Predictors of Falls per Step and Falls per Year At and Away From Home in Glaucoma

PRADEEP Y. RAMULU, ALEKSANDRA MIHAILOVIC, SHEILA K. WEST, LAURA N. GITLIN, AND DAVID S. FRIEDMAN

• OBJECTIVE: **To determine where glaucoma patients most often fall and how integrated visual field (IVF) damage affects falls rates per year (falls/year) and per step (falls/step) at and away from home.**

• DESIGN: **Prospective, observational cohort study.**

• METHODS: **In 225 patients with glaucoma or suspected glaucoma, falls data were collected via calendars, fall location was classified through follow-up questionnaires, and steps taken at and away from home were judged by integrating data from annual week-long accelerometer and GPS trials. Main outcome measures were the association of IVF sensitivity with fall rates per year or step, stratified by location.**

• RESULTS: **Participants took more away steps than home steps (2366 vs 1524, $P < .001$), and differences in away vs home steps did not vary with IVF sensitivity ($P = .22$). A total of 57% of falls occurred at home, with each home step twice as likely to result in a fall as compared to each away step (rate ratio = 2.02, $P < .001$). Worse IVF sensitivity was not associated with a higher rate of home falls/year or away falls/year ($P > .1$ for both), but was associated with a higher rate of home falls/step (rate ratio = 1.34/5 dB worse sensitivity, $P = .03$) and away falls/step (rate ratio = 1.47/5 dB worse sensitivity, $P = .003$).**

• CONCLUSIONS: **In this glaucoma population, most falls occurred at home, and the risk of any step resulting in a fall was higher at home. Those with greater VF damage were more likely to fall for each step taken both at and away from home. Efforts such as home environmental modification should be considered in the visually impaired to prevent falls while maintaining physical activity. (Am J Ophthalmol 2019;200:169–178. © 2019 Elsevier Inc. All rights reserved.)**

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From the Glaucoma Center of Excellence (P.Y.R., A.M., S.K.W.) and Dana Center for Preventive Ophthalmology (P.Y.R., A.M.,S.K.W., D.S.F.), Wilmer Eye Institute, Johns Hopkins University, Baltimore, Maryland, USA; and Johns Hopkins School of Nursing, Baltimore, Maryland, USA (L.N.G.).

Dr Gitlin is now working at Drexel University, College of Nursing and Health Professions, Philadelphia, Pennsylvania, USA.

Inquiries to Pradeep Y. Ramulu, Johns Hopkins Hospital, 600 North Wolfe St, Maumenee B110, Baltimore, MD 21287, USA; e-mail: pramulu@jhmi.edu

FALLS ARE THE LEADING CAUSE OF INJURY-RELATED death in American adults over the age of 65[1] and account for most injury-related emergency room visits and hospitalizations in this age group as well.[2] Annually, fall-related costs for Medicare recipients alone exceed $30 billion.[3] Fall survivors are frequently worse off in numerous ways, including greater social isolation, depression, activity restriction owing to fear of falling, and worse overall quality of life.[4] Caregiver burden for those who have fallen is also substantial and can range into the tens of thousands of dollars after even a single injurious fall.[4]

Falls are a particular problem in the visually impaired,[5,6] and numerous studies have suggested that visual screening should be conducted as part of fall prevention programs.[7] Among the various types of visual damage, visual field (VF) damage (difficulty with peripheral vision) is particularly relevant to falls, with 1 population-based study demonstrating greater VF damage, but not worse visual acuity (the ability to discriminate fine details), to be associated with a higher rate of falling.[8]

An important first step in preventing falls in persons with VF damage is to determine where individuals with VF damage are most prone to falling. In particular, it is important to understand the relative risk of falling in the home, where environmental modifications are most possible, and away from home, where environmental modifications may not be possible. Previous research with older adults has suggested that up to 70% of falls may occur within the home,[9] though these studies did not specifically investigate persons with visual impairment. Also, prior studies did not consider the amount of physical activity performed at and away from home. Falls are not possible in the absence of activity, and differences in annual fall rates across locations may simply reflect differing amounts of activity done in each location. Only by accounting for activity can one judge the extent to which activity (ie, walking) in each location is dangerous.

The Falls in Glaucoma Study (FIGS) was designed to identify where falls occurred in persons with glaucoma, and to identify potentially reversible risk factors for falls. While several prior studies have examined fall rates in the context of glaucoma,[10–13] none accounted for differences in physical activity across the spectrum of VF damage, and none investigated the specific locations where falls are most risky. Here, we examine falls in glaucoma at home and away from home in a

