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Foot clearance and variability in mono- and multifocal intraocular lens users during stair navigation

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Abstract—Intraocular lenses (IOLs) provide distance and near refraction and are becoming the standard for cataract surgery. Multifocal glasses increase the variability of toe clearance in older adults navigating stairs and increase fall risk; however, little is known about the biomechanics of stair navigation in individuals with multifocal IOLs. This study compared clearance while ascending and descending stairs in individuals with monofocal versus multifocal IOLs. Eight participants with multifocal IOLs (4 men, 4 women; mean age = 66.5 yr, standard deviation [SD] = 6.26) and fifteen male participants with monofocal IOLs (mean age = 69.9 yr, SD = 6.9) underwent vision and mobility testing. Motion analysis recorded kinematic and custom software-calculated clearances in three-dimensional space. No significant differences were found between groups on minimum clearance or variability. Clearance differed for ascending versus descending stairs: the first step onto the stair had the greatest toe clearance during ascent, whereas the final step to the floor had the greatest heel clearance during descent. This preliminary study indicates that multifocal IOLs have similar biomechanic characteristics to monofocal IOLs. Given that step characteristics are related to fall risk, we can speculate that multifocal IOLs carry no additional fall risk.

Key words: balance, biomechanics, fall risk, foot clearance, intraocular lenses, monofocal, motion analysis, multifocal, older adults, stair negotiation, vision, visual impairment.

INTRODUCTION

Many older adults experience declining visual function and need assistive technology (e.g., bifocal spectacles or surgical procedures such as intraocular lenses [IOLs]) to see adequately. While monofocal IOLs often correct distance-vision–related impairments, more than 85 percent of recipients also need bifocal glasses to correct intermediate and near vision [1–2]. However, bifocals can impair visual detection of obstacles located on the floor or lower level because of impaired depth perception and contrast sensitivity [3]. This impairment is pronounced

Abbreviations: ETDRS = Early Testing Diabetic Retinopathy Study, IOL = intraocular lens, LHEE = left heel, LTOE = left toe, RHEE = right heel, RMANOVA = repeated-measures analysis of variance, RTOE = right toe, SD = standard deviation, SOT = Sensory Organization Test, VA = Department of Veterans Affairs, VAMC = VA medical center.

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when potential hazards are viewed from intermediate distances (30–80 cm) [4], such as during stair navigation; therefore, bifocals are considered a fall risk factor in older adults that could lead to injury [3,5–6]. Stair falls are responsible for 10 percent of fatal fall accidents [7]. Factors contributing to fall risk and incidence in older adults while ascending and descending stairs include reduced ability to generate high eccentric torque at the ankle in the leading limb [8], highly variable levels of minimum foot clearance [9–14], and extremely low (i.e., close to the stair) foot clearance [15].

Traversing stairs involves an alternation of obstacle perception in and then out of the visual field. Visual information related to stair properties (i.e., stair edges) is crucial for stair negotiation. Older and young adult individuals visually fixate on future stepping locations 90 percent of the time for stair ascent and 75 to 90 percent of the time for descent [15], with older adults fixating ahead with less variability than young adults. Though visual information informs working memory, visual fixation is highly utilized in stair navigation. Zietz and Hollands identified older adults as consistently looking 2 to 4 steps ahead during stair ascent and descent [15]. This finding shows how crucial visual information is in navigation, because it is necessary for visual information to be accurate with respect to stair location and foot placement. Some individuals employ a protective strategy and increase their foot clearance on stairs in situations of decreased visibility or when the individual has reduced vision [16]. Poor vision could especially affect descending stairs, because more up to date visual information of stair properties is needed to guide stair descent [15]. Indeed, descending stairs is particularly difficult for older adults because there is less visual information available, resulting in greater likelihood that the individual may contact the stair's edge, possibly leading to hazardous consequences. In fact, catching the heel on the stair's edge is the most frequent cause of falls while descending stairs [17]. Other potential risk factors for falls on stairs include aging and balance impairments. Typically, nondisabled older adults with good balance have larger and, therefore, safer vertical and horizontal foot clearance than more balance-impaired older adults [15].

