A Brief Report

A Twin Study on the Heritability of Walking Ability Among Older Women

Alfredo Ortega-Alonso,1 Nancy L. Pedersen,2 Urho M. Kujala,1 Sarianna Sipilä,1 Timo Törmäkangas,1 Jaakko Kaprio,3,4 Markku Koskenvuo,3 and Taina Rantanen1

1Department of Health Sciences, University of Jyväskylä, Finland. 2Department of Medical Epidemiology and Biostatistics, Karolinska Institutet, Stockholm, Sweden. 3Department of Public Health, University of Helsinki, Finland. 4Department of Mental Health and Alcohol Research, National Public Health Institute, Helsinki, Finland.

Background. This study examined the role of genetic and environmental factors explaining individual differences in women’s walking ability in old age.

Methods. A maximal walking speed test over 10 meters and a 6-minute walking endurance test were done under standard conditions among 92 monozygotic and 105 dizygotic pairs of twin sisters reared together, aged 63–75 years.

Results. The mean maximum walking speed was 1.73 ± 0.32 m/s and the mean distance covered in the 6-minute walking test was 525.6 ± 77.3 m. Multivariate genetic modeling showed that a minor part of the variances in walking speed (16%, 95% confidence interval [CI]: 0%–54%) and endurance (20%, 95% CI: 0%–56%) were accounted for by genetic influences, and that the genetic influences were common to both traits. The corresponding proportions for common environmental factors were 37% (95% CI: 4%–58%) and 26% (95% CI: 0%–52%), and for individual environmental factors 46% (95% CI: 35%–59%) and 54% (95% CI 42%–68%), respectively. The environmental effects were partially common to both traits.

Conclusions. Among relatively healthy older women, a modest portion of the variances of walking speed and endurance were accounted for by genetic factors, whereas shared and individual environmental factors explained most of the variance in both traits.

Walking limitations become more common with increasing age. Tests of walking ability may be used to identify persons at risk for poor quality of life, institutionalization, and mortality (1–4). The most common tests measure maximal or customary walking speed over a short distance. However, as it has been suggested that an older person needs to walk at least 400 meters to be able to live in the community (5), tests of walking endurance are also relevant.

The immediate prerequisites for walking any distance are adequate strength and balance and, with increasing distance and pace, maximal oxygen uptake (VO2max) (6,7). Impairments in any of the requirements may limit walking. Strength, balance, and VO2max by themselves are moderately to highly heritable (8–10), indicating that genetic variation may also contribute to variability in walking speed and endurance. However, to the best of our knowledge, no previous studies have addressed the heritability of walking endurance in older persons, although the heritability of customary walking speed has been reported to be 42% among a group of older men (11). Previous reports from our study using somewhat different approaches have estimated the heritability of maximal walking speed to be moderate among older women (12,13).

The aim of this study was to estimate the extent to which genes and environmental factors may explain individual differences in maximal walking speed and endurance among community-living older women in relatively good health, and also to estimate the extent to which those factors influencing a short and fast walk also influence a longer, sustained performance.

METHODS

Participants

The present study is part of the Finnish Twin Study on Aging (FITSA) (10). The study sample was recruited from among the participants in The Finnish Twin Cohort Study (14). The zygosity of the participating pairs was initially determined by using a validated questionnaire.

An invitation to participate in FITSA was sent to 414 female pairs aged 63 to 76 years surviving in 2000. To be included, both twin pair members had to agree to take part. The reasons for nonparticipation were that one or both sisters were unwilling to take part (106 pairs), had poor health status (85 pairs), or had died after vital status was last updated for all cohort members (6 pairs). As a result of the procedures, the study group consisted of 217 twin-sister pairs, including 102 monozygotic (MZ) and 115 dizygotic (DZ) pairs.

The walking speed test was performed by 199 MZ and 219 DZ individuals and the walking endurance test by 170
MZ and 189 DZ individuals. Altogether, 20 pairs of the initial study group were excluded from the analyses because data were missing for one of the sisters in both the walking speed and the endurance test, or because data were missing for both sisters in the walking endurance test. Values were imputed for the walking endurance test for those cases where data existed for both sisters on walking speed and were missing for one sister on walking endurance (n = 37 individuals: 15 MZ and 22 DZ). For these cases, data were imputed using the Markov Chain Monte Carlo (MCMC) simulation technique using SAS 8.2, which uses information on the individuals walking speed result, her sister’s speed and endurance test results, and the age of the twin pair (15,16). After these procedures, the numbers of pairs in the analyses were 92 MZ and 105 DZ.