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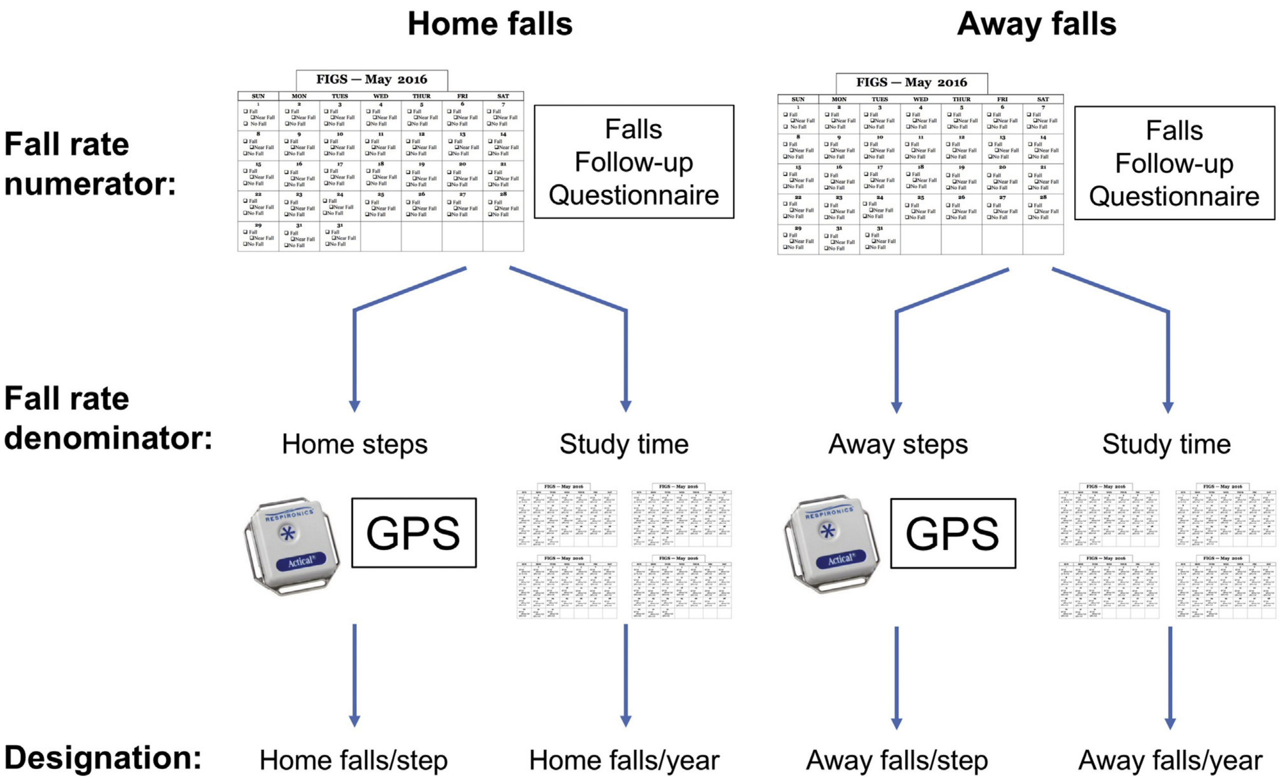

FIGURE 1. Description of the 4 distinct fall rates evaluated as part of the study. Data needed to calculate each element of the numerator or denominator are given below the description in words. For example, home falls are determined through calendar and falls follow-up questionnaire data, home steps are determined by accelerometer and GPS data, and study time is determined by the number of calendars returned to yield falls data.

comprehensive fashion by (1) using falls calendars and falls follow-up questionnaires to determine how many falls occur at and away from home over a 2-year period of time, and whether the rates of falls per year at home and/or away from home are associated with the degree of VF damage (Figure 1); (2) using accelerometers to measure real-world physical activity levels, and integrating these data with location information derived from wearable GPS devices to define the amount of physical activity occurring at home and away from home, and whether the preferred location for activity varies with the extent of VF damage; (3) using fall and fall location data along with the integrated accelerometer and GPS data described above to calculate the rate of at-home falls per steps taken at home and away-from-home falls per steps taken away from home, and examining how these rates vary with the degree of VF damage (Figure 1); and (4) determining if walking is more dangerous at vs away from home for the full cohort and for individuals with varying degrees of VF damage.

Our results will help answer fundamental questions about where older individuals are most at risk of falling, and inform the optimal design of targeted fall prevention interventions in high-risk visually impaired older adults.

METHODS

ALL STUDY PROCEDURES WERE APPROVED BY THE JOHNS Hopkins institutional review board and recruited participants signed written informed consent. Detailed methods about this prospective observational cohort study have been previously published.[14]

• **STUDY PARTICIPANTS:** Study participants were recruited from the Johns Hopkins Wilmer Eye Institute glaucoma service between September 2013 and March 2015 and were 57 years of age or older at the time of recruitment (ie, at least 60 years of age at the end of the 3-year study period). Participants had a clinical diagnosis of glaucoma or suspect glaucoma (ie, ocular hypertension, narrow angles, a positive family history, or borderline findings for glaucoma). Individuals with neovascular or uveitic glaucoma were excluded. Individuals were also excluded if they had visual acuity worse than 20/40 in either eye for reasons other than glaucoma, had been hospitalized in the last month, or had any ocular or nonocular surgery within the last 2 months.

• **VISUAL ASSESSMENT:** Baseline testing used to judge visual ability included visual acuity assessment with a backlit

ETDRS chart and right and left eye VF testing on a Humphrey HFA-2 perimeter (Carl Zeiss Meditec, Carlsbad, California, USA) using the 24-2 Swedish Interactive Testing Algorithm. Pointwise sensitivities from the right and left VFs were combined to generate a sensitivity at each spatial coordinate using the maximum sensitivity approach, and then to calculate average sensitivity across this integrated VF (IVF), as previously described.[15] Average IVF sensitivities from individuals with normal VFs were in the range of 31 dB, with lower sensitivities suggesting VF damage. IVF sensitivities were also used to categorize participants as having mild VF damage (>28 dB), moderate damage (23-28 dB), or severe damage (<23 dB), as these sensitivities roughly correspond with criteria set forth by Hodapp, Anderson, and Parrish.[16] Of note, participants with normal VFs were included in the mild VF damage category.