An effective compensation for reduced vision appears to be increasing toe clearance while ascending stairs. For example, in young nondisabled control subjects ascending stairs, maximum toe clearance increased after diverting vision from the stair for a few seconds prior to stepping. This increase occurred within 2 s of looking away from a stair and initiating the step. But this increased clearance was reduced after subjects walked up two stairs before stepping on a stair without vision. Retaining information with working memory about the height and position of a stair relative to the body can be enhanced by motor actions associated with interactions with the object; however, information about stair height is rapidly lost, affecting effective stair climbing [16]. Slower and older adults in particular are often not able to benefit from their working memory of motor interaction with stairs [16]. Vision is therefore crucial to stair navigation, especially for older adults who are very reliant on visual input.

Multifocal IOL implants, which have zones providing multiple-focused vision at far and reading distance and eliminate the need for bifocals in 98 percent of users [1], could have similar effects as bifocals on vision function, with the accompanying increased fall risk [18]. Compared to monofocal counterparts, individuals with multifocal IOLs have increased visual function at a variety of distances and light levels. But, multifocal IOLs are also subject to impaired depth perception and contrast sensitivity as well as halo creation experienced with bifocal glasses [10], suggesting that multifocal IOLs may also affect fall risk adversely.

The foot clearance biomechanics of ascending and descending stairs in monofocal versus multifocal IOL users has not been characterized. Such information could be used to generalize mono- and multifocal IOLs' effects on older individuals' ability to navigate in a complex environment. We aimed to determine whether there are (1) differences between monofocal and multifocal IOL users in minimum and maximum toe clearance (while ascending) and heel clearance (while descending) and (2) differences in the variability of foot clearance between mono- and multifocal IOL users. We hypothesized that individuals with multifocal IOLs would exhibit greater minimum toe and heel clearance and greater variability.

METHODS

Participants

All participants provided informed consent in accordance with the Atlanta Department of Veterans Affairs (VA) Medical Center (VAMC) Research and Development Committee and Emory University Institutional Review

Board, and the study adhered to the tenets of the Declaration of Helsinki. Twenty-four older individuals were recruited for the study. Eight participants (4 women, 4 men; mean age = 66.5 yr, standard deviation [SD] = 6.26) had undergone bilateral implantation with a multifocal IOL (ReSTOR IOL, Alcon Research, Ltd; Fort Worth, Texas), and 16 participants (16 men; mean age = 69.13 yr, SD = 7.32) had undergone implantation with a conventional, monofocal IOL (ACRYSOF SA 60; Alcon Research, Ltd). One participant in the monofocal group had fewer than two trials of clearance data and was therefore excluded from analysis, resulting in a cohort of 15 participants for the monofocal IOL group (15 men; mean age = 69.9 yr, SD = 6.9). The monofocal IOL participants were recruited from the Eye Clinic at the Atlanta VAMC, and the multifocal IOL participants were recruited from the Eye Clinic at the Emory Eye Center. Further eligibility criteria included uncomplicated bilateral cataract extraction with implantation of an IOL 6 mo to 1 yr before participation, ≤1.0 diopter of corneal astigmatism, no other ocular pathology, the ability to ambulate household distances without assistance, and no progressive neurological disorder.

Materials and Procedures

All participants completed one 2 to 3 h study visit to the Atlanta VAMC. Participants completed questionnaires to assess general health, number of falls in past year, balance-related confidence, and quality of life. All participants completed a battery of binocular vision, balance, and mobility tests. Participants were asked to wear any prescribed corrective spectacles (e.g., bifocals) for all visual tests. The following measures were taken to characterize the sample.

Balance Confidence

Balance confidence was measured with the Activities-Specific Balance Confidence scale [19]. Subjects completed a 16-item questionnaire regarding their confidence in performing 16 different everyday activities (e.g., walking around in their house or up and down stairs) without losing their balance or becoming unsteady. The scale ranged from 0 to 100 percent: 0 percent represented "no confidence," and 100 percent represented "completely confident." An overall average balance confidence score was calculated for each participant.

