Journal of Gerontology: MEDICAL SCIENCES
Cite journal as: J Gerontol A Biol Sci Med Sci
2009. Vol. 64A, No. 2, 312–317
doi:10.1093/gerona/gln015

Advance Access publication on January 31, 2009

Hearing as a Predictor of Falls and Postural Balance in Older Female Twins

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Background. The purpose of the present study was to examine, first, whether hearing acuity predicts falls and whether the potential association is explained by postural balance and, second, to examine whether shared genetic or environmental effects underlie these associations.

Methods. Hearing was measured using a clinical audiometer as a part of the Finnish Twin Study on Aging in 103 monozygotic and 114 dizygotic female twin pairs aged 63–76 years. Postural balance was indicated as a center of pressure (COP) movement in semitandem stance, and participants filled in a fall-calendar daily for an average of 345 days after the baseline.

Results. Mean hearing acuity (better ear hearing threshold level at 0.5–4 kHz) was 21 dB (standard deviation [*SD*] 12). Means of the COP velocity moment for the best to the poorest hearing quartiles increased linearly from 40.7 mm^2/s (*SD* 24.4) to 52.8 mm^2/s (*SD* 32.0) (p value for the trend = .003). Altogether 199 participants reported 437 falls. Age-adjusted incidence rate ratios (IRRs) for falls, with the best hearing quartile as a reference, were 1.2 (95% confidence interval [CI] = 0.4–3.8) in the second, 4.1 (95% CI = 1.1–15.6) in the third, and 3.4 (95% CI = 1.0–11.4) in the poorest hearing quartiles. Adjustment for COP velocity moment decreased IRRs markedly. Twin analyses showed that the association between hearing acuity and postural balance was not explained by genetic factors in common for these traits.

Conclusion. People with poor hearing acuity have a higher risk for falls, which is partially explained by their poorer postural control. Auditory information about environment may be important for safe mobility.

Key Words: Hearing—Postural balance—Fall—Twin study—Heritability—Aging.

HEARING and balance impairments as well as falls are common among older people (1,2), and they may correlate, first, because hearing provides acoustic information about the environment, enabling us to notice and avoid environmental hazards that may lead to a fall. Second, the structure and function of the inner ear suggest that they may share etiological factors in common. Hearing and vestibular organs are anatomically closely localized, share fluid-filled bony compartments and blood circulation, are both served by the eighth cranial nerve, and have similar mechanosensory receptor hair cells, which detect sound, head movements, and orientation in space. Loss of these receptor cells can occur in the cochlea (3) and vestibular organ (4) through a degenerative aging process but also through a variety of insults, including exposure to ototoxic drugs and noise (5–7).

Studies on the associations between hearing acuity and postural balance as well as between hearing acuity and falls are scarce and the results have been contradictory. Gerson and colleagues (8) observed that the same people often report both hearing and balance problems, whereas Baloh and colleagues (9) reported that a decrease in hearing paralleled a decrease in balance among older people during a follow-up of 8–10 years. Occupational health studies have shown a correlation between greater noise exposure and impaired postural balance (10,11). Some evidence exists that home accidents, most often falls, are more common among people with than without hearing problems (12). However, other studies have found only a minor or no association between hearing acuity and postural balance or falls (13–15).

In previous twin studies, approximately two thirds of the individual differences in hearing acuity (16–18) and more than a third of the individual differences in postural balance were accounted for by genetic factors (19,20). Familial factors, consisting of genetic and shared environmental influences, explained about 30% of the variability in the susceptibility to falls (21). No previous twin studies have been carried out to clarify whether hearing acuity, postural balance, and falls share genetic or environmental influences in common for these traits.