• **FALL ASSESSMENT AND FOLLOW-UP:** A fall was defined for participants verbally as unintentionally coming to rest on the ground or a lower level and illustrated using a previously developed instructional video.[17] Participants were provided with falls calendars after their baseline in-clinic assessment, and were asked to mark their calendars daily to indicate the presence or absence of a fall and to return calendar data at the end of the month via mail or e-mail. Individuals not returning their calendar data were contacted by phone and/or e-mail until data were obtained or a period greater than 3 months passed, at which time data were recorded as missing. Individuals with less than 1 month of falls data were excluded from our final analyses, as were individuals found to have excessive falls (>5 per year) secondary to a neurologic condition.

Patients reporting a fall were called within 2 weeks of the study team receiving the calendar indicating the fall in order to complete an over-the-phone falls follow-up questionnaire. This questionnaire was used to determine the location of the fall, with falls defined as "home" if the fall occurred in the home or just outside the home (ie, on the porch/stairs, driveway, or yard). All other falls locations were defined as "away." Additional questions also determined if a fall was injurious, as judged by the presence of bruising, swelling, pain, sprained ligaments/tendons, joint dislocation, pulled muscle, or broken bone/fracture.[18]

• **ACTIVITY AND LOCATION ASSESSMENT:** At the beginning of each of their 3 study years, participants completed concurrent 1-week assessments (7 consecutive days) of physical activity and geolocation, assessed using a waistband accelerometer (Actical; Respironics Inc, Murrysville, Pennsylvania, USA) and a waist-worn GPS tracker (QStarz, Inc, Taipei, Taiwan), respectively. Accelerometers provided activity data including steps on a minute-by-minute level over the week, while GPS trackers provided latitude and longitude on a minute-by-minute level. Overnight location coordinates between 2 AM and 4 AM taken over the 1-week assessment were used to empirically define the home location. A distance from home was calculated for every study minute where location data were available, and the individual was defined as being at home for that minute if they were within 50 meters of the empirically defined home location. Fifty meters was chosen as a radius given that 97% of 2-4 AM locates placed the individual within this distance when using the empirically defined home location. Also, this radius is expected to include both the home and an outdoor area immediately surrounding the home, given that even a large (5000-square-foot) single-floor home would be expected to extend only 20-30 meters from the center of the home. Study minutes not associated with a successful locate were classified as home, away, or unknown/missing based on the approach described in the Supplemental Table (Supplemental Material available at AJO.com).

Steps for each minute were defined as home steps if the person's location for that minute was defined as home, as away steps if the subject was defined as being away from home for that minute, or unknown (missing) if no home/away designation was assigned. Data from each 1-week trial of accelerometer and GPS wear were used to infer the amount and location of physical activity for the upcoming 12 months (ie, until an updated assessment was performed). Days with inadequate device data (fewer than 12 hours of total GPS data between 5 AM and 11 PM or fewer than 8 hours of continuous daytime accelerometer wear) were not included.[19] Hours of continuous accelerometer wear were calculated as the time between the first and last minutes demonstrating any activity over the period between 12 AM and 4 AM added to the time between the first and last active minutes over the period between 4:01 AM and midnight. Data were not used for device trial weeks with fewer than 4 days of valid GPS and accelerometer data based on prior data suggesting that 4 days of activity data can predict long-term patterns.[20–22] In participants with less than 4 valid days of combined GPS and accelerometer data for a specific study year (11.7% of study years), data were imputed based on the GPS/accelerometer from the nearest year with 4 or more valid days of data, assuming such data were available. For example, for an individual with ≥4 days of valid GPS and accelerometer data at baseline and the 2-year follow-up time points, but only 2 days of valid GPS and accelerometer data at the 1-year follow-up time point, baseline data would be used to infer steps at and away from home for the first 24 study months. Subjects with no study weeks with 4 or more valid days of GPS and accelerometer data were excluded from our analyses.

• **ASSESSMENT OF COVARIATES:** Demographic data were gathered using standardized questionnaires. Participants were asked if they had been diagnosed with any of 15 potential comorbid illnesses known to affect physical activity (arthritis, broken or fractured hip, back problems, history of heart attack, history of angina/chest pain, congestive heart failure, peripheral vascular disease, high blood pressure, diabetes, emphysema, asthma, stroke, Parkinson disease, cancer other than the skin cancer, and history of vertigo or Menière disease),[23] and total illnesses were summed to generate a comorbid index. As there were very few individuals with greater than 5 illnesses (n = 8), these individuals were reclassified as having 5 comorbid illnesses. To determine the number of prescription non–eye drop medications used, medication bottles were observed directly or information was collected via questionnaire when direct observation was not possible. Polypharmacy was defined as the use of 5 or more systemic medications.[24] Weather was not considered as a covariate based on its lack of association with either physical activity or out-of-home travel in prior studies from the same clinical population.[23,25]

• **STATISTICAL ANALYSES:** Separate Kaplan-Meier analyses were conducted to report the cumulative incidence of a home fall or an away-from-home fall over time. Individuals remained eligible (ie, were not censored) for a home fall event even after an away-from-home fall occurred, and vice versa. Average daily steps taken at vs away from home were compared using paired *t* tests. The total number of falls for each person occurring at vs away from home was compared using the Wilcoxon signed rank test.