Static Balance

Standard measures of balance were recorded using the Sensory Organization Test (SOT) on the NeuroCom Equitest System (Natus Medical Inc; Pleasanton, California). The SOT assesses the use of sensory information for balance by measuring postural sway under conditions in which visual and somatosensory feedback is altered. The SOT is organized into a series of six conditions of increasing difficulty. The first three conditions involve a stable support surface with eyes open (condition 1) or eyes closed (condition 2) and sway-referenced visual surround (condition 3), and the last three involve a sway-referenced surface with eyes open (condition 4) or eyes closed (condition 5) and sway-referenced visual surround (condition 6). SOT composite score was the variable of interest. It is a weighted average of the six conditions and has good validity and reliability [20].

Comfortable Gait Speed

Comfortable gait speed was determined by instructing participants to walk at their normal pace over a 9 m pathway. The time to walk the middle 6 m was measured using a stopwatch, and gait speed was calculated.

Vision Tests

Vision tests included acuity, contrast sensitivity, and depth perception. If participants reported that they wore bifocals for everyday use, the prescription for both the top and bottom portion of their everyday glasses was measured with a standard clinical lensometer. Then, trial lenses were selected to represent those two prescriptions. Participants were tested with both sets of trial lenses during depth perception testing. Only the distance lens was used for acuity and contrast sensitivity.

Acuity. Acuity was measured binocularly and for each individual eye at a distance of 3 m (a distance comparable to the distance from eye level to floor level two steps ahead; a distance of concern for obstacles in one's path) using standard Early Testing Diabetic Retinopathy Study (ETDRS) charts [21]. Scoring was letter-by-letter. The overhead lighting in the testing room was set at approximately 100 cd/m^2 for testing on the ETDRS charts.

Pelli-Robson Contrast Sensitivity. Contrast sensitivity was measured using the Pelli-Robson Contrast Sensitivity Chart [22] at 1 m with letter-by-letter scoring. The ambient lighting in the testing room was set at 100 cd/m^2. The Pelli-Robson chart uses letters composed of a complex mixture of horizontal, vertical, oblique, and curved square-wave targets formed by a range of spatial frequencies. The chart measures a broad band of frequencies around the peak of the contrast sensitivity function and is not sensitive to changes in low or high spatial frequencies.

Depth Perception. Depth perception was measured using the Howard Dolman depth perception apparatus [23]. The apparatus consists of a black box with a window through which two white rods are displayed. Subjects were seated 3 m from the front of the device and at eye level with the rods. One rod remains at a fixed distance from the subject, and the other rod can be moved back and forth on a track by pulling on two long cords. Subjects completed three trials in which they were instructed to line up the rods by pulling on the two cords. The error of displacement (the distance between the two rods in millimeters) was recorded by the experimenter for each trial and then averaged across the three trials. Between the trials, the experimenter obscured the view of the rods from the subject and displaced the rods quasi-randomly.

Motion Analysis

Three-dimensional marker (infrared light-emitting diodes) data were collected using a six-camera Vicon motion analysis system (Vicon Motion Systems; Lake Forest, California) (minimum detection at 1 mm). Kinematic data were collected at 120 Hz. The Woltring filter method was applied to data based on its similarities to the low-pass Butterworth method, but the Woltring also allows one to set cutoffs per the software, instead of the user, providing more flexibility [24]. Markers were placed on the subjects' shoes as close as possible to the first and fifth metatarsal heads, midpoint of the calcaneus, and the right and left navicular bones (**Figure 1(a)**). Because participants were not required to remove their shoes, shoe measurements were taken into account since they added length to participants' feet; therefore, shoe length was used instead of foot length in the custom software to calculate vertical toe and heel clearance.

Kinematic Data Processing and Analysis

Participants stood still for 30 s in a static trial. Participants were next asked to perform three trials in which they ascended three stairs (**Figure 1(c)**), crossed a 4 ft central plateau, and descended three stairs. However, only two trials per participant were considered for analyses given that three trials were not available for all participants. The second and third trials were chosen in order to account for practice effects of the first trial, which was not always robust to collection failures. The second and third trials were most consistent because all participants' stair navigation was successfully recorded in at least one of these trials, while other trials were subject to too many markers dropping out, calibration troubles, and/or equipment malfunctions. The dimensions of the staircase were recorded and are depicted in **Figure 1(b)**. Four markers placed on each stair and the plateau (left front, left rear, right front, and right rear; 28 total) provided spatial dimensions of the task environment. For analyses, the steps of participants were operationalized. Each step taken by participants was assigned a number: 1st through 4th steps. When navigating the stairs, depending on whether they were ascending or descending the stairs, participants would take their first step from the floor/plateau to the 1st stair, a second step from the 1st stair to the 2nd stair, a third step from the 2nd stair to the 3rd stair, and a fourth step from the 3rd stair to the plateau or floor.

