The effects of age and central field loss on maintaining balance control when stepping up to a new level under time-pressure

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Objective. To investigate the effects of age and central field loss on the landing mechanics and balance control when stepping up to a new level under time-pressure.

Methods. Eight older individuals with age-related macular degeneration (AMD), eight visually normal older and eight visually normal younger individuals negotiated a floor-based obstacle followed by a 'step-up to a new level' task. The task was performed under 1) no-pressure; 2) time-pressure: an intermittent tone was played that increased in frequency and participants had to complete the task before the tone ceased. Landing mechanics and balance control for the step-up task was assessed with a floor-mounted force plate on the step.

Results. Increased ground reaction forces and loading rates were observed under time-pressure for young and older visually normal individuals but not for AMD participants. Across conditions, loading rates and ground reaction forces were higher in young normals compared to older normals and AMD participants. Young visual normals also demonstrated 35-39% shorter double support times prior to and during the step-up compared to older normals and AMD participants. All groups shortened their double support times (31-40%) and single support times (7-9%) in the time-pressure compared to no-pressure condition. Regarding balance control, the centre-of-pressure displacement and velocity in the anterior-poster direction were increased under time-pressure for young and older visual normals but not for AMD participants. The centre-of-pressure displacement and velocity in the medial-lateral direction were decreased for the AMD participants under time-pressure but not for young and older visual normals.

Conclusions. Despite walking faster, AMD participants did not adapt their landing mechanics under time-pressure (i.e., they remained more cautious), whilst older and young adults with normal vision demonstrated more forceful landing mechanics with the young being most forceful. A more controlled landing might be a safety strategy to maintain balance control during the step-up, especially in time-pressure conditions when balance control in the anterior-posterior direction is challenged more.

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Running title: Effects of age and vision loss on balance control during time-pressured adaptive gait

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1   **ABSTRACT**

2   **Objective.** To investigate the effects of age and central field loss on the landing mechanics and

3   balance control when stepping up to a new level under time-pressure.

4   **Methods.** Eight older individuals with age-related macular degeneration (AMD), eight visually

5   normal older and eight visually normal younger individuals negotiated a floor-based obstacle

6   followed by a 'step-up to a new level' task. The task was performed under 1) no-pressure; 2)

7   time-pressure: an intermittent tone was played that increased in frequency and participants had to

8   complete the task before the tone ceased. Landing mechanics and balance control for the step-up

9   task was assessed with a floor-mounted force plate on the step.

10   **Results.** Increased ground reaction forces and loading rates were observed under time-pressure

11   for young and older visually normal individuals but not for AMD participants. Across

12   conditions, loading rates and ground reaction forces were higher in young normals compared to

13   older normals and AMD participants. Young visual normals also demonstrated 35-39% shorter

14   double support times prior to and during the step-up compared to older normals and AMD

15   participants. All groups shortened their double support times (31-40%) and single support times

16   (7-9%) in the time-pressure compared to no-pressure condition. Regarding balance control, the

17   centre-of-pressure displacement and velocity in the anterior-poster direction were increased

18   under time-pressure for young and older visual normals but not for AMD participants. The

19   centre-of-pressure displacement and velocity in the medial-lateral direction were decreased for

20   the AMD participants under time-pressure but not for young and older visual normals.

21   **Conclusions.** Despite walking faster, AMD participants did not adapt their landing mechanics

22   under time-pressure (i.e., they remained more cautious), whilst older and young adults with

23   normal vision demonstrated more forceful landing mechanics with the young being most

24   forceful. A more controlled landing might be a safety strategy to maintain balance control during

25   the step-up, especially in time-pressure conditions when balance control in the anterior-posterior

26   direction is challenged more.

28   **Key words:** Visual Impairment, Age-related Macular Degeneration, Postural Control, Mobility,

29   Time Pressure, Human Locomotion

31   **INTRODUCTION**

32   Falls occur in 30-60% of older adults each year and the majority of the falls are environment-

33   related (Rubenstein, 2006). Stepping up or down to a new level is considered the most challenging

34   and hazardous activity of daily living, evidenced by reports that stair falls account for more than

35   10% of fatal fall accidents (Startzell et al., 2000). Although the causes of falls are multifactorial,

36   vision loss has been identified as an important individual risk factor (Rubenstein, 2006). Age-

37   related macular degeneration (AMD) is the leading cause of permanent vision loss in the United

38   Kingdom and is characterised by central field loss (Bunce, Wormald, 2006). Individuals with AMD

39   report difficulties in performing everyday tasks such as navigating steps and pavement curbs

40   (Taylor et al., 2016). They also perceive higher levels of anxiety during scenes that show stair

41   negotiation (Taylor et al., 2019) and are twice as likely to experience a fall compared to those with

42   normal vision (Szabo et al., 2010; Soubrane et al., 2007).

44   The negotiation of steps and stairs places a high demand on the somatosensory, visual, and

45   vestibular systems (Startzell et al., 2000) and the functioning of these systems deteriorates with

46   ageing (Goble et al., 2009; Li et al., 2015; Hsieh, Lin & Lee, 2014; Congdon et al., 2004; Baloh, Jacobson

47   & Socotch, 1993). The age-related deterioration of these systems is associated with impaired

48   balance control (McChesney, Woollacott, 2000; Aartolahti et al., 2013; Lord, 2006; Serrador et al.,

49   2009) and it is widely accepted that poor balance control increases the susceptibility to falling in

50   the elderly (Muir et al., 2013; Mignardot et al., 2014). Balance control is further deteriorated in older

51   adults with AMD, which resulted in a higher falls risk compared to older adults with normal

52   vision (Szabo et al., 2008). The mechanics of stair and step negotiation have been well described

53   for healthy older adults (Jacobs, 2016) but studies in older adults with AMD are scant.