VF damage and other covariates were then investigated as predictors of the rate of home falls and away falls. Risk factors associated with fall rates were evaluated in 4 models described in Figure 1. Two separate negative binomial models were designed to determine risk factors associated with a higher rate of home and away falls over time (falls/year), with the number of falls occurring in the area of interest (home or away) taken as the event of interest, and total study time in years (equivalent for both models) taken as the offset (rate denominator). Two additional negative binomial models were designed to determine risk factors associated with a higher rate of falling while walking (falls/step), with the number of falls occurring in the area of interest (home or away) taken as the event of interest, and the number of home or away steps taken in the area of interest over the study period (distinct for the 2 models) taken as the offset (rate denominator). All models controlled for age, race, sex, comorbidities, and polypharmacy. Finally, negative binomial models accounting for clustering across fall/step rates at and away from home within the same individual were employed to determine if steps taken at home were more likely to result in a fall as compared to steps taken away from home.

RESULTS

• **VALIDITY OF ACCELEROMETER AND GPS DATA:** Among all study participants, 90% of accelerometer trial days and 83% of GPS trial days demonstrated sufficient hours of data for inclusion, while 79% of trial days had sufficient hours in both GPS and accelerometer measures, allowing merger of both data streams. Prolonged gaps between successful GPS locates were rare within valid study days (Figure 2).

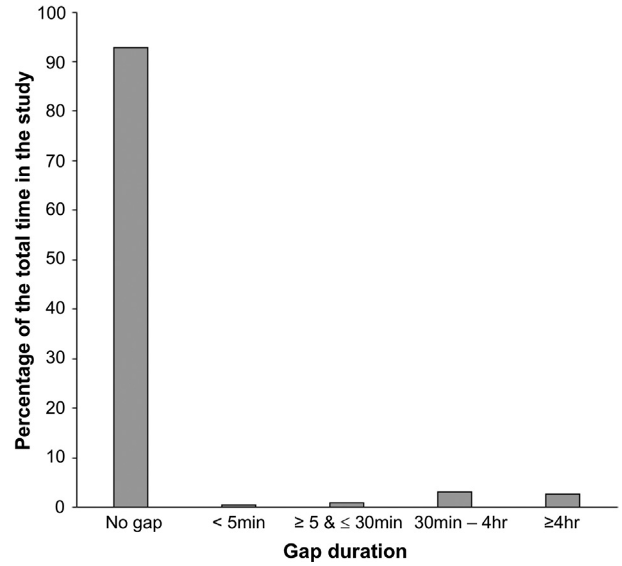

FIGURE 2. Percentage of the minutes missing location information within the valid dataset defined by the gap duration.

• **CHARACTERISTICS OF ANALYZED PARTICIPANTS:** Two-hundred forty-five participants enrolled in the study, with 20 (8.2%) excluded on the basis of excessive neurologic condition–related fall data (n = 2), unavailable fall data (n = 1), absence of any suitable accelerometer/GPS data (n = 16), or missing VF data (n = 1), leaving an analytic sample of 225 study participants. Excluded participants did not differ from those analyzed with regard to age, race, sex, employment status, live-alone status, or level of education ($P > .08$ for all). Twenty-four percent of individuals had location and activity data imputed for 1 or 2 years (in other words, 11.7% of study years were imputed), since they had sufficient number of valid days of combined GPS and accelerometer data for some of the study years, but not for others. Average participant age was 70.4 years at the beginning of the study period and 28% were African-American (Table). Median IVF sensitivity was 27.9 dB (normal value = 31 dB, interquartile range [IQR] = 25.9-29.8 dB), while median better- and worse-eye mean deviations were -2.52 (IQR = -5.42 to -0.64) and -5.72 (IQR = -13.48 to -2.62), respectively.

• **INCIDENCE OF FALLS AT AND AWAY FROM HOME:** A total of 294 falls were noted over 5134 calendar months (0.69 falls/year across all participants), and 287 (98%) of these falls were successfully assigned a location based on the completion of a falls follow-up questionnaire. Of these

TABLE. Falls in Glaucoma Study Population Characteristics

Demographics	Values (N = 225)
Age (y), mean (SD)	70.4 (7.5)
African-American race, n (%)	63 (28)
Female sex, n (%)	109 (48)
Employed, n (%)	81 (36)
Lives alone, n (%)	42 (19)
Education, n (%)	
Less than high school	7 (3)
High school	28 (13)
Some college	31 (14)
Bachelor's degree	54 (24)
More than bachelor's degree	104 (46)
Health	
Comorbid illnesses >1, n (%)	143 (64)
Polypharmacy, n (%)	69 (31)
Body mass index (kg/m^2), mean (SD)	27.2 (5.2)
Grip strength (kg), mean (SD)	31.8 (10.6)
Lower body strength (kg), mean (SD)	17.8 (6.1)
Vision	
IVF sensitivity (dB), median (IQR)	27.91 (25.93, 29.77)
MD better eye, median (IQR)	−2.52 (−5.42, −0.64)
MD worse eye, median (IQR)	−5.72 (−13.48, −2.62)
Better-eye acuity, logMAR, median (IQR)	0.06 (0, 0.16)
Binocular log CS, median (IQR)	1.72 (1.64, 1.76)

CS = contrast sensitivity; IQR = interquartile range; IVF = integrated visual field; logMAR = logarithm of the minimum angle of resolution; MD = mean deviation.