According to our experience, many clinicians think that hearing problems, balance impairments, and falls coexist. However, results of the previous studies about the issue have been contradictory and hearing is rarely mentioned as a fall risk factor in the literature. Studies about associations of poor hearing, balance impairments, and falls, all of them common geriatric syndromes, are clearly needed to clarify this issue. Purpose of the present study was to examine whether hearing acuity predicts falls and whether the potential association is explained by postural balance. Second, our aim was to examine whether hearing acuity, postural balance, and falls share genetic or environmental effects in common.

Methods

Participants

The present data are drawn from the Finnish Twin Study on Aging (FITSA), a broader study of genetic and environmental effects on the disablement process in older women. The recruitment process and participation have been described in more detail elsewhere (19,22). Briefly, the participants were recruited from the nationwide Finnish Twin Cohort, which comprises all same-sex twins born in Finland before 1958 with both co-twins alive in 1975. Invitation to the present study was sent to 414 female twin pairs aged 63–76 years drawn on the basis of age and zygosity. The final FITSA sample consisted of 103 monozygotic (MZ) and 114 dizygotic (DZ) twin pairs. Zygosity was confirmed using highly polymorphic genetic markers genotyped from DNA. The main reasons for nonparticipation in the FITSA study were refusal, poor health status, or death of one or both twin sisters after vital status had been updated for all cohort members. We excluded five persons with otosclerosis from the current analysis as they could have confounded the results. In addition, postural sway results were lacking for nine participants, in seven cases due to health problems and in two cases due to a technical problem. Six persons did not participate in the fall follow-up (three refused and three had health issues). The number of participants with data available at least for one trait was 429 and for all traits 417.

Procedures

As a part of a broader study, including a physician's examination and multiple clinical tests on functional capacity, audiometric measurements were performed by an audiology assistant in a sound-isolated booth using a clinical audiometer Madsen OB 822 equipped with TDH 39 headphones (Madsen Electronics, Taastrup, Denmark). Air conduction pure-tone hearing thresholds were measured at the frequencies of 0.125, 0.25, 0.5, 1, 2, 4, and 8 kHz for each ear separately according to ISO 8253-1 (23). In the analysis, the better ear hearing threshold level (BEHL), defined as a mean of the pure-tone air conduction thresholds at 0.5, 1, 2 and 4 kHz, was used. A person was defined as having at least a mild hearing impairment if the $BEHL_{0.5–4\ kHz}$ was ≥21 dB (24).

Postural sway was measured with the subject standing in stocking feet in a semitandem position on a force platform (Good Balance System; Metitur Ltd, Jyväskylä, Finland). One foot was placed one-half of a foot length ahead of the other, with feet touching. Participants were advised to stand as still as possible, keep their arms down by their sides, and gaze fixed at a marked point at eye level at the distance of 2 m. Postural stability was recorded for 20 seconds. From the movement of the center of pressure (COP), three outcome variables were calculated: mean mediolateral and anteroposterior sway velocity (mm/s) and the velocity moment (mm^2/s). The measurement was conducted by two physiotherapists working on alternate days. The measurement and parameters are described in more detail by Pajala and associates (19). Semitandem stance was measured as part of the larger postural balance battery including also measurements in side-by-side stance with eyes open and closed and tandem stance with eyes open. Postural balance in semitandem stance was selected for this study because most of the participants were able to do the test, and it discriminated the balance performance better than the side-by-side stance.

After the completion of the hearing and balance assessments, information on falls was gathered for 12 months of follow-up. Participants marked daily on a calendar whether they fell or not. A fall was defined as unintentionally coming to rest on the ground, floor, or other lower level for reasons other than sudden onset of acute illness or overwhelming external force (25). At the end of each month, participants mailed their calendar page to the research center. If the participant forgot to mail the calendar page, she was reminded by telephone. If a fall was reported, the participant was interviewed over the phone about the occurrence, circumstances, causes, and consequences of the fall. We categorized participants according to whether they had at least one fall or at least two falls or at least one injurious fall. Injuries included fractures, bruises, lacerations, and pain. During the fall follow-up, three persons died and 12 persons did not return all of their calendar pages. Their data were included in the analysis up to the month their participation ceased.