**Measurements**

After a clinical examination, walking speed and endurance were tested. Maximal walking speed over 10 meters (17) was measured using a validated method (18) in the laboratory corridor. Every person was asked “to walk as fast as possible, without compromising safety.” For security reasons, two persons used a cane. To minimize the effects of acceleration and deceleration, measurements were taken over the middle 10 meters of a longer walkway where 3 meters before the start were allowed for acceleration. Time was recorded by photocell devices. The best performance of two trials was taken as the final outcome.

Walking endurance was assessed using a validated 6-minute walking test (19). The participants were requested to walk up and down a 50-meter indoor straight track for 6 minutes and to complete as many laps as possible. The standardized protocol and security conditions followed the American Thoracic Society Statement (19). The distance covered by the end of the 6 minutes was recorded as the outcome.

**Statistical Analyses**

The sample description and tests on data normality (Kolgomorov–Smirnoff) and equality of means and variances (analysis of variance; ANOVA) by zygosity were computed using SPSS 12.0 (20). The twin-based genetic analyses focus on the comparison of trait resemblances between MZ and DZ pairs. MZ twins share 100% of their genes, and DZ twins share, on average, 50% of their segregating genes. Thus, the extent to which MZ twins are more similar than DZ twins suggests the importance of genetic influences. Environmental influences shared by siblings in a family are common to both types of twins and are expected to contribute equally to the similarity of the MZ and DZ pairs. Individual-specific (nonshared) environmental factors contribute to differences within pairs. As a consequence, the variance in the trait is divided into three components: additive genetic (labeled as A), common environmental (C), and individual-specific environmental (E) factors.

The within-pair resemblances were initially examined by computing the intra-class correlation coefficients. To estimate the proportion of the total variance in the trait due to A, C, and E, different explanatory models were computed.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>MZ (N = 184)</th>
<th>DZ (N = 204)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>67.90 ± 3.55</td>
<td>68.78 ± 3.08</td>
<td>68.37 ± 3.33</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>69.53 ± 12.01</td>
<td>70.40 ± 12.05</td>
<td>69.98 ± 12.02</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.58 ± 0.06</td>
<td>1.59 ± 0.06</td>
<td>1.59 ± 0.06</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>27.92 ± 4.85</td>
<td>27.75 ± 4.70</td>
<td>27.83 ± 4.76</td>
</tr>
<tr>
<td>Walking speed, m/s</td>
<td>1.77 ± 0.34</td>
<td>1.71 ± 0.31</td>
<td>1.74 ± 0.33</td>
</tr>
<tr>
<td>Walking endurance, m</td>
<td>522.25 ± 85.36</td>
<td>526.59 ± 69.65</td>
<td>525.63 ± 77.35</td>
</tr>
</tbody>
</table>

Notes: *p for statistical difference between MZ and DZ twins. MZ = monozygotic; DZ = dizygotic; SD = standard deviation.

Genetic model fitting was based on structural equation models using MX software (21). A full information maximum likelihood method was applied using individual-based observations and imputed values. First, univariate models for each walking trait were tested. Then, a bivariate correlated factors model was used to evaluate whether the genetic and environmental factors that affect walking speed were shared by walking endurance. The bivariate model that was theoretically acceptable and fitted the data well was chosen using fit statistics of the full model and hierarchically nested models. Age was included as a covariate in all models.

**RESULTS**

There were no significant differences between MZ and DZ twins in mean values for body height, weight, walking speed over 10 meters, or distance covered in the 6-minute walk (Table 1). The mean age of the MZ pairs was slightly lower than that of the DZ pairs, and age correlated with the measures of walking speed and endurance in the total study sample.