54

55   To date, only two studies have investigated the movement mechanics in individuals with AMD

56   when stepping up or down to a new level (Alexander et al., 2014; Timmis et al., 2014). These studies

57   demonstrated that when stepping up to a new level, individuals with AMD adopted a slower (and

58   by implication more cautious) gait speed compared to those with normal vision. Whilst a slower

59   gait speed allows more time to acquire visual information for the control of adaptive locomotion

60   (Patla, Greig, 2006), it also results in a longer time spent in a dynamically unstable situation (i.e.,

61   single support phase) during step ascent. This longer single support phase might be detrimental

62   for individuals with AMD as their balance control is impaired compared to older adults with

63   normal vision (Wood et al., 2009). However, Wood and colleagues (Wood et al., 2009) measured

64   balance control during standing conditions instead of dynamic situations such as step ascent.

65

66   Two key concepts for balance control are the individual's centre-of-mass (CoM) and centre-of-

67   pressure (CoP) (Winter, 1995). The CoM is the point equivalent of the total body mass in the

68   global reference system and is a passive variable controlled by the balance control system

69 (Winter, 1995). The CoP is the point location of the vertical ground reaction force vector and

70 represents the sum of all forces acting between the human body and its supporting surface

71 (Winter, 1995). The trajectory of the CoP is commonly evaluated because it reflects the responses

72 of the central nervous system to movements of the CoM.

73

74 Research using simulated blur has revealed deficits in balance control when negotiating a step

75 (Buckley et al., 2005b). Healthy older adults with simulated blur demonstrated an increased root

76 mean square (change in position of the CoP) in the medial-lateral (ML, sideways) direction when

77 stepping up a curb and the root mean square was further increased when stepping down (Buckley

78 et al., 2005b). These findings indicate that ML balance during step ascent was challenged more

79 when vision was blurred. On the other hand, Heasley and colleagues (Heasley et al., 2004) found

80 that healthy older adults reduced their ML displacement of the CoP (i.e., increased dynamic

81 stability) when stepping up a curb with simulated blur, suggesting that these individuals were

82 able to increase dynamic stability (i.e., improving balance control), likely by adjusting their

83 movement mechanics during step negotiation. They increased their dynamic stability by keeping

84 the horizontal position of the CoM close to the centre of the base of support (Heasley et al., 2004).

85 It is possible that adjustments to both postural perturbations and sensory loss are age-dependent,

86 meaning that healthy young adults might react differently to simulated blur compared to healthy

87 older adults when stepping up a curb. This needs to be investigated in future studies. In addition,

88 simulated blur of the whole visual field is different from the loss of the central field and

89 consequent development of an eccentric locus for fixation that often occurs over time in

90 individuals suffering from AMD (Verghese, Vullings & Shanidze, 2021).

91

92   In all the aforementioned literature on simulated blur (Buckley et al., 2005b; Heasley et al., 2004)

93   and AMD (Alexander et al., 2014; Timmis et al., 2014), the negotiation of a step was not time-

94   constrained. However, routine stepping tasks, such as stepping up or down a sidewalk when

95   crossing the road, are often executed under time-pressure (e.g., a traffic signal that restricts the

96   time to cross). To date, it remains unclear how individuals with central field loss negotiate a step

97   in a time-pressure situation.

98

99   Step negotiation under time-pressure will limit the time available to view key features in the

100   environment (e.g., curb edge and 3-D dimensions of the curb). Additionally, processing of

101   posture during locomotion becomes more cognitively controlled with ageing and thus requires

102   more of the limited attentional resources (Ruffieux et al., 2015), especially when vision is impaired

103   (Krishnan, Cho & Mohamed, 2017; Turano, Geruschat & Stahl, 1998). Consequently, task-relevant

104   processes other than postural control, such as the awareness of hazards in the environment,

105   become less of a priority (Young et al., 2016; Uiga et al., 2015; Ellmers et al., 2016; Ellmers, Young,

106   2019). It is therefore not surprising that older adults with normal vision and those with AMD

107   adopt a more cautious movement strategy to safely negotiate stairs and steps (Telonio et al., 2014;

108   Novak et al., 2016; Christina, Cavanagh, 2002; Timmis et al., 2014; Alexander et al., 2014).

109

110   Increased walking speed in a time-pressure situation will also affect the mechanics of step and

111   stair negotiation. To illustrate, stair negotiation at an increased walking speed resulted in greater

112   peak joint moments (i.e., turning forces) and powers (i.e., turning forces multiplied by turning

113   velocity) at the ankle, knee, and hip of healthy young adults (Vallabhajosula, Yentes & Stergiou,

114   2012; Vallabhajosula et al., 2012). These data suggest that the lead foot landed on the step with

115   more force and support previous work in healthy young adults who increased the ground reaction

116   forces for the propulsion and stability during locomotion at higher speeds (Nilsson, Thorstensson,

117   1989). Currently, it is unclear how ageing and visual impairment impact step and stair negotiation

118   at increased walking speed.

119

120   Therefore, the present study examines the effects of aging and vision loss (i.e., AMD) on balance

121   control and movement kinematics when ascending a step under time-pressure. It is hypothesised

122   that in the no-pressure condition, older adults with AMD will negotiate the step more cautiously

123   (i.e., longer single and double support times, lower ground reaction forces, and slower rates of

124   force development) to maintain balance compared to healthy older adults and young adults.