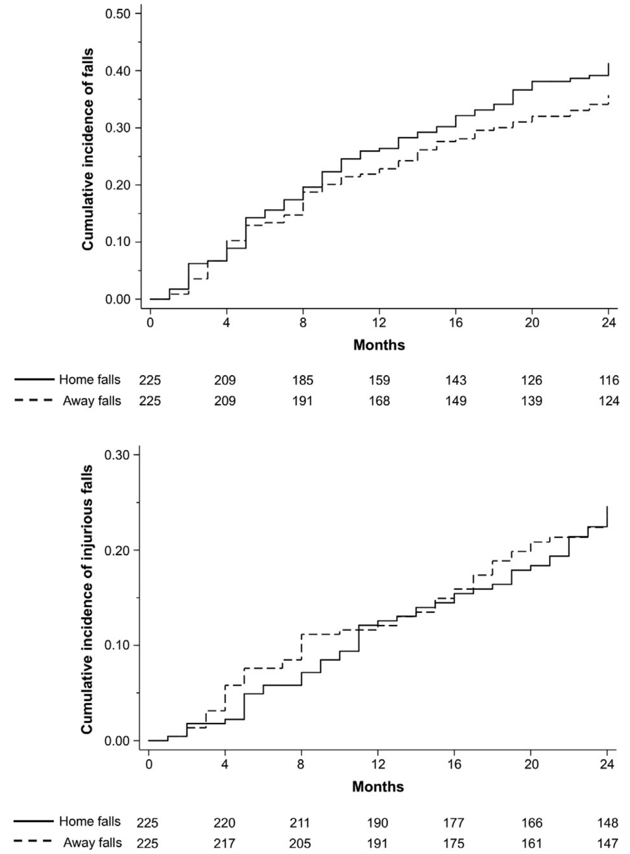

FIGURE 3. (Top) Cumulative incidence of home and away-from-home falls. (Bottom) Cumulative incidence of home and away-from-home injurious falls.

287 location-designated falls, 163 (57%) were reported as occurring at home (100 [61%] within their house/apartment, 63 [39%] just outside their house), while the remaining 124 (43%) were defined as occurring away from home (P = .13). At 12 and 24 calendar months, the cumulative probability of study participants experiencing 1 or more home falls was 26% and 41%, respectively, while the cumulative probability of participants experiencing 1 or more away falls was 23% and 36% (Figure 3, Top). The cumulative probability of injurious home falls was 13% and 24% at 12 and 24 months, respectively, while the cumulative probability of injurious away falls was 12% and 24% (Figure 3, Bottom).

• **LOCATION OF WALKING:** In valid study days from the analytic sample, 97% of steps were successfully designated as occurring at or away from home. Participants took more daily away steps as compared to home step (2366 vs 1524, P < .001). Within-participant differences in away vs home steps did not vary with IVF sensitivity (P = .22).

• **FACTORS PREDICTING FALLS PER YEAR AT AND AWAY FROM HOME:** In univariate models, IVF sensitivity was not associated with a higher rate of home falls/year (rate ratio [RR] = 1.18/5 dB worse sensitivity, 95% confidence interval [CI] = 0.93-1.49, P = .17) or away falls/year (RR = 1.09/5 dB worse sensitivity, 95% CI = 0.84-1.41, P = .5). In multivariable models, IVF sensitivity was not associated with a higher rate of home falls/year (RR = 1.21/5 dB worse sensitivity, 95% CI = 0.95-1.54, P = .12) or away falls/year (RR = 1.22/5 dB worse sensitivity, 95% CI = 0.92-1.60, P = .17) (Figure 4, Top), and similar results were also observed for IVF sensitivity in either the superior or inferior hemifields (P > .10 for both). Likewise, female sex, polypharmacy, and the number of comorbid illnesses were not associated with home falls/year or away falls/year (P > .05 for all). Older age was associated with more home falls/year (RR = 1.17 per 5-year age increment, 95% CI = 1.02-1.35, P = .02) but not with more away falls/year (RR = 1.06 per 5-year increment, 95% CI = 0.91-1.25, P = .45). African-Americans had a lower rate of away falls/year as compared to whites (RR = 0.54, 95% CI = 0.30-0.97, P = .04) but were not different with regard to the rate of home falls/year (RR = 0.69, 95% CI = 0.41-1.17, P = .17).

• **FACTORS PREDICTING FALLS PER STEP AT AND AWAY FROM HOME:** In univariate models, IVF sensitivity was associated with a 33% higher rate of home falls/step (RR = 1.33/5 dB worse sensitivity, 95% CI =1.02-1.73,