Trial by trial data were visually inspected, and missing marker gaps were filled or missing points interpolated with Vicon Workstation software. We used a customized computer program (Stair Toe/Heel Clearance software) in Visual Basic (Microsoft; Redmond, Washington) to analyze processed Vicon motion analysis data and determine toe and heel clearance on stairs. Minimum and maximum toe and heel clearance calculations included all data points while the moving foot crossed the *z*- and *y*-axes of the apex of the step (**Figure 1(a)**). This study collected both limbs' toe and heel clearance while ascending and descending stairs given that the left and right legs both passed over the stair.

After Vicon data were collected, the coordinate positions were translated to a three-dimensional image. First, the space between the heel and toe was calculated and a vector was created along the *z*-axis of each stair. The right heel (RHEE), right toe (RTOE), and right little toe created a three-dimensional plane of the foot. The same procedure was applied to the left foot (left heel [LHEE], left toe [LTOE], and left little toe). Markers for the right and left arch were placed in their respective locations based off the positions of the other markers. The midpoints (toe-leading edge and heel-leading edge) were calculated from the existing markers. Midpoints were used as the farthest points forward and backward on the foot. These were the final points used in calculating clearances

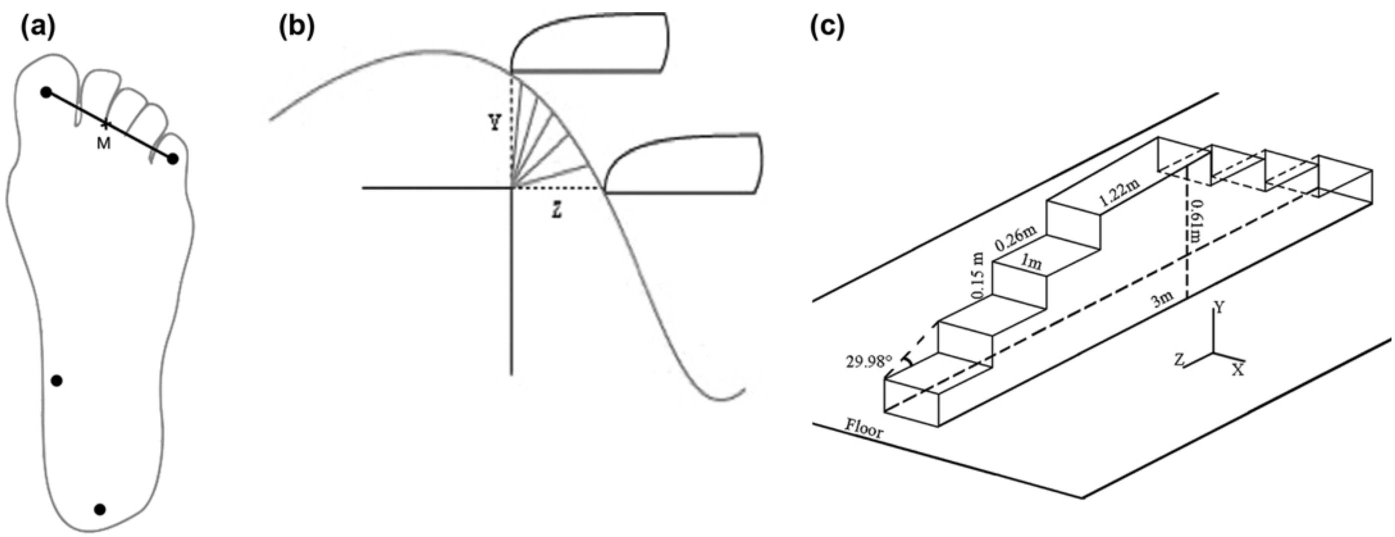

Figure 1.
(a) Markers of the right foot on the 1st and 5th metatarsal bones, the navicular bone, and the calcaneus. The midpoint (M) was calculated as the middle distance between the 1st and 5th metatarsals. **(b)** Clearances captured in between *y*- and *z*-axes about the apex of the step. **(c)** Stair setup. Axes used for calculation in "Stair Heel Toe Clearance" program are labeled along with dimensions of the stairs and location relative to the floor.

with the "Stair Toe/Heel Clearance" custom software. **Figure 1(a)** demonstrates the placement of the foot markers on the right shoe.