125   Under time-pressure, a cautious strategy of lengthening the single and double support times can

126   no longer be applied and increased ground reaction forces and rates of force development are

127   necessary to maintain balance. However, older adults will show less of an increase (i.e., remain

128   more cautious) to an extent that balance is still well controlled, and this effect will be

129   exaggerated when central vision is impaired due to AMD.

130

131   **MATERIALS & METHODS**

132   **Participants**

133   A total of 24 participants were recruited to take part in this study. Eight were diagnosed with

134   AMD by an ophthalmologist, eight were healthy older adults with normal or corrected-to-normal

135   vision, and eight were healthy young adults with normal or corrected-to-normal vision. Inclusion

136   criteria were: ability to walk without a walking aid, aged $\geq$ 60 years for AMD participants and

137   healthy older adults, aged 18-35 years for healthy young adults, visual impairment (AMD

138   participants only) as defined by the World Health Organization International Classification of

139   Diseases (i.e., visual acuity > 0.301 logMAR) (World Health Organization, 2018). Exclusion criteria

140   were: any neuromuscular and skeletal problems that could interfere with balance or gait, usage of

141   medication that causes dizziness, and worse than normal vision for healthy older and young

142   adults (i.e., visual acuity > 0.301 logMAR) (World Health Organization, 2018). The health of the

143   participants was assessed through a self-report questionnaire and subjective physical activity

144   levels were assessed in a face-to-face interview using the Global Physical Activity Questionnaire

145   (World Health Organization, 2012). The experimental procedures were in accordance with the

146   Declaration of Helsinki and written informed consent was obtained from all participants prior to

147   the start of the study. Study approval was provided by the Research Ethics Committee of the

148   Anglia Ruskin University (approval number: FMSFREP 16/17 008).

149

150   **Visual examination**

151   The visual examination included three tests that were executed in the same order for all

152   participants while wearing best-corrected spectacles. First, binocular visual acuity was measured

153   using the Bailey-Lovie logMAR chart at a working distance of 4 m using a letter-by-letter

154   scoring system (0.02 logMAR) (Bailey, Lovie, 1976). For AMD participants, this was their

155   measured visual acuity whether they used eccentric fixation or not. Shorter distances were used

156   when a subject was not able to read the largest size letters at 4 m distance and scores were

157   adjusted accordingly. Second, binocular contrast sensitivity was assessed using the Pelli-Robson

158   chart at 1 m distance, and scored per group of three letters (0.15 log units) of which two had to

159   be correct (Pelli, Robson, 1988). Third, the monocular visual field was examined with a Humphrey

160   Field Analyzer SITA-Standard 30-2 threshold test (Carl Zeiss Meditec Inc., Dublin, CA). The

161   "best location" model was used to calculate the binocular visual field from the monocular visual

162   field scores (Nelson-Quigg, Cello & Johnson, 2000).

163

164   **Experimental setup**

165   The walkway was 7 m long, 1.2 m wide, and positioned in the middle of a research laboratory.

166   The view of the travel path was blocked at the start of each trial by a cardboard wall. Participants

167   were instructed to place their right hand on a pressure pad before the start of each trial. Each trial

168   commenced after the sound of a single 'beep'. Then, participants released their hand from the

169   pressure pad, turned round the corner of the cardboard wall, and started walking along the travel

170   path. The travel path consisted of a 10.0 cm high, 62.0 cm wide, and 1.8 cm deep obstacle

171   followed by a floor-mounted force plate (4.5 cm high, 50.2 cm wide, and 50.2 cm deep)

172   reflecting a pavement curb to step-up onto at a pedestrian crossing point. A step-up height of 4.5

173   cm was chosen because curb heights lower than 6.0 cm are particularly difficult for blind and

174   partially sighted to detect the edge of the curb (Thomas, 2011). Participants had to step over the

175   obstacle followed by the step-up onto the floor-mounted force plate. The obstacle was included

176   to ensure that participants did not simply target the single step at the end of the walkway, rather,

177   had to initially attend to the obstacle. The trial was completed after the right hand was placed on

178   the pressure pad at the end of the walkway after stepping up onto the step. Another cardboard

179   wall at the end of the walkway prevented the participants from seeing the data collectors. The

180   pressure pads were used to record the duration of each trial. The obstacle was randomly

181   positioned between 4.05 and 5.30 m from the start position and the force plate was always

182   positioned at 7.00 m from the start position. Therefore, participants had to adjust their gait

183   between trials which prevented the learning of a repeated motor pattern. The height of the

184 obstacle and force plate reflected typical heights encountered in everyday life (Timmis, Pardhan,

185 2012). The colour of the obstacle and force plate contrasted with the black background of the

186 laboratory carpet.

187

188 All participants performed the task with their best-corrected vision. Participants started the

189 experiment with nine baseline walking trials in which no obstacle was present (i.e., to get

190 familiar with the task and walking surface). They had to walk up to the force plate at their

191 comfortable walking speed and step onto the force plate before placing the hand on the pressure

192 pad at the end of the walkway (i.e., to prevent the participants from having extra support during

193 the step-up phase). These trials were followed by trials where they had to negotiate a floor-based

194 obstacle before stepping onto the force plate under a time-pressure and no-pressure condition.

195 Time-pressure was induced by a custom-made timing device that produced an intermittent tone

196 that increased in frequency as a function of the total trial duration. The intermittent tone started

197 when the hand was released from the pressure pad at the start and stopped when the hand was

198 placed on the pressure pad at the end of the walkway. Participants were instructed to finish the

199 task before the tone extinguished which meant that they had to walk 20% faster than their

200 comfortable walking speed throughout the entire trial. A 20% faster walking speed was deemed

201 feasible for both young and older participants (Sheik-Nainar, Kaber, 2007). The participants heard

202 the intermittent tone once before starting the time-pressure trials so they were familiar with the

203 duration of each trial. Participants' comfortable walking speed was calculated as the average

204 walking speed over the last three baseline walking trials. In the no-pressure condition, the tone

205 was absent and participants were told to perform the task at their comfortable walking speed.