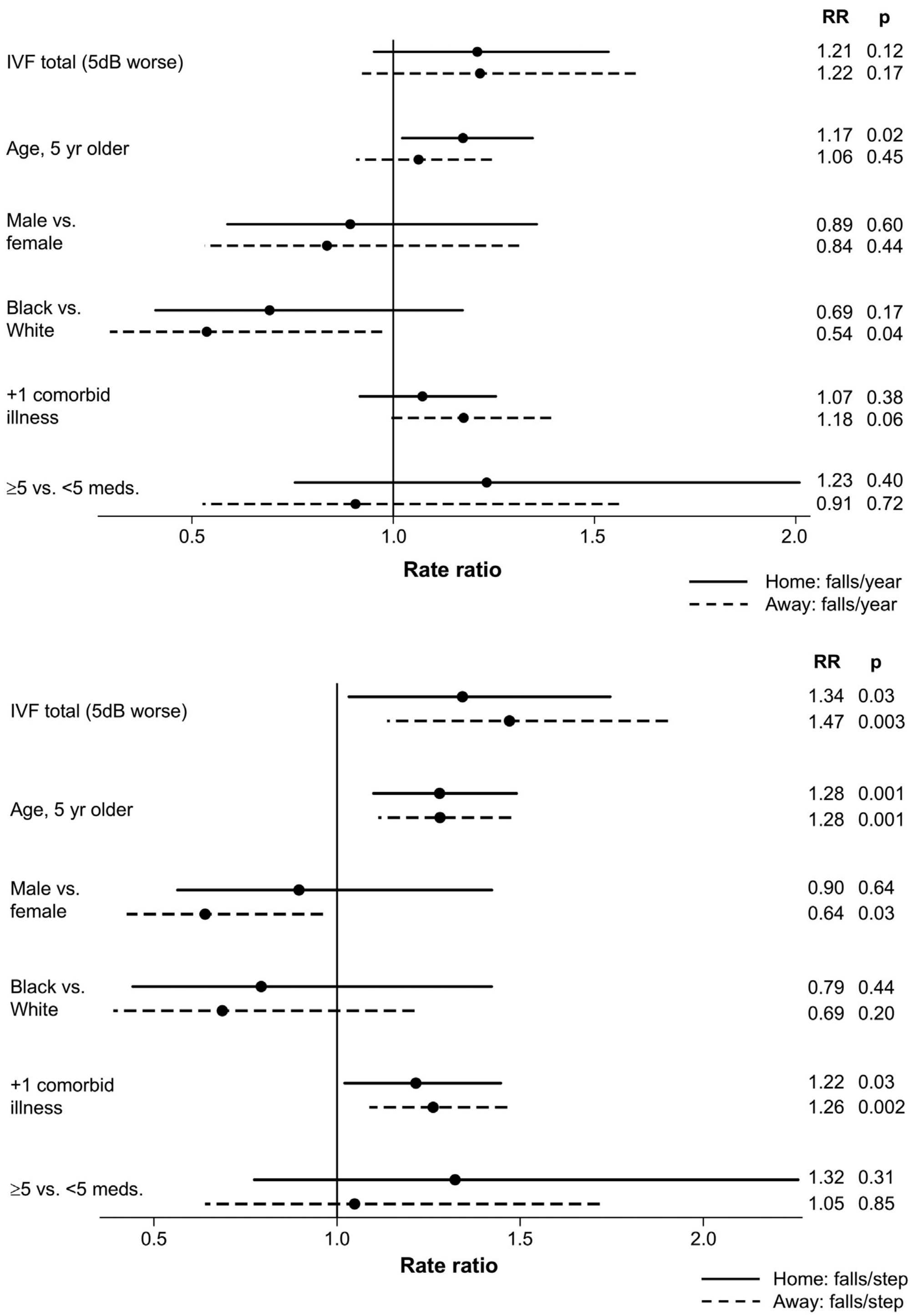

FIGURE 4. (Top) Association between rates of falls at home and away-from-home per year with degree of visual field damage and other patient characteristics. (Bottom) Association between rates of falls at home and away from home per step, with degree of visual field damage and other patient characteristics. IVF = integrated visual field; meds = medications; RR = rate ratio.

P = .03) and a 45% higher rate of away falls/step (RR = 1.45/5 dB worse sensitivity, 95% CI = 1.12-1.90, P = .006). Additional multivariable negative binomial models were designed to identify risk factors associated with more frequent home falls/step, or more frequent away falls/step. In models including all study participants, worse IVF sensitivity was associated with both a 34% higher rate of at-home falls/step (RR = 1.34/5 dB worse sensitivity, 95% CI = 1.03-1.75, P = .03) and a 47% higher rate of away falls/step (RR = 1.47/5 dB worse sensitivity, 95%