The comparison of the age-adjusted intraclass correlation coefficients for walking speed (rMZ = 0.55; rDZ = 0.45) and endurance (rMZ = 0.51; rDZ = 0.31) suggested the presence of additive genetic effects in both phenotypes. Supported by preceding univariate modeling (results available from authors upon request), a bivariate model with additive genetic, common, and specific environmental effects (ACE) was found to be the most parsimonious and theoretically acceptable (fit statistics in Table 2). That bivariate ACE model showed an overlap of genetic influences on the walking phenotypes that explained 16% (95% CI, 0%–54%) of the variance in maximal walking speed and 20% (95% CI, 0%–56%) in walking endurance. The rest of the influences on each phenotype were explained by common or individual environmental influences (Table 2) that were partially shared by both phenotypes. The correlation between the common and specific environmental factors were rC = 0.74 (95% CI, –1.00 to 1.00) and rE = 0.63 (95% CI, 0.53–0.70), respectively.

**DISCUSSION**

The results of our study showed that, among community-living older women in relatively good health, common additive genetic influences accounted for a modest
The most relevant part of the influences on walking speed are mediated through genetic control of body size and obesity. Obesity increases the risk of walking balance are the immediate prerequisites for walking any distance. Previous twin studies among older people have suggested that the heritability of these traits ranges from 35% to 60% (9,10). Consequently, at least part of the genetic effects on walking any distance could be mediated through the genetic effects on postural control and muscle strength and power. Another genetic mechanism influencing walking may be mediated through genetic control of body size and obesity. Obesity increases the risk of walking limitation and is influenced by genetic factors (22,23). In the current sample, about one fourth of the participants had a body mass index > 30; consequently, it is possible that part of the familial factors on walking speed and endurance were mediated through genetic influences on obesity (13).

The most relevant part of the influences on walking speed and endurance came from common or individual environmental factors. Both common and individual environmental factors were shared between the walking speed and endurance phenotypes ($r_e = 0.74$; $r_c = 0.60$). Regarding the common environmental factors, it is likely that influences coming from common childhood or adulthood environment, including components such as physical activity, may have long-lasting effects on health habits in later life, and thus contribute to the resemblance of twin sisters. In contrast, physical activity habits, in addition to injuries or chronic diseases, may be different in each individual of a pair and thus contribute to individual environmental influences explaining variability in maximal walking speed and endurance.

Maximal walking speed and walking endurance shared 60% of the specific environmental influences, which means that most but not all environmental factors were affecting both walking speed and endurance. The proportion that is different may be explained by the different energetic cost and metabolic use of the short and long walking tests. The 10-meter maximal walking test is a short and intensive performance in which energy is primarily produced through anaerobic mechanisms. The 6-minute walking test is a submaximal performance (24), and energy is primarily recruited through aerobic procedures. The tests differ in their metabolic demands, which may explain why the contributing environmental factors are not totally shared between the two walking phenotypes.

It must be remembered that both genetic and environmental factors may either protect from walking limitation or predispose to it. Thus, some people may be genetically robust and others more vulnerable. However, genes interact with nongenetic factors, and people may respond in different ways to physical activity or inactivity according to their genetic liability. In clinical geriatric practice it would be useful to be able to identify those persons most likely to benefit from intervention programs to allocate resources in a meaningful way. However, it is not yet possible in terms of scanning the genetic constitution of an individual. Consequently, screening and modification on nongenetic factors is the best approach to enhance mobility and preserve independence within the community.

Most of the previous information about the heritability of functional abilities has been based on self-reports and is potentially influenced by reporting bias (11). The advantage of this study is that it is based on standardized performance measures usable in clinical practice. Our study was limited to women without severe disability; therefore, the results

**Table 2. Estimated Factors and Correlations (and 95% Confidence Intervals [CI]) for the Walking Speed and Endurance Phenotypes (92 Monozygotic and 105 Dizygotic Pairs)**