The presence of self-reported chronic diseases, medications, and smoking habits were confirmed by a physician during the clinical examination. The Mini-Mental State Examination (MMSE) for cognitive function was administered (26). Body mass index (BMI) was calculated by dividing measured body weight by height squared (kg/m^2). Information about occurrence of falls within the previous 12 months, difficulties in walking 2 km, physical activity level, noise exposure, frequent middle ear infections (more than three episodes), hearing disorders other than those caused by otosclerosis or middle ear infections, and accidents, for example, explosions, tympanic membrane perforations, or severe head injuries, was gathered using a structured questionnaire.

The study was approved by the Ethics Committee of the Central Finland Health Care District and all participants gave an informed consent.

Statistical Analysis

We transformed the $BEHL_{0.5–4\ kHz}$ by the square root of the inverse, $f(x) = (1/\sqrt{BEHL}) \times 10$. For the sway variables, we used natural logarithmical transformation. After the transformations, the absolute values of skewness and kurtosis were acceptable. For analytical purposes, we categorized hearing acuity ($BEHL_{0.5–4\ kHz}$) into quartiles. An adjusted Wald test was used to compare whether COP movements and proportion of fallers differed between the hearing acuity quartiles. Incidence rate ratios (IRRs) for falls were computed from a negative binomial regression model. Negative binomial regression modeling takes into account that fall events are nonindependent incidents and that the occurrence of a single fall makes a subsequent fall more likely.

Genetic analyses were started with analyzing the comparability of MZ and DZ twins. The equalities of the means of continuous variables and distributions of the categorical variables between the MZ and DZ twins were calculated and tested using an adjusted Wald test to take into account the within-pair dependence of twin individuals. The equality of the variances was tested using the variance ratio test. We used our earlier findings about heritability of hearing (16,17), postural balance (19), and falls (21) as a starting point when we examined whether shared genetic or environmental effects underlie the association between these traits. First, a bivariate age-adjusted Cholesky decomposition model was constructed to determine whether the genetic and environmental influences were specific to hearing acuity and postural balance or whether there were genetic or environmental influences shared by both phenotypes. Phenotypic variation can be decomposed into additive genetic effects (A); nonadditive, dominant, genetic effects (D); shared environmental effects (C); and nonshared environmental effects (E). The aim is to find a model that provides a theoretically meaningful interpretation, fits the data well, and has as few explanatory parameters as possible (27). To condense information, we used the $BEHL_{0.5–4\ kHz}$ and COP velocity moment in the modeling.

Finally, we identified MZ twin pairs discordant for hearing acuity to compare the fall risk of the better hearing sister to her co-twin with poorer hearing acuity. This genetically controlled case-control analysis provides information about whether the studied traits correlate with each other regardless of genetic factors.

Data were analyzed with SPSS version 14.0 (28) and Stata version 9.0 (29). Genetic modeling was done with Mx, using full-information maximum likelihood with raw data input (27).

Results

The mean age of the participants was 68.6 years (standard deviation [*SD*] 3.4), number of chronic diseases 2.0 (*SD* 1.5), number of prescription medicines 2.0 (*SD* 2.0), BMI 28.0 (*SD* 4.8), height 158.5 cm (*SD* 6.1), weight 70.1 kg (*SD* 12.0), and MMSE score 26.9 (*SD* 2.3). Exposure to noise was reported by 23% of subjects, hearing aid use by 2%, auditory diseases by 1%, and auditory accidents by 2%. Additionally, the prevalence of current smoking was 5%, cardiovascular diseases 55%, rheumatoid arthritis 4%, and diabetes 6%. A fall within the 12 months prior to the laboratory measurements was reported by 19% of the participants. Major difficulties in walking 2 km was reported by 9%, and 10% of the participants were physically inactive, reporting no physical activity other than what is necessary for activities in daily living. The mean hearing acuity ($BEHL_{0.5–4\ kHz}$) of the participants was 21 dB (*SD* 12) and the mean COP velocity moment in the semitandem stance was 48 mm^2/s (*SD* 29) (Table 1).