206 Four trials were performed per condition of which three trials included the obstacle and one trial

207 was without the obstacle. Before the start of each trial, participants did not know whether the

208 obstacle would be present or not. The condition was known to the participants and practice trials

209 were not permitted. Participants randomly started with the no-pressure or time-pressure

210 condition.

211

212 **Data collection**

213 Prior to data collection, 14 reflective markers were attached to the following body locations

214 either to the shoes or directly to the skin: hallux, fifth metatarsal head, medial and lateral side of

215 the posterior part of the calcaneus, nail of the thumb, nail of the index finger, and the ulnar

216 styloid process. In addition, four markers were placed on the edges of the pressure pad at the end

217 of the walkway to determine when the hand touched the pad (denoting the end of a trial), and

218 two markers each were placed on the upper front edge of the obstacle and force plate to

219 determine the height and location of both hazards within the laboratory coordinate system.

220

221 An eight-camera 3-D motion capture system (Vicon, Oxford Metrics Ltd, Oxford, UK) was used

222 to record the marker trajectories at 100 Hz during the performance of the adaptive gait task. The

223 analysis of the marker data was performed in Visual 3D (C-Motion Inc., Rockville, MD., USA).

224 The data were filtered with a fourth-order low-pass Butterworth filter at 7 Hz before timestamps

225 were calculated of adaptive gait events.

226

227 A single force plate (AccuGait, Advanced Mechanical Technology, Inc., Watertown, MA, USA)

228 was used to collect the ground reaction forces and CoP data at 100 Hz. Data were recorded with

229 the NetForce Acquisition Software (version 2.4.0; Advanced Mechanical Technology, Inc.,

230 Watertown, MA, USA). Further analysis of the data was performed with a custom Matlab script

231 (version 2016a; The Mathworks, Natick, MA, USA) in which the data were filtered with a

232 fourth-order low-pass Butterworth filter at 8 Hz before the ground reaction forces and CoP data

233 were calculated.

234

235 **Data analysis**

236 The total performance time was measured from the instant that the right hand was released from

237 the pressure pad at the start of the trial until the right hand was placed on the pressure pad at the

238 end of the walkway, denoting the end of the trial.

239

240 Additional temporal variables were obtained from analysis of the 3-D marker data in Visual3D

241 (C-motion Inc., Rockville, MD., USA). The following temporal variables were calculated, which

242 have previously been determined as important for stepping up to a new level (Timmis et al., 2014):

243 1. Double support phase before step-up in seconds: time from final foot placement (i.e.,

244   instant of heel strike) to lead foot toe-off before stepping onto the force plate.

245 2. Single support phase during step-up lead foot in seconds: swing time of the lead limb

246   during the step-up whereby only the trail foot is in contact with the ground.

247 3. Double support phase during step-up in seconds: time from lead foot contact on the force

248   plate to trail foot toe-off before stepping onto the force plate.

249 4. Single support phase during step-up trail foot in seconds: swing time of the trail limb

250   during the step-up whereby only the lead foot is in contact with the force plate.

251 Toe-off was defined as the instant where the resultant velocity of the foot's toe marker first

252 increased more than 0.9 m/s for ten consecutive frames (Zult et al., 2019). Participants' initial

253   contact with the force plate was either with the heel or forefoot. Heel strike was defined as the

254   instant when the resultant velocity of the foot's medial heel marker first decreased less than 0.6

255   m/s for ten consecutive frames (Zult et al., 2019). Toe strike was defined as the instant when the

256   resultant velocity of the foot's toe marker first decreased less than 0.2 m/s for ten consecutive

257   frames.

258

259   Note that Supplemental Data Analysis S1 includes the analysis of kinematic variables related to

260   obstacle negotiation. The results of this analysis will be published alongside this article because

261   the current article focuses on the 'step-up to a new level' task. The included kinematic variables

262   for obstacle negotiation are similar to a previous article that investigated the effects of time-

263   pressure in participants with (simulated) vision loss (Zult et al., 2019).

264

265   Figure 1 depicts a schematic representation of the step-up action and the measured ground

266   reaction forces. Peak ground reaction forces were calculated in the vertical ('z'), anterior-

267   posterior ('y'), and medial-lateral ('x') direction during the landing of the lead foot on the force

268   plate and expressed as a percentage of body mass. The loading rate (i.e., rate of force

269   development) was also calculated in each direction from the instant that the lead foot contacted

270   the force plate (i.e., a vertical ground reaction force above 20 N) (Buckley et al., 2005b) to the

271   time-point that the force reached its peak. The loading rate is expressed in N/s.

272

273   *[Figure 1]*

274   Figure 1. Schematic representation of the step-up action (A) and a representative trace of the

275   ground reaction force from a single participant in the vertical direction (B), anterior-posterior

276   direction (C), and medial-lateral direction (D) when landing onto the floor-mounted force plate.

277   Of note, the left foot was the lead foot in this example. AP, anterior-posterior; ML, medial-

278   lateral.

279

280   The X and Y coordinates of the CoP were calculated using the formulas provided by the

281   manufacturer of the force plate (Advanced Mechanical Technology, Inc.):

282
$$x = \frac{-(M_y + F_x \times d_z)}{F_z} \qquad y = \frac{-(M_z + F_y \times d_z)}{F_z}$$

283   M_y and M_z are the moments in the anterior-posterior and vertical direction respectively. F_x, F_y,

284   and F_z are the forces in the medial-lateral, anterior-posterior, and vertical direction respectively.