<table>
<thead>
<tr>
<th>Model</th>
<th>$a_x^2$</th>
<th>$a_y^2$</th>
<th>$r_{xy}$</th>
<th>$c_x^2$</th>
<th>$c_y^2$</th>
<th>$r_{cx}$</th>
<th>$e_x^2$</th>
<th>$e_y^2$</th>
<th>$r_{ex}$</th>
<th>$-2LL$</th>
<th>$df$</th>
<th>$\chi^2$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACE</td>
<td>0.16</td>
<td>0.20</td>
<td>1.00</td>
<td>0.37</td>
<td>0.26</td>
<td>0.74</td>
<td>0.46</td>
<td>0.54</td>
<td>0.60</td>
<td>250.154</td>
<td>775</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>(0.00–0.54)</td>
<td>(0.00–0.56)</td>
<td>(−1.00 to 1.00)</td>
<td>(0.04–0.58)</td>
<td>(0.00–0.52)</td>
<td>(−1.00 to 1.00)</td>
<td>(0.35–0.59)</td>
<td>(0.42–0.68)</td>
<td>(0.48–0.69)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AE</td>
<td>0.56</td>
<td>0.48</td>
<td>0.84</td>
<td>0.44</td>
<td>0.52</td>
<td>0.58</td>
<td>0.44</td>
<td>0.52</td>
<td>0.58</td>
<td>240.775</td>
<td>778</td>
<td>9.379</td>
<td>.024</td>
</tr>
<tr>
<td></td>
<td>(0.44–0.66)</td>
<td>(0.34–0.59)</td>
<td>(0.72–0.93)</td>
<td>(0.34–0.56)</td>
<td>(0.41–0.66)</td>
<td>(0.45–0.68)</td>
<td>(0.39–0.60)</td>
<td>(0.30–0.53)</td>
<td>(0.70–0.91)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CE</td>
<td>0.50</td>
<td>0.42</td>
<td>0.82</td>
<td>0.50</td>
<td>0.58</td>
<td>0.63</td>
<td>0.50</td>
<td>0.58</td>
<td>0.63</td>
<td>248.989</td>
<td>778</td>
<td>1.165</td>
<td>.761</td>
</tr>
<tr>
<td></td>
<td>(0.39–0.60)</td>
<td>(0.30–0.53)</td>
<td>(0.70–0.91)</td>
<td>(0.40–0.61)</td>
<td>(0.47–0.70)</td>
<td>(0.53–0.70)</td>
<td>(0.39–0.60)</td>
<td>(0.30–0.53)</td>
<td>(0.70–0.91)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>174.791</td>
<td>781</td>
<td>75.363</td>
<td>.000</td>
</tr>
</tbody>
</table>

Notes: A, C, and E refer to additive genetic, common environmental, and nonshared environmental influences, respectively; $a_x^2$, $c_x^2$, and $e_x^2$ are standardized estimates (and 95% CI [confidence interval]) of the proportion of additive genetic and nonshared environmental components of variance for the walking speed phenotype, and $a_y^2$, $c_y^2$, and $e_y^2$ are the similar estimates for the walking endurance phenotype; $r_{xy}$, $r_{cx}$, and $r_{ex}$ are the genetic, common environmental, and specific environmental correlations (and 95% CI) between phenotypes.

LL = Log-likelihood; df = degrees of freedom; $\chi^2$ = difference chi-square between the ACE model and the fitted model.
should not be directly generalized to men and to more disabled people. Nevertheless, the results of the current study showed that approximately half of the individual differences in walking speed and endurance were explained by familial factors and about half by individual environmental factors.

Due to limited power in the statistical analyses frequent in moderately sized twin studies, the genetic as well as the common environmental correlation estimates presented in the current study were accompanied by wide confidence intervals; therefore, they should be interpreted with caution. Further studies with larger sample sizes are needed to conclusively answer the extent to which common genetic and environmental factors underlie both walking speed and endurance.

**Conclusion**

This study provides novel evidence that the walking ability of older women is modestly influenced by genetic factors and that the same genetic influences affect walking speed and endurance. The majority of the influences on both walking performances came from environmental factors. The need for discerning between genetic influences and the interaction of genetic and nongenetic factors in the development of walking limitation warrants further study to develop efficacious rehabilitation approaches.

**ACKNOWLEDGMENTS**

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Address correspondence to Alfredo Ortega-Alonso, MSc, University of Jyväskylä, Department of Health Sciences, P.O. Box 35 (Viveca), Jyväskylä, 40014 Finland. E-mail: alfredo.ortega@sport.jyu.fi

**REFERENCES**


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