Table 1. Means and Standard Deviations (*SD*s) of Auditory and Postural Balance Characteristics, and Numbers and Percentages of Participants Who Had at Least One Fall, at Least Two Falls, or at Least One Injurious Fall

Characteristic	Mean	*SD*
$BEHL_{0.5–4\ kHz}$ (dB) (*n* = 429)	21	12
COP movement in semitandem stance (*n* = 420)		
Mediolateral velocity (mm/s)	15	4
Anteroposterior velocity (mm/s)	12	4
Velocity moment (mm^2/s)	48	29
Fall occurrence (*n* = 423)	*n*	%
At least one fall	199	47
At least two falls	92	22
At least one injurious fall	121	29

Note: COP = center of pressure; $BEHL_{0.5–4\ kHz}$ = better ear hearing threshold level at frequencies of 0.5–4 kHz.

Altogether 423 persons participated in the fall follow-up. The mean follow-up time for falls was 345 days (*SD* 39), comprising 4,868 person-months. A total of 199 participants reported 437 falls, with 44% of them being injurious. Approximately half (47%) of the participants fell at least once and 22% sustained two or more falls (Table 1.) Typically, falls occurred outdoors (79%) and during daytime between 11 AM and 5 PM (55%). During the winter from November to April, the occurrence of falls was 38/mo, and in summer from May to October, it was 35/mo.

Participants were categorized into quartiles according to $BEHL_{0.5–4\ kHz}$. In the first, the best, hearing quartile were people whose $BEHL_{0.5–4\ kHz}$ was better than 11.5 dB. The range for the second quartile was 11.5–17.5 dB, for the third quartile 18–27 dB, and for the fourth, the poorest, quartile greater than 27 dB. The means of the COP velocity moment for the best to the poorest hearing quartiles were 40.7 (*SD* 24.4), 46.3 (*SD* 25.5), 50.6 (*SD* 33.4), and 52.8 mm^2/s (*SD* 32.0) (*p* value for the trend = .003). Fall rates for the best to the poorest hearing quartiles were 7.1, 6.7, 10.4, and 11.3 falls per 100 person-months. The proportion of people who had two or more falls was 30% in the poorest hearing quartile and 17% in the best hearing quartile ($p = .042$) (Table 2).

Table 2. Indices of COP Movement Variables and Occurrence of Falls According to Different Hearing Acuity Quartiles

	Hearing Acuity ($BEHL_{0.5–4\ kHz}$) Quartiles (N = 429)				Between-Groups Wald Test
	First, the Best, Quartile (1), Mean (*SD*)	Second Quartile (2), Mean (*SD*)	Third Quartile (3), Mean (*SD*)	Fourth, the Poorest, Quartile (4), Mean (*SD*)	1–4, *P*
COP movement in semitandem stance (n = 420)					
Mediolateral velocity (mm/s)	14.1 (3.3)[3,4]	15.1 (4.2)	15.7 (4.6)[1]	15.9 (4.3)[1]	.009
Anteroposterior velocity (mm/s)	10.9 (4.2)[3,4]	11.4 (3.7)	12.2 (4.1)[1]	12.3 (3.8)[1]	.018
Velocity moment (mm^2/s)	40.7 (24.4)[3,4]	46.3 (25.5)	50.6 (33.4)[1]	52.8 (32.0)[1]	.003
Fall occurrence (n = 423)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*p*
At least one fall	46 (43)	51 (49)	49 (45)	53 (53)	.583
At least two falls	18 (17)[4]	19 (18)	25 (23)	30 (30)[1]	.176
At least one injurious fall	27 (25)	30 (29)	27 (25)	37 (37)	.270

Note: COP = center of pressure; SD = standard deviation; $BEHL_{0.5–4\ kHz}$, better ear hearing threshold level at frequencies of 0.5–4 kHz. Hearing quartile limits from the best to the poorest were as follows: $BEHL_{0.5–4\ kHz}$ <11.5, 11.5–17.5, 18–27, and >27 dB. Adjusted Wald test's *p* values for COP variables are given for logarithmized values. Superscript [1,3,4] indicate statistically significant differences (*p* value <.05) between hearing acuity quartiles.