The foot was projected onto a plane created from the vector of the stair's edge. Normal biomechanics were assumed, allowing the inference that ascending stairs would leave the toe closer to the edge and descending would leave the heel closer [15,25]. Therefore, heel clearance was analyzed for descending trials, whereas toe clearance was analyzed for ascending trials. Next, the RTOE and LTOE minimum and RHEE and LHEE minimum clearance (millimeters) for each step were calculated by subtracting the *y*-coordinate of the stair edge from the *y*-coordinate of the limb closest to the edge. These values were calculated over the entire *x*-axis of the projected stair vector to the lowest point (minimum clearance) of the toe or heel during participants' ascending or descending the stairs. The variables of interest were defined as minimum heel/toe clearance—the least clearance of the limb when passing over the stair, maximum heel/toe clearance—the greatest clearance of the limb when passing over the stair, group variability—variability of minimum clearance of the stairs in both trials compared between groups (determined for both the ascending and descending directions), and trial variability—variability of the clearance of both legs passing over each step compared between trial 1 and trial 2 (determined for both the ascending and descending directions).

Statistical Analysis

For all vision, balance, and stair clearance data, between-group differences were analyzed using independent sample *t*-tests. The data were examined for equality of variance using *F*-test two sample for variances option (Microsoft Excel 2010). The effects of multifocal and monofocal IOL lenses on minimum heel or toe clearance, maximum heel or toe clearance, and variability between trials were examined with repeated-measures analysis of variance (RMANOVA). Separate RMANOVAs were used for ascending and descending conditions, with toe clearance analyzed for ascending trials and heel clearance analyzed for descending trials. The independent variables for the RMANOVAs were trial (1 or 2) and step taken (1st, 2nd, 3rd, or 4th) as within-subjects factors. The type of IOL (monofocal vs multifocal) was the between-subjects factor. Initial analyses with independent *t*-tests investigated the effects of foot (left or right) to check for differences between legs, including stability, favoritism of legs, and consistency of clearance. There were no significant differences between minimum clearance of left and right feet; therefore, the data for left and right feet were averaged for the respective variable, per step, for the RMANOVAs. Appropriate pairwise comparisons were performed if main effects of step, trial, or group were detected. Heel and toe clearance variability between groups for descending and ascending conditions, respectively, were determined by taking the SD of all the clearances for both limbs (8 instances). Alpha was set at 0.05.

RESULTS

There were no statistical differences between groups on demographics, vision, or mobility characteristics. Participants had more than one comorbidity, had corrected visual acuity, were slightly overweight based on their body mass index, and had good balance confidence. Participants were considered community ambulators based on their gait speed [26–27]. For visual tests, participants had decreased depth perception, but contrast sensitivity was within normal ranges (**Table 1**).

Significant Interactions and Effect of Group

There were no significant interactions to report. There was no main effect of the type of IOL on minimum and maximum foot clearance while participants ascended and descended stairs (**Table 2**).

Ascending Stairs

There was a main effect of the step taken on minimum toe clearance ($F(3,19) = 69.991$, $p < 0.001$, $\eta_p^2 = 0.971$), maximum toe clearance ($F(3,19) = 9.105$, $p = 0.001$, $\eta_p^2 = 0.590$), and left/right limb variability ($F(3,19) = 4.576$, $p = 0.014$, $\eta_p^2 = 0.42$) of toe clearance while participants ascended the stairs. The 1st step from the floor to the 1st stair had significantly greater minimum and maximum clearance values than the 2nd through 4th steps (**Figure 2(a)**).