285   d_z is the thickness of the force plate which was 41.3 mm.

286

287   Figure 2 shows the CoP data that were used to analyse the main postural control parameters. The

288   formulas for calculating those parameters were adopted from previous literature

289   (Khanmohammadi et al., 2017). The following postural control parameters were calculated for the

290   single support phase during the step-up action of the trail foot (kinematic variable 4):

291   1. Total displacement of the CoP in the anterior-posterior and medial-lateral direction

292   expressed in cm.

293   2. Average velocity of the CoP displacements in the anterior-posterior and medial-lateral

294   direction expressed in cm/s.

295

296   *[Figure 2]*

297   Figure 2. A representative trace of the centre-of-pressure displacement (A) and velocity (B) from

298   a single participant when stepping onto the floor-mounted force plate. Of note, the left foot was

299   the lead foot in this example. Postural control parameters were calculated from the centre-of-

300   pressure data (see text for details).

301

302   Even though the instructions were to complete the step-up action before placing the hand on the

303   pressure pad (i.e., denoting the end of the trial), some participants placed the hand on the

304   pressure pad before the step-up action was completed in 21% of the trials (29 out of 141 trials).

305   To ensure that placement of the hand on the pressure pad did not bias stability data (i.e.,

306   improving postural control), these trials were removed and instead, we only analysed the first

307   correctly performed trial in each condition.

308

309   In the time-pressure condition, seven participants ran out of time, meaning that they performed

310   the trial slower than the pre-defined target time. These included three AMD participants (six

311   trials), two older visual normals (three trials), and two young visual normals (three trials). These

312   12 trials were not repeated because each participant had at least one successful time-pressure

313   trial. The 12 non-successful time-pressure trials were not included in the final analysis.

314

315   **Statistical analysis**

316   Data in text and figures are expressed as mean ± SD. The statistical analysis was performed

317   using SPSS version 24. The Kolmogorov-Smirnov test was used to check normality and each

318   variable was normally distributed. Between group differences in group characteristics were

319   determined with a one-way analysis of variance (ANOVA) for the continuous variables and a

320   Chi-square test for the dichotomous variable sex. A group (AMD, older normals, young normals)

321   by condition (no-pressure, time-pressure) mixed ANOVA was performed to test for differences

322   in total performance time, peak ground reaction forces, loading rates, temporal kinematic

323   variables, and postural control parameters. Significant *F* values from the ANOVAs were

324   subjected to an LSD post hoc pairwise comparison to determine the means that were different.

325   The level of significance (α) was set at $p < 0.05$. Effect sizes were calculated using Cohen's *d*.

326

327   A priory power analysis with G*Power 3.1 was performed to calculate the sample size that was

328   required to obtain a significant group by condition effect on the ANOVA for each variable of

329   interest. The effects of ageing and visual impairment on step negotiation are evident when there

330   are no time constrains but these effects are unknown for time-constrained situations. Therefore, a

331   medium effect size of 0.50 was used for the power analysis to prevent underestimation of the

332   sample size. The calculated sample size was 21 (i.e., 7 subjects per group) based on an effect size

333   of 0.50 with a power of 95% at the $p < 0.05$ significance level.

334

335   **RESULTS**

336   **Group characteristics**

337   Table 1 shows the group characteristics. Expected significant differences were found for age ($F_{2,}$

338   $_{21} = 147.9$, $p < 0.001$). Post hoc testing revealed that young visual normals were significantly

339   younger than older visual normals and AMD participants (both $p < 0.001$, $d \geq 6.73$). There was

340   no significant difference in age between older visual normals and AMD participants ($p = 0.059$)

341

342   A significant main effect of group was also observed for visual acuity ($F_{2, 21} = 133.9$, $p < 0.001$),

343   contrast sensitivity ($F_{2, 21} = 152.3$, $p < 0.001$), and visual fields ($F_{2, 21} = 23.7$, $p < 0.001$). Post hoc

344   testing showed that visual acuity and contrast sensitivity were better in young visual normals

345   than older visual normals and AMD participants (all $p \leq 0.004$, $d \geq 1.81$), and were better in

346   older visual normals than AMD participants (both $p < 0.001$, $d \geq 5.43$). Visual fields were

347   significantly better in young and older visual normals compared to AMD participants (both $p <$

348   0.001, $d \geq 2.55$). Visual fields were not significantly different between young and older visual

349   normals ($p = 0.513$). Of note, none of the participants contacted the obstacle or curb edge during

350   the performance of the mobility course.

351

352   Sedentary behaviour and moderate-to-vigorous physical activity were assessed with the Global

353   Physical Activity Questionnaire. A main effect of group was observed for sedentary behaviour

354   ($F_{2, 21} = 8.4$, $p < 0.002$) but not for moderate-to-vigorous physical activity ($F_{2, 21} = 0.7$, $p <$

355   0.503). Post hoc analysis showed that young visual normals spent more time per week being

356   sedentary than older visual normals and AMD participants (both $p = 0.002$, $d \geq 1.41$).

357

358   *[Table 1]*

359

360   **Total performance time**

361   The total performance time showed a significant main effect of group ($F_{2, 21} = 7.4$, $p = 0.004$) and

362   condition ($F_{1, 21} = 91.1$, $p < 0.001$) (Table 2). Post hoc testing for the group effect showed that

363   young visual normals had a 32% shorter total performance time than the AMD participants ($p =$

364   0.001, $d = 1.32$). No other significant differences were observed between groups ($p \geq 0.054$). The

365   condition effect revealed that the total performance times was 24% shorter in the time-pressure

366   than no-pressure condition ($p < 0.001$, $d = 1.07$). No significant group by condition interaction

367   was observed ($F_{2, 21} = 0.5$, $p = 0.616$).