Age-adjusted IRRs for falls in model I, with the best hearing quartile as a reference, were 1.2 (95% confidence interval [CI] = 0.4–3.8) in the second, 4.1 (95% CI = 1.1–15.6) in the third, and 3.4 (95% CI = 1.0–11.4) in the poorest hearing quartiles. In model II adjusted for age, each unit increase in COP velocity moment, using logarithmized values, more than doubled the fall risk (IRR 2.2 [95% CI = 1.1–4.5]). When both hearing and COP velocity moment were added into model III simultaneously, the increased risks for falls among those people with the poorest hearing decreased from 3.4 (95% CI = 1.0–11.4) to 2.4 (95% CI = 0.8–7.4) (Table 3). Further adjustments with cognitive impairment (MMSE score ≤24), major difficulties in walking 2 km, or physical inactivity, one at a time, did not materially change the results.

Genetic analyses were started by analyzing the distributions, or means and variances, of the auditory, postural stability, and fall characteristics between MZ and DZ twins. No systematic differences were found between MZ and DZ twin individuals in the means or variances for the hearing acuity ($BEHL_{0.5–4\ kHz}$) and COP movement variables, number of chronic diseases or prescription medicines, BMI, height, weight, or MMSE scores. Occurrence of falls or exposure to noise, auditory diseases or accidents, smoking, cardiovascular diseases, rheumatoid arthritis, and diabetes did not differ according to zygosity.

A bivariate Cholesky decomposition model was constructed to examine whether hearing acuity ($BEHL_{0.5–4\ kHz}$) and COP velocity moment have genetic or environmental effects in common. No statistically significant effects in common were found. (Data are available from author upon request.) An association independent of genetic factors between hearing acuity and falls was suggested. There were 18 MZ twin pairs discordant for hearing acuity, with one sister having $BEHL_{0.5–4\ kHz}$ 21 dB or greater and other sister less than 21 dB. The age-adjusted IRR for falls among the sister with poorer hearing compared with the better hearing sister was 8.8 (95% CI = 1.1–68.5).

Discussion

This study showed that older women with poor hearing acuity had higher risk for falls than those with good hearing acuity and that higher fall risk was partially explained by their poorer postural control. Genetic influences in common did not explain the association between hearing acuity and postural stability. When controlled for shared genetic and environmental effects within twin pair comparisons, the poorer hearing sister had a significantly higher risk for falls than her better hearing twin sister.

There are several explanations for why poor hearing acuity may predict increased fall incidence. First, people with poorer hearing acuity showed greater COP displacement and velocity than people with good hearing acuity. Greater COP movement indicates poorer postural balance and correlates with increased risk for falls (30–32). Second, good hearing acuity

Table 3. Incidence Rate Ratios (IRRs) and Confidence Intervals (95% CIs) for Falls From Negative Binomial Regression Models Adjusted for Age

	Model I, N = 423, IRR (95% CI)[a]	Model II, N = 417, IRR (95% CI)	Model III, N = 417, IRR (95% CI)[a]
Second hearing quartile	1.2 (0.4–3.8)	—	0.7 (0.3–1.7)
Third hearing quartile	4.1 (1.1–15.6)	—	1.8 (0.6–5.8)
Fourth hearing quartile	3.4 (1.0–11.4)	—	2.4 (0.8–7.4)
COP velocity moment (mm^2/s)[b]	—	2.2 (1.1–4.5)	1.8 (0.9–3.4)

Notes: COP = center of pressure.