Descending Stairs

There was a main effect of step taken on the minimum heel clearance ($F(3,63) = 5.817$, $p = 0.001$, $\eta_p^2 = 0.271$), maximum heel clearance ($F(3,63) = 41.917$, $p < 0.001$, $\eta_p^2 = 0.666$), and left/right limb variability ($F(3,63) = 22.176$, $p < 0.001$, $\eta_p^2 = 0.514$) while participants descended the stairs. The minimum and maximum values of heel clearance of the 4th step to the floor were significantly greater than that of the 1st through 3rd steps (**Figure 2(b)**).

Group and Trial Variability

There was no statistical difference between the monofocal or multifocal groups on variability of stair clearance. No statistical differences were observed between trials for monofocal or multifocal users (**Table 3**).

Table 1.
Participant characteristics. Data presented as mean (standard deviation) unless otherwise noted.

Characteristic	Monofocal (n = 15)	Multifocal (n = 8)	p-Value
Sex, n			
Male	15	4	—
Female	—	4	—
Age (yr)	69.9 (6.9)	66.5 (6.3)	0.27
No. Comorbidities	3.4 (2.1)	3.0 (1.2)	0.64
Activities-Specific Balance Confidence Scale (/100%)	85.1 (14.7)	88.5 (13.0)	0.59
Body Mass Index (kg/m^2)	29.4 (5.2)	26.1 (4.4)	0.14
Gait Speed (m/s)	0.9 (0.2)	1.0 (0.1)	0.21
Sensory Organization Test Composite Score	68.5 (7.7)	67.9 (6.8)	0.84
ETDRS (logMAR)	–0.1 (0.1)	0.0 (0.1)	0.27
Depth Perception Test Stereoacuity Threshold (arcsec)*	25.5 (15.4)	21.4 (12.8)	0.55
Pelli-Robson Test of Contrast Sensitivity (binocular)†	1.7 (0.1)	1.7 (0.1)	0.42

*Stereonormal is from –13 to 13 arcsec [42].
†Normal ranges for contrast sensitivity tests: 0.8 to 2.5 [43]
ETDRS = Early Testing Diabetic Retinopathy Study, logMAR = logarithm of the minimum angle of resolution.

Table 2.
Estimated marginal means and standard errors of the left and right foot minimum and maximum and group variability of both feet's clearance over steps 1 through 4 ascending and steps 1 through 4 descending.

Clearance	Monofocal (n = 15)	Multifocal (n = 8)	$F_{1,21}$	p-Value	η_p^2
Ascending (toe)					
Minimum (mm)	60.1 (3.7)	59.0 (5.0)	0.028	0.87	0.001
Maximum (mm)	98.8 (6.2)	104.9 (8.5)	0.337	0.57	0.160
Group Variability (mm)	44.0 (7.2)	40.8 (3.3)	0.007	0.69	—
Descending (heel)					
Minimum (mm)	36.3 (4.1)	42.4 (5.7)	0.048	0.83	0.002
Maximum (mm)	85.2 (7.9)	88.1 (10.9)	0.771	0.39	0.035
Group Variability (mm)	39.5 (3.2)	36.2 (4.8)	0.731	0.55	—

DISCUSSION

Monofocal versus Multifocal Lenses

This study provides initial evidence suggesting similar biomechanics of stair navigation between those with monofocal and multifocal IOLs. Both groups performed relatively similar in obstacle clearance with no substantial differences. Our findings are consistent with the findings of Calladine et al., in which monofocal and multifocal IOLs were similar at all distances, except where multifocal IOLs improved near sight [28]. If both IOLs perform similarly at moderate visual distances, then it can be theorized that clearances would be similar. However, ascending the first step onto a stair after leaving the floor had the greatest toe clearance, while in descent, the final descending step to the floor had the greatest heel clearance for the entire sample. This phenomenon may be a strategy that leads to safer clearance of stairs. That both groups exhibited these safe biomechanical characteristics, and given that biomechanical clearance of the steps is strongly related to trip risk, there may be no additional fall risk negotiating stairs for multifocal IOL users compared to monofocal IOL users. The literature also suggests that the varying foci of multifocal