368

369 **Normalised peak ground reaction forces**

370 A main effect of group was found for the vertical component of the peak ground reaction force

371 ($F_{2, 21}$ = 7.6, p = 0.003, Table 2). Post hoc testing revealed that the peak vertical ground reaction

372 force in young visual normals was 7-10% higher than older visual normals and AMD

373 participants (both p ≤ 0.013, d ≥ 0.79). No significant condition effect ($F_{1, 21}$ = 3.3, p = 0.083) or

374 group by condition interaction ($F_{2, 21}$ = 1.8, p = 0.184) was observed.

375

376 The anterior-posterior component of the peak ground reaction force showed a group ($F_{2, 21}$ =

377 11.4, p < 0.001), condition ($F_{1, 21}$ = 12.1, p = 0.002), and interaction effect ($F_{2, 21}$ = 5.2, p =

378 0.015) (Table 2). Post hoc testing for the interaction effect showed that in the time-pressure

379 condition only, young visual normals had a 35-96% higher peak force than older visual normals

380 and AMD participants (both p ≤ 0.003, d ≥ 1.41) and older visual normals demonstrated a 46%

381 higher peak force than AMD participants (p = 0.006, d = 1.50). On comparing between

382 conditions for each group, young and older visual normals showed a 31-39% higher force in the

383 time-pressure vs. no-pressure condition (both p ≤ 0.020, d ≥ 0.85), while AMD participants did

384 not significantly change their peak ground reaction force (p = 0.637).

385

386 No significant group ($F_{2, 21}$ = 1.2, p = 0.336), condition ($F_{1, 21}$ = 2.1, p = 0.161), or interaction

387 effect ($F_{2, 21}$ = 1.2, p = 0.327) was found for the medial-lateral component of the peak ground

388 reaction force (Table 2).

389

390 **Rate of force development**

391   The rate of force development in the vertical direction showed a group ($F_{2,21}$ = 8.2, p = 0.002),

392   condition ($F_{1,21}$ = 18.6, p < 0.001), and interaction effect ($F_{2,21}$ = 3.8, p = 0.038) (Figure 3A,

393   Table 2). Post hoc testing for the interaction effect showed that young visual normals had a 41-

394   43% higher rate of force development than older visual normals and AMD participants in the no-

395   pressure condition (both p ≤ 0.007, d ≥ 1.32), and young and older visual normals had a 64-

396   103% higher rate of force development compared to AMD participants in the time-pressure

397   condition (both p ≤ 0.034, d ≥ 1.26). On comparing between conditions for each group, young

398   and older visual normals showed a 50-73% higher rate of force development in the time-pressure

399   vs. no-pressure condition (both p ≤ 0.002, d ≥ 1.23), while AMD participants did not

400   significantly change their rate of force development (p = 0.822).

401

402   The rate of force development in the anterior-posterior direction showed a group ($F_{2,21}$ = 4.4, p =

403   0.025), condition ($F_{1,21}$ = 10.9, p = 0.003), and interaction effect ($F_{2,21}$ = 4.9, p = 0.017) (Figure

404   3B, Table 2). Post hoc testing for the interaction effect revealed that in the time-pressure

405   condition only, young visual normals had a 189% higher rate of force development than AMD

406   participants (p = 0.003, d = 1.51), while no between group differences were found for older

407   visual normals (both p ≥ 0.087). On comparing between conditions for each group, young and

408   older visual normals demonstrated a 101-104% higher rate of force development in the time-

409   pressure vs. no-pressure condition (both p ≤ 0.020, d ≥ 1.09), while AMD participants did not

410   significantly change their rate of force development (p = 0.585).

411

412   The rate of force development in the medial-lateral direction showed a group ($F_{2,21}$ = 3.8, p =

413   0.040), condition ($F_{1,21}$ = 7.9, p = 0.011), and interaction effect ($F_{2,21}$ = 4.7, p = 0.020) (Figure

414   3C, Table 2). Post hoc testing for the interaction effect revealed that in the time-pressure

415   condition only, young visual normals had a 56-129% higher rate of force development than older

416   visual normals and AMD participants (both $p \leq 0.036$, $d \geq 0.90$), while the rate of force

417   development was not significantly different between older visual normals and AMD participants

418   ($p = 0.215$). On comparing between conditions for each group, young visual normals

419   demonstrated a 74% higher rate of force development in the time-pressure vs. no-pressure

420   condition ($p = 0.001$, $d = 1.11$), while older visual normals and AMD participants did not

421   significantly change their rate of force development (both $p \geq 0.147$).

422

423   *[Figure 3]*

424   Figure 3. Rate of force development in the vertical direction (A), anterior-posterior direction (B),

425   and medial-lateral direction (C) in the two different conditions when stepping up to the force

426   platform with the lead foot. ‡, between group difference ($p < 0.05$); *, group by condition

427   interaction between the time-pressure and no-pressure condition ($p < 0.05$).

428

429   **Temporal variables**

430   *Duration of the double support phase*

431   The double support phase prior to the step-up showed a significant main effect of group ($F_{2, 21} =$

432   6.5, $p = 0.006$) and condition ($F_{1, 21} = 111.9$, $p < 0.001$) (Table 2). Post hoc testing for the group

433   effect showed that young visual normals had a 37-38% shorter double support phase than the

434   older visual normals and AMD participants (both $p \leq 0.007$, $d \geq 1.26$). The double support phase

435   was not significantly different between older visual normals and AMD participants ($p = 0.818$).