[a] In model I and model III, the first, the best, hearing quartile is the reference group. Hearing quartile limits from the first, the best, to the fourth, the poorest, were as follows: $BEHL_{0.5–4\ kHz}$ (better ear hearing threshold level at frequencies of 0.5–4 kHz) <11.5, 11.5–17.5, 18–27, and >27 dB.

[b] IRRs are calculated using logarithmized values.

helps in spatial orientation and avoiding environmental hazards that may lead to a fall. Third, compared with younger people, older people have to allocate a greater proportion of their attention to maintaining their balance during common daily activities, such as walking (33). Impaired hearing may place additional demands on attention sharing and thus further increase fall risk. Fourth, it is possible that poor hearing leads to a vicious circle where poor hearing may decrease participation in various activities, and this, in turn, may accelerate the disablement process and increase fall risk.

The present results suggest that hearing is important in maintaining balance. Traditionally, the maintenance of postural balance is described as a process where the correct output of the musculoskeletal system relies on the interaction of the somatosensory, vestibular, and visual systems with probability of balance impairment increasing with increasing number of underlying systems affected (33–35). It is possible that, at least to some extent, deterioration in one sensory subsystem can be compensated for by information through other subsystems, including hearing.

The association between hearing acuity and postural balance was not explained by genetic influences in common to the traits. Although the hearing and vestibular organs are anatomically and physiologically closely connected, they appear to have their own etiology in terms of genetic and environmental factors. However, we cannot completely rule out the possibility of a common genetic background with hearing and vestibular organs. The current method for assessing postural balance while standing on a force platform does not provide data specifically about vestibular functions but rather describes the co-operation of all the subsystems involved in postural control. Further study with more specific quantitative vestibular function tests could deepen understanding of the factors underlying the association between hearing acuity and postural balance.

Our hypothesis was that postural balance acts as a mediator between hearing and falls. According to our results, people with poorer hearing were at three- to fourfold higher risk for falls compared with people with good hearing. Adjustment for postural balance decreased the risk markedly, but still, people with poorer hearing were at twofold risk for falls. Even though the IRR's were not statistically significant any more, we would not rule out hearing as a significant predictor of falls. Part of the increased risk for falls is explained by poorer postural control among those with poorer hearing acuity.

The strengths of this study were that it comprised a genetically informative population-based sample of older community-dwelling women. The audiometric and postural sway measurements were done in standardized conditions, and results provide reliable and valid descriptions about the traits. Moreover, fall data were gathered prospectively and systematically for a year, and the participation rate in the follow-up was very high. The results of this study can be generalized to older female, community-dwelling high-functioning population. To be recruited for this study, both sisters of the twin pair had to participate and be able to travel to the research laboratory from their town of residence. Consequently, people with severe health problems were not able to take part in the study. Further studies among men, different age groups, and people with more functional limitations are warranted.

Hearing impairments are mainly considered to be communication disorders, but deficits in hearing may have more wide-ranging consequences than difficulties in conversation. Poor hearing may increase the risk for falls and injuries, thus having a direct effect on disability. Poor hearing may also reduce activity and participation, leading eventually to an inactive way of life and decreased quality of life. Primary and secondary prevention of hearing loss should be a priority when aiming to promote health and well-being among older people.

Acknowledgments

This study was funded from grants by the Academy of Finland, the Ministry of Education, Finland, and the GENOMEUTWIN project (EU grant no. QLG2-CT-2002-01254). S.P. was supported by the Intramural Research Program of the National Institutes of Health, National Institute on Aging. We are indebted to all the participants for their commitment to the study.

Conflict of Interest

We declare that we have no conflicts of interest.

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Received December 12, 2007
Accepted May 10, 2008
Decision Editor: Luigi Ferrucci, MD, PhD