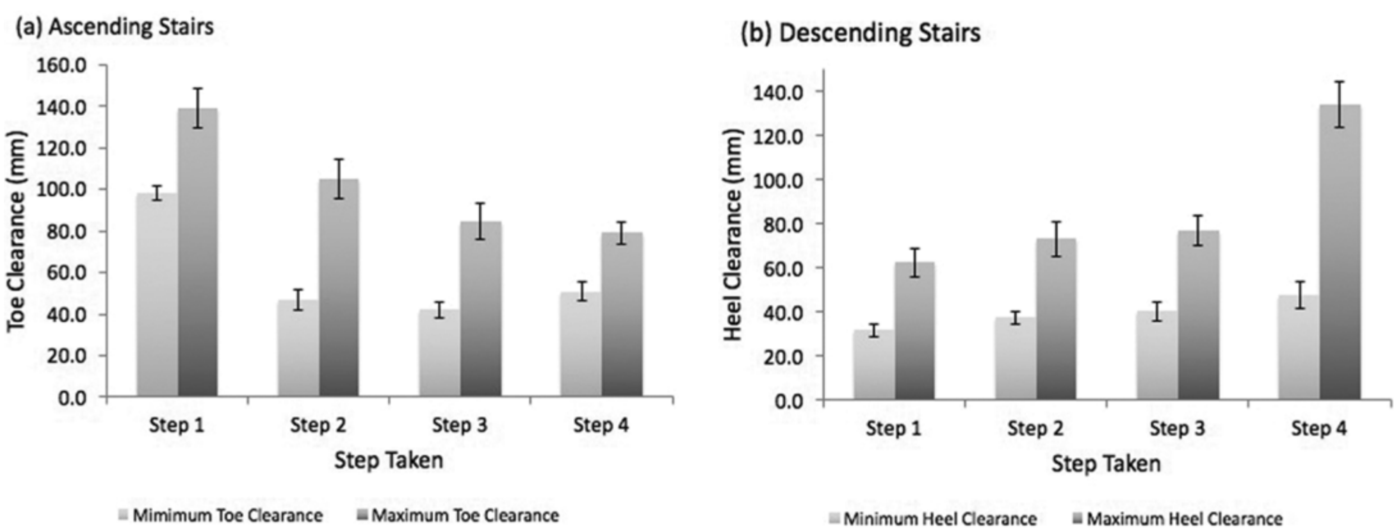

Figure 2.
(a) Minimum and maximum clearance values and standard error of toe clearance (estimated marginal means) while participants ascended stairs. light gray = minimum toe clearance, dark gray = maximum toe clearance. **(b)** Minimum and maximum values and standard error of heel clearance (estimated marginal means) while participants descended stairs. light gray = minimum heel clearance, dark gray = maximum heel clearance.

Table 3.
Estimated marginal means and standard errors for intertrial variability for the sample while ascending and descending stairs.

Trial	Average Variability (mm)	$F_{1,21}$	p-Value	η_p^2
Ascending (toe)				
Trial 1	30.5 (5.5)	0.035	0.85	0.002
Trial 2	29.4 (3.5)	0.035	0.85	0.002
Descending (heel)				
Trial 1	34.9 (3.4)	1.221	0.28	0.055
Trial 2	32.0 (3.6)	1.221	0.28	0.055

IOLs [10] do not have a negative effect on fall risk and thus varying foci should not be considered as a factor against multifocal implantation. Multifocal users do have higher satisfaction overall, and the variable distances achieved with multifocal IOLs are often more desirable for patients [2,29]. The desired attributes of multifocal IOLs may be a higher initial cost but could potentially minimize ophthalmic visits and corrective lenses coverage for insurers. These advantages seem to increase quality of life of users and should be considered by physicians when prescribing IOL implantation.

Direction

We demonstrated that there is smaller toe clearance than heel clearance when ascending, and lesser heel clearance than toe when descending. One reason for this is an unstable center of gravity. **Figure 2(b)** demonstrates that safe ambulation resulted in greater minimum heel clearance in the final step down to the ground, which was true of both monofocal and multifocal IOL users. Zietz et al. and Reeves et al. corroborate the finding that descending stairs requires further extension of the limb from the center of gravity than does ascension [30–31]. Extending the limb beyond the center of gravity likely causes increased instability, evidenced by the fact that more falls occur while stepping down than stepping up stairs in community-dwelling older adults [32]. In fact, falls during stair descent outnumber those during ascent three to one. Further, falls are more likely to occur on the last and second to last steps of descent [7,33].