436   The condition effect revealed that the double support phase was 40% shorter in the time-pressure

437 than no-pressure condition (p < 0.001, d = 1.40). No significant group by condition interaction

438 was observed (F$_{2, 21}$ = 1.0, p = 0.394).

439

440 The double support phase during the step-up showed a significant main effect of group (F$_{2, 21}$ =

441 4.7, p = 0.021) and condition (F$_{1, 21}$ = 86.8, p < 0.001) (Table 2). Post hoc testing for the group

442 effect showed that young visual normals had a 35-39% shorter double support phase than the

443 older visual normals and AMD participants (both p ≤ 0.025, d ≥ 1.12). The double support phase

444 was not significantly different between older visual normals and AMD participants (p = 0.666).

445 The condition effect revealed that the double support phase was 31% shorter in the time-pressure

446 than no-pressure condition (p < 0.001, d = 0.94). No significant group by condition interaction

447 was observed (F$_{2, 21}$ = 2.8, p = 0.084).

448

449 *Duration of the single support phase*

450 The single support phase, during the step-up of the lead foot, showed a significant main effect of

451 condition (F$_{1, 21}$ = 6.0, p = 0.024, Table 2). Post hoc testing for the condition effect revealed that

452 the single support phase was 9% shorter in the time-pressure than no-pressure condition (p =

453 0.024, d = 0.57). No significant group (F$_{2, 21}$ = 0.4, p = 0.707) or interaction effect (F$_{2, 21}$ = 1.5, p

454 = 0.255) was observed.

455

456 The single support phase, during the step-up of the trail foot, showed a significant main effect of

457 condition (F$_{1, 21}$ = 5.4, p = 0.031, Table 2). Post hoc testing for the condition effect showed that

458 the single support phase was 7% shorter in the time-pressure than no-pressure condition (p =

459   0.031, d = 0.57). No significant group ($F_{2, 21}$ = 1.5, p = 0.256) or interaction effect ($F_{2, 21}$ = 0.2, p

460   = 0.826) was observed.

461

462   **Balance control single support phase**

463   *Centre-of-pressure displacement*

464   The CoP displacement in the anterior-poster direction showed a condition ($F_{1, 21}$ = 8.9, p = 0.007)

465   and interaction effect ($F_{2, 21}$ = 4.1, p = 0.032) (Figure 4A, Table 2). Post hoc testing for the

466   interaction effect showed that in the time-pressure condition only, young visual normals had

467   115% more CoP displacement compared to AMD participants (p = 0.04, d = 1.81). No other

468   between group differences were observed (all p ≥ 0.111). On comparing between conditions for

469   each group, young and older visual normals showed 89-128% more CoP displacement in the

470   time-pressure vs. no-pressure condition (both p ≤ 0.045, d ≥ 0.98), while AMD participants did

471   not significantly change their CoP displacement (p = 0.647). No significant main effect of group

472   was observed ($F_{2, 21}$ = 2.0, p = 0.158).

473

474   The CoP displacement in the medial-lateral showed a group ($F_{2, 21}$ = 4.6, p = 0.023) and

475   interaction effect ($F_{2, 21}$ = 4.7, p = 0.025) (Figure 4B, Table 2). Post hoc testing for the interaction

476   effect showed that in the no-pressure condition only, young and older visual normals had 56-

477   68% less CoP displacement than AMD participants (both p ≤ 0.005, d ≥ 1.27). No other between

478   group differences were observed (all p ≥ 0.511). On comparing between conditions for each

479   group, AMD participants decreased their CoP displacement 46% in the time-pressure vs. no-

480   pressure condition (p = 0.009, d = 0.95), while young and older visual normals did not

481   significantly change their CoP displacement (both p ≥ 0.276). No significant main effect of

482   condition was observed ($F_{1, 21}$ = 0.9, p = 0.367).

483

484   *Centre-of-pressure velocity*

485   The average CoP velocity in the anterior-posterior direction showed a condition ($F_{1, 21}$ = 17.5, p

486   < 0.001) and interaction effect ($F_{2, 21}$ = 5.3, p = 0.014) (Figure 4C, Table 2). Post hoc testing for

487   the interaction effect showed that young visual normals had a 105% higher CoP velocity than

488   AMD participants in the time-pressure condition (p = 0.003, d = 1.80). No other between group

489   differences were observed (all p ≥ 0.051). On comparing between conditions for each group,

490   young and older visual normals showed a 108-149% higher CoP velocity in the time-pressure vs.

491   no-pressure condition (both p ≤ 0.014, d ≥ 1.18), while AMD participants did not significantly

492   change their CoP velocity (p = 0.995). No significant main effect of group was observed ($F_{2, 21}$ =

493   2.8, p = 0.085).

494

495   The average CoP velocity in the medial-lateral direction showed a group ($F_{2, 21}$ = 4.6, p = 0.022)

496   and interaction effect ($F_{2, 21}$ = 3.9, p = 0.037) (Figure 4D, Table 2). Post hoc testing for the

497   interaction effect showed that AMD participants had a 60-71% higher CoP velocity than young

498   and older visual normals in the no-pressure condition (both p ≤ 0.008, d ≥ 1.20). No other

499   between group differences were observed (all p ≥ 0.562). On comparing between conditions for

500   each group, AMD participants showed a 44% lower CoP velocity in the time-pressure vs. no-

501   pressure condition (p = 0.017, d = 0.80), while young and older visual normals did not

502   significantly change their CoP velocity (both p ≥ 0.277). No significant main effect of condition

503   was observed ($F_{1, 21}$ = 0.4, p = 0.538).

