Effect of multifocal lens glasses on the stepping patterns of novice wearers

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ABSTRACT
Multifocal lenses glasses (MfLs) negatively affect vision, increase falling risk and contribute to gait changes during stepping. Previous studies on the effects of MfLs on gait have focused on experienced wearers. Thus, the initial response of first-time wearers, who may face significant challenges in adapting to these glasses, is not well understood. This study aimed to quantify the effects of MfLs on novice wearers during stepping up and down. Additionally, young adults were compared against a middle-aged adults to determine the validity of convenience sampling in testing novice response to MfLs. Fifteen young adults (18–34 y.o.) and seven middle-aged adults (46–56 y.o.) were recruited to perform stepping trials while wearing progressive MfLs and blank single lens glasses. Participants stepped up and down from a 75 mm and 150 mm step in randomized order. Step placement, minimum toe clearance, lower body kinematics and stepping time were measured during step up. Step placement, minimum heel clearance, vertical forces and stepping time were measured during step down. MfLs significantly increased toe clearance in the lead and trailing legs, hip flexion, knee flexion and stepping time during step up and increased vertical forces and stepping time during step down. Step placement and hip angle explained 17% of the toe clearance variability. Changes during step up suggest a more conservative adaptation while increased forces during step down suggest a reduced level of control. No age group effects were observed, which supports the use of convenience sampling for evaluating the novice response to MfLs.

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1. Introduction
Falls are a major health problem with high societal costs. Falling is prevalent in occupational settings costing 13 billion dollars annually [1]. Multifocal lens glasses (MfLs) increase falling risk by 70–130% in elderly adults [2,3]. These studies only included elderly adults despite MfL’s prevalence among middle-aged adults who also have an increased fall risk. Presbyopia, which is typically treated with MfLs [4], affects >85% of middle aged adults [5] and adults aged 45–54 fall at 88% higher rate than adults aged 25–34 [6]. While the MfL diopter assists in near distance viewing, it causes significant vision impairments for distant vision in the lower visual field [7]. Unlined progressive lenses distort ground-level objects due to the shape of the lens as it transitions between the distance focal length to the shorter focal length diopter. Furthermore, MfLs reduce contrast sensitivity and distort depth perception in older [2,8] and middle-aged [7] populations, which are needed for precisely locating steps. This visual impairment may explain why MfL wearers experience more trips, falls outside of the home and falls around steps than non-MfL wearers [2]. Understanding the effects of MfL-induced distortions and impairments on gait patterns of middle-aged adults is critical to developing strategies that reduce falls in this group.

Visual feedback is critical to maintaining a safe and stable gait pattern. Visual information allows for detection of obstacles or steps and is used to alter foot placement and stepping strategies [9]. When ascending or descending stairs, visual gaze is typically fixated on step surfaces and edges located approximately 3–4 steps away [10]. MfLs affect foot movement patterns, step placement, stepping time and kinematics of stepping. Specifically, participants alter gait patterns when stepping up by increasing the distance [11,12] and variability [11] between their toe and the step edge, increasing toe clearance of the stepping foot [11,13] and reducing magnitude [11,13] while increasing variability [11] of the distance between their heel and the step edge after step up. Strong MfL dipters also cause an increase in tripping on steps [13]. Additionally, MfLs are thought to negatively affect landing control during step down by altering ground reaction forces, center of mass dynamics, lower body kinematics and step time [14,15].

Studies examining the effects of MfLs on gait have primarily focused on elderly and very experienced MfL wearers [11–14,16,17].

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A paucity of information is available about the gait adaptations during stepping when MFLs are first used. Increased fall incidences have been linked with new prescription [18], suggesting that fall risk may increase during the initial adaptation period.

The purpose of this study is to gain better insight of the effects of MFL glasses on stepping gait patterns for novice MFL-wearers. Specifically, this study:

1. Examined the initial changes to gait caused by MFLs in novice wearers by considering foot kinematics, spatiotemporal variables, lower-body kinematic variables and kinetic variables during step up and step down tasks.
2. Determined if young adult novice wearers can be used as a valid representation of middle-aged novice wearers for testing the initial effects of MFLs on stepping.