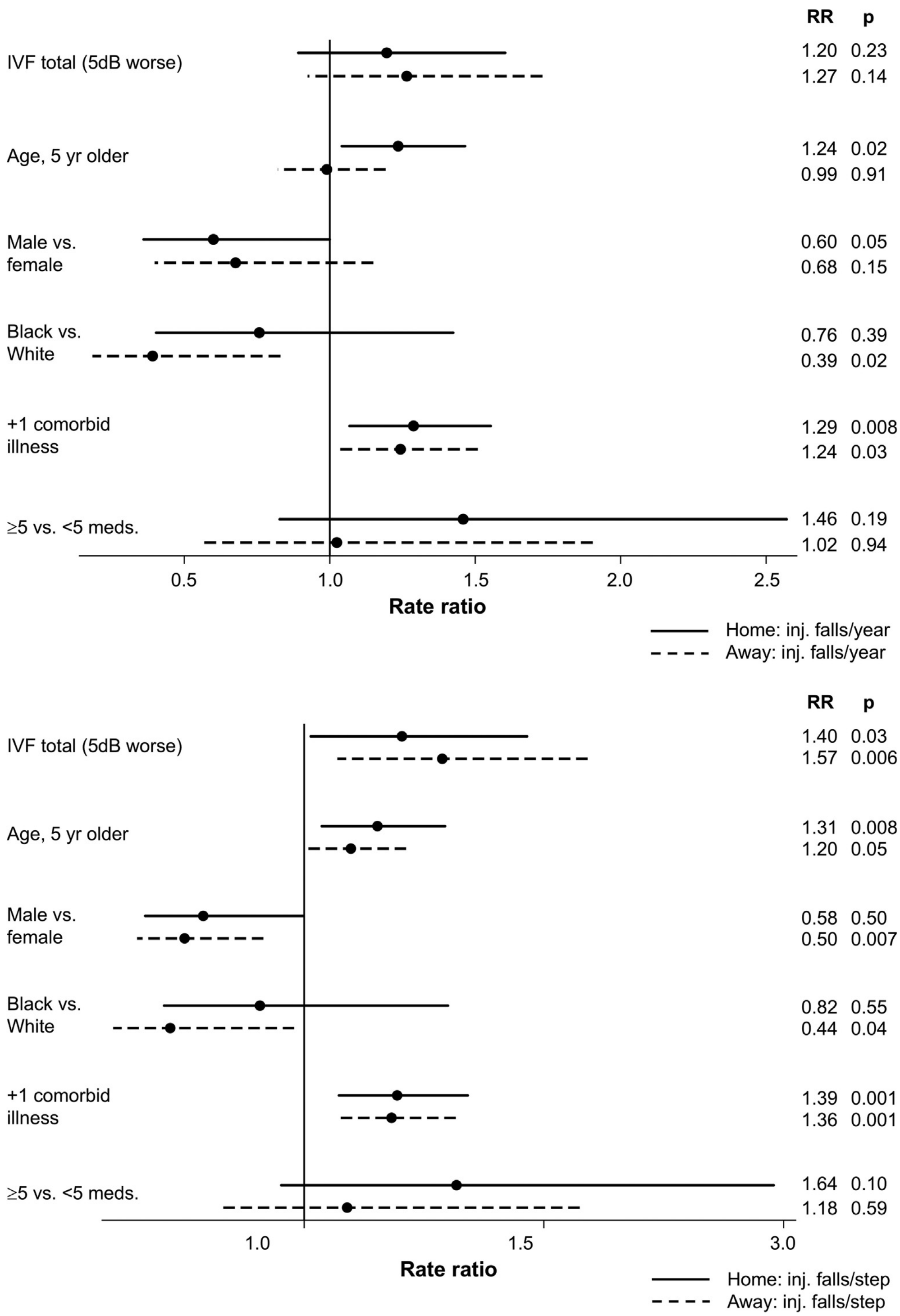

FIGURE 5. (Top) Association between rates of injurious falls at home and away from home per year, with degree of visual field damage and other patient characteristics. (Bottom) Association between rates of injurious falls at home and away from home per step, with degree of visual field damage and other patient characteristics. inj = injurious; IVF = integrated visual field; meds = medications; RR = rate ratio.

CI = 1.14-1.90, $P = .003$) (Figure 4, Bottom). Similar regression coefficients were observed when subjects with mild or no glaucoma were excluded. Older age and comorbid illness were also associated with both more home falls/step and more away falls/step ($P < .04$). Neither African-American race nor polypharmacy were associated with either home falls/step or away falls/step ($P > .2$ for all). Female subjects, when compared to male, experienced more away falls/step ($P < .05$) but did not experience more home falls/step ($P > .6$).

All analyses in which IVF sensitivity was taken as the measure of glaucoma damage were repeated using IVF sensitivity in the inferior hemifield instead. Similar results were observed in all situations, and in all the cases the rate ratio attributable to a 5 dB decrement in inferior IVF sensitivity was slightly lower (closer to no association) than the rate ratio attributable to a 5 dB decrement in overall IVF sensitivity.

• **RELATIONSHIP BETWEEN VISUAL FIELD DAMAGE AND INJURIOUS FALLS:** As was noted for all falls (regardless of resulting injury), worse IVF sensitivity was not associated with more injurious home falls/year or injurious away falls/year ($P > .10$) (Figure 5, Top) but was associated with a 40% higher rate of injurious home falls/step (RR = 1.40/5 dB worse sensitivity, 95% CI = 1.03-1.93, $P = .03$) and a 57% higher rate of injurious away falls/step (RR = 1.57/5 dB worse sensitivity, 95% CI = 1.14-2.18, $P = .006$) (Figure 5, Bottom).

• **WHERE STEPS ARE MORE LIKELY TO PRODUCE A FALL:** In negative binomial models modeling step location (home vs away) as a risk factor for falling, each step taken at home was noted to be roughly 2 times more likely to result in a fall as compared to each step taken away from home (RR = 2.02, 95% CI = 1.47-2.78, $P < .001$). Similar results were also obtained in analyses restricted to participants with mild (RR = 1.87, 95% CI = 1.19-2.93), moderate (RR = 2.18, 95% CI = 1.33-3.57), and severe VF damage (RR = 1.64, 95% CI = 0.52-5.24).

DISCUSSION

IN OUR COHORT OF INDIVIDUALS WITH GLAUCOMA, THE MAjority of falls occurred in and around the home even though participants took more steps away from home as compared to at home, reflecting the fact that walking is more dangerous at home as compared to away from home. Thus, while both home and away falls are significant safety issues in glaucoma, our data suggest that the home setting is particularly important when considering methods to prevent falls.

