal of Aging and Physical Activity*, *7*, 129–161.

Rose, M. (1991). *Evolutionary biology of aging*. Oxford University Press.

Salomon, J. A., Wang, H., Freeman, M. K., Vos, T., Flaxman, A. D., Lopez, A. D., & Murray, C. J. L. (2012). Healthy life expectancy for 187 countries, 1990–2010: A systematic analysis for the Global Burden Disease Study. *The Lancet*, *380*(9859), 2144–2162.

Sayer, A. A., Syddall, H. E., Dennison, E. M., Martin, H. J., Phillips, D. I. W., Cooper, C., & Byrne, C. D. (2007) Grip strength and the metabolic syndrome: Findings from the Hertfordshire Cohort Study. *QJM: An International Journal of Medicine*, *100*(11), 707–713.

Shephard, R., Berridge, M., & Montelpare, W. (1990). On the generality of the "Sit and Reach" test: An analysis of flexibility data for an aging population. *Research Quarterly*, *61*(4), 326–330.

Sinaki, M., Nwaogwugwu, N., Phillips, B., & Mokri, M. (2001). Effect of gender, age, and anthropometry on axial and appendicular muscle strength. *American Journal of Physical Medicine and Rehabilitation*, *80*, 330–338.

Syddall, H., Cooper, C., Martin, F., Briggs, R., & Sayer, A. (2003). Is grip strength a useful single marker of frailty? *Age and Ageing*, *32*, 650–656.

Wang, L.-I. (2008). The kinetics and stiffness characteristics of the lower extremity in older adults. *Journal of Sports Science and Medicine*, *7*, 379–386.

Warburton, D. E. R., Jamnik, V., Bredin, S. S. D., Shephard, R. J., & Gledhill, N. (2015). The 2015 Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and electronic Physical Activity Readiness Medical Examination (ePARmed-X+). *The Health & Fitness Journal of Canada*, *8*(1), 53–56.