2. Methods

2.1. Participants and experimental protocol

Fifteen young adults between the ages of 18 and 28 years (5 male and 10 female; aged 24.3 ± 3.65 years, 1.68 ± 0.083 m tall, 66.4 ± 16.5 kg) and seven middle-aged adults between the ages of 46 and 56 years (3 male and 4 female; aged 51.9 ± 3.98 years, 1.63 ± 0.13 m tall, 71.4 ± 13.4 kg) were recruited to participate. Participants were only included if they had never used MFLs previously (i.e., were novice MFL wearers) and did not have any clinically significant musculoskeletal or neurological condition that would affect their walking. Because participants were required to wear different MFL and single lens (SL) glasses during the study, only participants who wore contact lens or no corrective lenses at all were included (i.e., subjects requiring glasses for corrected distance viewing were excluded). The University of Wisconsin-Milwaukee Institutional Review Board approved the study and participants consented prior to being enrolled.

Participants were fit with 29 markers and a safety harness. Relevant marker locations for the anatomical coordinate systems included bilateral anterior superior iliac spine, medial and lateral femoral epicondyles, medial and lateral malleoli, heel and the front of the toe as well as a sacral marker. Three additional markers were placed on each of the thigh and shank segments to create a measurement coordinate system that was tracked during the dynamic trials [19]. Data were collected using a motion capture system (10 Motion Analysis Raptor cameras, Santa Rosa, CA) and two force platforms (AMTI, Watertown, MA). Participants completed three trials of four different stepping conditions (75 mm step up, 150 mm step up, 75 mm step down and 150 mm step down) (Fig. 1) as well as six walking trials without any step for each eyewear type (4 stepping conditions × 3 trials per stepping condition + 6 walking trials = 18 trials per type of glasses). Participants wore SLs with no magnification and MFLs (18 trials per type of glasses × 2 eyewear types × 3 trials per participant). Progressive lens (i.e., no lined bifocals) MFLs transitioned from no power in the upper region to a dioptr add region of +2.75 in the lower quarter and central third (~15 mm wide). All eyewear was from Zenni Optical. Participants wore glasses high up on the nose and were not allowed time to adapt to new glasses before the start of data collection. The step contained a level platform (2 m × 2 m) and an adjacent ramp (2 m × 2 m). The riser of the step was unpainted wood while the landing of the step and the surrounding floor were blue vinyl tile illuminated at 460–480 lux (Fig. 1). The step edge was 2–3 cm after the force platform during step up and 2–3 cm before the force platform during step down. Participants took at least two strides before and after stepping up or down to avoid gait initiation or termination from affecting their step. Participants’ starting position was adjusted until participants cleanly hit the first force platform during level walking trials. After this point, the starting location was not adjusted during session. Participants were instructed to walk at a comfortable pace to the opposite side of the room. The five unique tasks were intended to force participants to use visual feedback for navigating the steps as opposed to proprioception similar to other studies examining the effects of MFLs on stepping [11]. In addition to randomizing the order of trials within a single glasses condition, the order in which eyewear were presented was also randomized. Walking trials were collected but not analyzed in this study.

2.2. Data processing and statistical analyses

Variables that were considered during step up included step placement before and after the step, toe clearance of the first stepping foot (“lead foot”) and the second stepping foot (“trailing foot”), stepping time and lower-body kinematics during stepping. Toe clearance was calculated as the minimum perpendicular distance between the front of the toe marker and a line connecting two markers placed on the step edge during step-up. The variables considered during step down included step placement before (“toe-to-step distance”) and after the step (“heel-to-step distance”), heel clearance during step down, stepping time and peak normal ground reaction forces. Step placement variables were analyzed to determine if participants altered foot placement in response to MFLs, while ankle, knee and hip angles were analyzed to determine if participants altered their stepping patterns. Stepping time was evaluated to determine if participants quickened or slowed their stepping process due to the MFLs. Toe clearance during step up and heel clearance during step down were evaluated as foot clearance has been suggested to be related with trip risk [20]. Peak normal force was calculated as a measure of stepping control. The timing of foot contact was identified using force platform data, when available, or heel marker data similar to [21]. Lower-body kinematics were calculated by developing a seven segment model including the feet, lower legs, thighs and pelvis. Joint angles were calculated in 3D according to the rotation order suggested in [22–24], where zero reference angles represent the state of the joint in standard anatomical position. Peak angles in ankle dorsiflexion, knee flexion and hip flexion were used to characterize the stepping gait adaptations. Peak normal force was normalized to body weight and only clean hits with one foot were included.