Foot Clearance and Stair Navigation

Whether or not an obstacle is in an individual's field of vision can strongly affect foot clearance, which also may account for the differences between ascending and descending stairs, both in terms of biomechanical characteristics and fall risk. If a participant is able to have feed-forward cues or other visual data, by foveal and peripheral vision, to adjust their steps before performing an obstacle, there is a greater likelihood of clearance. It is important to consider that stair navigation consists of peripheral and foveal vision, though peripheral input seems to diminish with age [34–38]. One study showed younger and older participants focused on the third stair ahead of them during ascending, while young participants focused four stairs ahead and older participants focused two stairs ahead when descending [15]. This demonstrates that having this information before a step allowed the users to safely clear obstacles and avoid contact with the obstacle. Rietdyk and Rhea found that a reduction in visibly perceptible obstacles increased likelihood of contact, in particular of heel clearance with obstacles [39]. Here, the first step had the highest clearance, with a general decrease in clearance for subsequent steps and increased variability throughout ascension. The reverse was true for descending the steps [9]. This demonstrates that as individuals were ascending, they were able to use visual cues and comfortably clear steps, but as the steps plateaued, there was no feed-forward visual data and they demonstrated a decrease in step clearance. Descending, there was a lack of feed-forward visual cue until the ground was within the participant's field of vision, accounting for the small clearances on the first few steps and larger clearance from the last step to the floor. These results are corroborated by Zietz and Hollands, who noted stair descent requires more up-to-date visual cues [15].

Limitations

This study was limited by a small sample, particularly in the multifocal group, which reduced power to detect effects. Future studies should include in-depth study on the maximum toe clearance for IOL users that can be attained before loss of balance is experienced. Shinya et al. reported a highly variable range of foot clearance in nondisabled young adults: 30 to 110 mm maximum foot clearance [16]. Collection of normal minimum and maximum values of foot clearance could inform stair design, i.e., riser-height design for older adults. Current standards from the Occupational Safety and Health Administration are set to heights of 15.24 to 19.05 cm [40]. Research is imperative to ensure riser heights are appropriate for individuals of all ages to traverse them. Insight into which limb is responsible for the most tripping incident contacts may show which limb should be of concern and possibly targeted with intervention to prevent falls. Interestingly, Alcock et al. found that older healthy women favored their stronger limb as lead [41]. Consideration of the relative weighting of visual information versus other feedback, i.e., the use of working memory of stair locale, is also of interest. The successful employment of working memory during stair navigation likely causes decreased weighting of visual information. Working memory informs a repeated kinematic stepping pattern that is used for subsequent steps, based on the assumption that the stair height and depth will not change, as concluded by Zietz and Hollands [15]. However, an experiment using variable heights for ascending and descending, after the participants have established a fixed kinematic stepping pattern, may be useful for determining the comparative weighting of stored information from working memory versus visual feedback. While not ecologically valid with respect to the present experiment, such investigation would provide additional information on the biomechanics of stepping, specifically for older adults. Better understanding, engendered from a motor control approach, of the kinematics of stepping will inform future diagnosis and interventions for stepping-related fall risk.

CONCLUSIONS

The type of IOL in older individuals with normal mobility and balance confidence and no additional motor issues does not appear to alter biomechanics of stair navigation, a functional activity that is linked to fall risk. Future studies should use larger samples to investigate whether having the stair edge in the participant's visual field and use of a particular limb plays a role in foot clearance. This research has potential benefits for candidates for cataract surgery in the future. The increased range of vision and decreased dependence on corrective lenses has led to self-reported higher quality of life in multifocal IOL users [2]. Given the increased incidence of falls with age and the morbidity and mortality associated with falls, the results of this study may benefit a substantial number of older adults because it may provide support and rationale to adopt multifocal rather than monofocal IOLs.

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Critical review of manuscript for important intellectual content: E. Renz, M. E. Hackney, C. D. Hall.
Statistical analysis: E. Renz, M. E. Hackney.
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Institutional Review: All participants provided informed consent in accordance with the Atlanta VAMC Research and Development Committee and Emory University Institutional Review Board, and the study adhered to the tenets of the Declaration of Helsinki.
Participant Follow-Up: The authors do not plan to inform participants of the publication of this study.

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