The preponderance of falls in the home environment is fairly surprising, given that fewer steps are taken there and the home environment is more familiar than the away environment. Additionally, individuals have greater control over their home environment and should, in theory, be able to modify their homes for safety. Previous work, however, has demonstrated that individuals with more severe glaucoma have an equivalent number of fall-related hazards in their home as compared to individuals with less VF damage, suggesting that individuals may not alter their home environments in response to worse vision or other perceived threats.[16,26] Still, the excess of risk in the home as compared to the more varied environment outside the home requires further explanation. One possible explanation is that individuals do not remove fall hazards at home, especially in their personal space (ie, bedrooms and bathrooms) where visitors are unlikely to visit, such that these areas become even more dangerous. Alternately, danger in the home environment may reflect a propensity to fall in poor lighting, which is likely experienced significantly more in the home environment (ie, just before bedtime, during nighttime awakenings, or on first walking in the morning) as opposed to outside the home environment. Finally, it is possible that individuals perceive themselves to be safer in their home environment and are therefore less careful when they walk through it and/or that they are accompanied when walking away from home. Of note, our findings of greater falls/step at home were consistent across the studied levels of VF damage, suggesting that our findings may be applicable to older adults with and without glaucoma.

VF damage was observed to be related to fall rates both at and away from home but, consistent with our prior publications for falls in any location, only when fall rates were analyzed as falls/step as opposed to falls/year.[18] Our findings again illustrate the importance of analyzing falls as a rate per steps taken, which demonstrate an association with VF damage, whereas falls/year do not. These findings are unsurprising given that VF damage has been observed to be associated with activity restriction that can, in turn, mask a higher rate of falls as fewer steps are taken over time.[23,27] Our falls/step models suggest that walking is more dangerous (ie, more likely to result in a fall) in individuals with VF damage. It is not clear whether individuals with glaucoma specifically reduce their activity as a result of previous falls, thus normalizing their rate of falls/year to the level of a visually normal patient, or if they inherently demonstrate lower activity rates. Prior research has suggested that the association between activity restriction and glaucoma is not the result of fear of falling, suggesting that these activity restrictions may not be the result of prior falls, but are still important to account for in models.[28]

Falling while walking (ie, falls/step) was associated with the degree of VF damage when considering both home falls/step and away falls/step, with a stronger association observed for the latter. This finding suggests that one's field of vision is important for preventing falls in all locations, but may be particularly important in identifying hazards in unfamiliar regions (ie, areas away from home). Indeed, several other variables (older age, comorbid illness) demonstrated stronger associations with the rate of away falls/step as compared to the rate of home falls/steps. These data suggest that safe walking outside the home may be more demanding, and may be more subject to disturbance by worse VF sensitivity (which may impair hazard detection), greater comorbid illness (which may affect strength and balance), and age (which may generally impair strength, balance, and/or awareness of/reaction time to respond to hazards).

While it is somewhat surprising that steps taken at home would be more dangerous than steps taken away from home, this finding does suggest a relatively straightforward first step in preventing falls while maintaining activity in the visually impaired. The broad literature has demonstrated that home environmental modifications can prevent falls,[29–31] though no such interventions have been particularly targeted at individuals with visual impairment. Nonetheless, it is quite plausible that environmental modifications may be able to prevent a significant proportion of falls (ie, those occurring within the home). While a broader solution design to eliminate both at-home and away-from-home falls might be more optimal, home modification is simple, straightforward, and likely cost-effective given that a single fall with hospitalization can result in over $17 000 of medical expenses to the patient and the US healthcare system.[32] Thus, our findings suggest the need to understand the specific conditions in homes that lead to higher fall rates among this population. Furthermore, the data suggest that we need to develop validated methods to modify the home to prevent falls in older adults with visual impairment. Ideally, such home modification efforts will not only be targeted at preventing falls, but would also improve functionality in the home and mitigate limitations in instrumental activities of daily living (IADLs).[33] Given the limited numbers of low-vision and occupational therapists,[34] systems are also needed to enable home modification without the workforce of highly trained experts who must go into homes to identify and correct hazards.

One limitation of the current work is that time and steps spent within the confines of the home could not be accurately distinguished from time and steps performed just outside the home, given limitations in the accuracy of the GPS tracker. Thus, falls occurring in and just outside the home were combined out of necessity, and it is unknown if similar conclusions would have been reached if only falls directly within the home were analyzed and compared to falls outside the home. Additionally, individuals more prone to falling were more likely to participate in our study,[18] which may have biased our results. Our study population was highly educated, and while education level did not differ from the clinic population,[18] it may not be reflective of the general glaucoma population in the United States. Location and activity patterns were not measured over the entire period for which falls data were obtained, but rather were extrapolated to each year of data from 1-week accelerometer and GPS trials. As such, though prior research suggests that long-term travel patterns may be approximated by as few as 4 days of data,[20–22] changes in activity occurring over the course of a year would have been missed, and error could have been introduced when study weeks were chosen that did not accurately represent the pattern of the full year. Finally, prospective data collection of the falls was based on the patient reporting using fall calendars, the gold standard for falls assessment.[35] Falls were not confirmed using objective measures or through report of a family member.

In summary, a majority of falls occurred at home in a cohort of glaucoma patients, and steps taken at home were noted to be more frequently associated with falls as compared to steps taken away from home. Steps at and away from home were also more likely to result in falls with worse VF damage. Efforts to prevent falls in this high-risk group should consider starting with environmental modifications of the home, and systems are needed to integrate the delivery of such services into the routine care of individuals with moderate and advanced glaucoma.

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