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The effects of MFLs and age group on the stepping patterns were tested using repeated measures ANOVA. All of the considered outcome variables were tested separately as dependent variables. Vertical force, the only variable requiring a transformation to achieve normality, was log transformed. Fixed-effects independent variables included lens type (MFLs or SLs), age group (middle-aged vs. young) and step height. Participant number was considered a random-effect independent variable. First-order interactions were also considered.

3. Results

MFLs were found to alter stepping patterns during step up and step down. During the step up trials, lens type, step size and the interaction between lens and step size were found to affect several stepping parameters, while age group, lens × age group and step size × age group were not found to affect any of the variables. Specifically, participants responded to MFLs by increasing toe clearances of the leading (p < 0.001) and trailing foot (p < 0.001) (Fig. 2). Participants also responded to the MFLs by increasing their peak hip (p < 0.01) and knee (p < 0.01) flexion angles. Hip angles (p < 0.001) and knee flexion (p < 0.001) angles were greater for the larger step than the small step. MFLs had a greater effect on hip and knee angles for the 75 mm step than the 150 mm step as indicated by a lens × step size interaction effect (p < 0.01 for both hip and knee) (Fig. 2). When wearing MFLs, participants slowed their stepping speed (p < 0.01). Finally, participants placed their foot more posteriorly before and after stepping on the larger step (i.e., larger toe-to-step distance, p < 0.05, and smaller heel-to-step distance, p < 0.01) than when approaching the smaller step. Post hoc analyses were performed to determine which foot placement and kinematic factors contributed most to leading foot toe clearance. Toe-to-step distance and hip flexion contributed most of the explainable variance in toe clearance (Table 1).

MFLs and step height were found to affect several step-down variables (Fig. 3). MFLs caused participants to step farther away from the edge of the step after stepping down (p < 0.05), increase the step time during step down (p < 0.01) and use greater vertical forces after step down (p < 0.05). The larger step height led to a

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**Fig. 2.** Effects of multifocal lens and step size on step up variables combined across age groups.

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larger heel clearance ($p < 0.01$), a reduction in the toe-to-step distance of the approach step ($p < 0.01$), an increased step time ($p < 0.001$) and larger vertical forces ($p < 0.001$). No group effects or interaction effects were observed.

4. Discussion

Multifocal lens glasses led to gait adaptations when stepping up and down in first-time wearers. MFLs altered joint kinematics, toe clearance and stepping time during step up. Larger toe clearances indicate that participants increased their margin of safety for a trip by elevating their foot higher above the step. An increase in hip flexion angle and the correlation between hip flexion angle and toe clearance suggests that lower-body joint kinematics were altered to achieve this safer stepping process. Stepping forces, foot placement after the step and stepping time were affected by MFLs during step down. While increased step time during step down indicates that participants implemented a more cautious strategy, increased peak vertical forces indicate that the landing was less controlled. No differences were observed between the 18–34 y.o. and the 46–56 y.o. age groups indicating that age is not a major factor in the response to MFLs in non-elderly adults.

The effects of MFLs on toe clearance during step up are consistent with previous studies of experienced MFL wearers. The strategy used by novice participants may be different than that of experienced wearers. Elliott and Chapman found that the changes in toe clearance were tightly coupled with a change in foot placement on the step (i.e., heel-to-step distance), which suggests that the toe clearance may have been a consequence of the foot crossing over the step during a different gait-cycle phase (i.e., stronger lenses led to a more posterior foot placement on the step causing the toe to cross over the step later in the stepping process) [13]. The current study, however, found that MFLs did not affect foot placement of novice wearers before or after a step up but instead cause an increase in hip flexion angles and increases the toe clearance. This finding indicates that in non-elderly adults, MFLs do not affect gait when approaching the step but rather affected the limb kinematics during the stepping up process. Increased foot elevation is consistent with results from Patla and Greig who determined that non-elderly adults elevate their feet higher during obstacle crossing when vision was occluded [25]. Interestingly, Patla and Greig also demonstrated that horizontal foot placement was more relevant to tripping than foot elevation [25]. Thus, novice wearers in the current study managed to increase elevation of their foot during step up without changing their horizontal foot placement. This finding may indicate that non-elderly adults may be at less risk of MFL-induced trips during step up than elderly adults.

Increases in peak vertical force indicate that participants had a less controlled landing phase during step down. MFL-induced changes to contrast sensitivity, visual acuity or minification/magnification [7,13,15,20] may have contributed to the poor landing control. Participants wearing MFLs increased their step down time and their post-step down foot placement but did not change their foot positioning when approaching the step. This finding indicates that participants may have had difficulty gauging the vertical height of the step but not the horizontal positioning.
Other studies have identified that impaired vision decreases or has no effect on forces during step down [14,26,27]. Some of these studies had participants stepping down from static standing [14,27], which allowed them to keep more weight on their stance foot during step down and use feedback control from other sensory systems during the stepping process (i.e., “feeling” for the floor for the floor surface) [14]. Concurrent feedback control may not be possible when the anterior momentum during gait carries a person over the step during dynamic stepping. Therefore, MfL-wearers may be able to gain more landing control by terminating gait prior to stepping down off of a curb and then using feedback control during step down.

MfLs minimally affected participants’ foot placement when approaching the step in either step up or step down condition. The lack of MfL effect on foot placement during the approach step is unexpected because vision is critical to fine-tuning the horizontal positioning of the foot when approaching an obstacle [25,26]. Elderly adults modify their foot placement when approaching a step while wearing MfLs [13] and young adults alter foot placement when the lower visual field is fully occluded [25,26]. These inconsistencies may indicate that (1) MfLs affect the approach to a step more in elderly than young adults; and (2) young participants are able to compensate for MfL-induced distortions but are unable to compensate for lower visual field occlusions.

Some of the changes in stepping patterns due to MfLs may be cautious adaptations that mitigate fall risk while other changes may indicate reduced control that increases fall risk. Increasing toe clearance values and step time may indicate caution to reduce the likelihood of tripping on the step. Blurring the entire visual field, which is likely to elicit a cautious response, was shown by Heasley et al. to cause the same increases in toe clearance and stepping time [28]. Other changes to the gait pattern, however, may be due to the negative effects of MfLs on balance and may lead to increased risk of falling. The increased step time, which is inversely related to cadence, increases the risk of a slip accident [29]. Also, increased vertical forces during step down may indicate a lack of control. Falls during step down due to a lack of control are likely to be more severe than trips during step up due to the additional potential energy that must be absorbed. Therefore, developing training strategies to teach first-time MfL wearers how to step down may be critical for adapting to their new glasses.

No age effect was found between the two age groups for the variables considered in this study. This finding is consistent with Zietz et al. who demonstrated that young adults had similar stepping patterns and similar responses to changes in ambient lighting as older adults [30]. Therefore, convenience sampling of various non-elderly adult age groups may be sufficient for future studies determining the effects of MfLs on novice wearers. This finding is important because of difficulty recruiting high numbers of adults in the typical MfL-wearing population who do not wear MfLs. Differences may still exist between non-elderly and elderly adults.

Significant gaps still remain in the understanding of the effects of MfLs on gait patterns and fall likelihoods. The cohort used in this study had not been prescribed MfLs and did not need that type of glasses. The effect of an individual’s need for MfLs on their sensitivity to these glasses is not well understood. The dioptric strength of the MfLs in this study (+2.75) is higher than what is typical for middle-aged adults (typical strength between 0.5 and 2 [31]). Weaker dioptric strengths should also be tested as they may cause more modest gait adaptations [13] to fully understand the range of this effect. Additionally, this study did not measure the effects of MfLs on blur, contrast sensitivity or other visual parameters, which limits its ability to directly correlate MfL-induced vision changes to the observed step changes. As mentioned earlier, though, the visual effects of MfL use for younger populations have been documented [7]. Furthermore, the adaptation period over the first few weeks, months and years of wearing MfLs has not received adequate attention. Determining the time period that it takes to adapt to MfLs and return to baseline walking (assuming that individuals do fully adapt) would be valuable in quantifying the risk period for first time MfL wearers.

Conflict of interest statement

There are no known conflicts of interest among the authors of this manuscript.

References