504

505   *[Figure 4]*

506   Figure 4. CoP displacement in the AP direction (A), CoP displacement in the ML direction (B),

507   CoP velocity in the AP (C), and CoP velocity in the ML direction (D) in the two different

508   conditions when stepping up to the force platform with the trail foot. AP, anterior-posterior; CoP,

509   centre-of-pressure; ML, medial-lateral; ‡, between group difference ($p < 0.05$); *, group by

510   condition interaction between the time-pressure and no-pressure condition ($p < 0.05$).

511

512   *[Table 2]*

513

514   **DISCUSSION**

515   Falls are common in older adults (Rubenstein, 2006), particularly when older adults have central

516   field loss (Szabo et al., 2010; Soubrane et al., 2007). Stepping up to a new level is considered a

517   challenging and hazardous everyday activity (Startzell et al., 2000) and older adults with AMD

518   experience difficulties negotiating steps and stairs (Taylor et al., 2016; Taylor et al., 2019). Step

519   negotiation in daily life (e.g., stepping up a pavement curb) is often performed under time-

520   pressure but the effects of time-pressure on step negotiation have not been investigated. The

521   present study highlights how age and central field loss affect the movement kinematics and

522   balance control when stepping up to a new level under time-pressure. The main findings reveal

523   that despite walking faster, AMD participants retained a controlled landing strategy under time-

524   pressure unlike young and older visual normals who demonstrated more forceful landing

525   mechanics to maintain balance control during the step-up. Young adults showed the most

526   forceful landing mechanics.

527

528   The loading rate in the vertical direction was affected by age, vision loss and time-pressure.

529   Young and older visual normals increased their vertical loading rate under time-pressure while

530   AMD participants did not (Figure 3A). This result shows that AMD participants adopted a more

531   cautious landing strategy under time-pressure compared to young and older visual normals. The

532   more cautious landing strategy under time-pressure might be the result of poor oculomotor

533   control and deficits in visual search behaviour that are observed in individuals with AMD

534   (Verghese, Vullings & Shanidze, 2021). To illustrate, individuals with AMD demonstrated longer

535   saccadic search latencies, more saccades, and longer fixation dwell times compared to

536   individuals with normal vision (Van der Stigchel et al., 2013; Boucart et al., 2015), suggesting that

537   individuals with AMD require more time to extract information from targets of interest. In

538   addition, individuals with AMD experienced increased pursuit latencies compared to visual

539   normals (Shanidze et al., 2016), implying that individuals with AMD need longer time to detect the

540   target of interest and reach steady-state pursuit. In time-constrained situations, there is less time

541   to detect targets of interest, reach steady-state pursuit, and extract information from those targets

542   of interest. The more cautious landing strategy under time-pressure might help AMD participants

543   to increase the kinaesthetic information in the absence of accurate visual information (i.e.,

544   feeling the way down to the step rather than dropping onto it).

545

546   Compared to young visual normals, AMD participants and older visual normals also landed with

547   less peak vertical force on the step. This finding corroborates that the amount of downward force

548   applied during stair ascent decreases with age (Stacoff et al., 2005). It remains speculative why

549   older adults apply less peak downward force but it is likely a combination of age-related

550   functional decline (Hebert, 1997) and age-related deficits in the somatosensory and vestibular

551 system (Goble et al., 2009; Li et al., 2015; Hsieh, Lin & Lee, 2014; Baloh, Jacobson & Socotch, 1993) that

552 require a more controlled landing of the lead foot when stepping up a curb. The more controlled

553 landing was not accompanied by a trade-off in foot velocity, because the single support time of

554 the lead foot during the step-up was not significantly different across groups.

555

556 Age and vision loss also affected the landing mechanics of the lead foot in the anterior-posterior

557 direction, especially when the step-up movement was performed under time-pressure. As a

558 consequence of completing the action faster under time-pressure (i.e., shorter single support

559 phase during the step-up of the lead foot), young and older visual normals recorded a higher

560 anterior-posterior loading rate and ground reaction force while these landing mechanics did not

561 increase in AMD participants. Interestingly, older visual normals and AMD participants spent

562 37-38% longer in the double support phase prior to the step-up than young visual normals, which

563 allowed more time to acquire visual information for the control of adaptive locomotion (Patla,

564 Greig, 2006). Visual information from the peripheral visual field is important for adjusting foot

565 placement and lower limb trajectory when stepping up to a new level (i.e., online feedback

566 corrections), while the central visual field is important for feedforward planning (Marigold, 2008;

567 Patla, 1997). The peripheral visual field tend to be generally intact in individuals with AMD and

568 motion processing is preserved in the periphery. Nonetheless, the AMD participants changed to a

569 more cautious landing strategy under time-pressure, suggesting that they did not receive

570 sufficient sensory information to adopt a more forceful landing strategy like the young and older

571 visual normals.

572

573 The somatosensory, visual, and vestibular systems are the sensory systems that play a role in step

574 negotiation (Startzell et al., 2000). Ageing compromises the functioning of these sensory systems

575 (Goble et al., 2009; Li et al., 2015; Hsieh, Lin & Lee, 2014; Congdon et al., 2004; Baloh, Jacobson &

576 Socotch, 1993) and pathologies such as AMD can accelerate this deterioration (Horak, Shupert &

577 Mirka, 1989). Individuals with AMD receive limited visual information from the central visual

578 field and the functioning of the vestibular system is compromised compared to older visual

579 normals, but the somatosensory system is intact (Elliott et al., 1995; Radvay et al., 2007). A

580 compromised vestibular system also affects the coordination of eye and head movements in

581 individuals with AMD due to deficiencies in vestibulo-ocular reflex cancellation (Verghese,

582 Vullings & Shanidze, 2021). This cancellation is an important reflexive mechanism during

583 locomotion to track and stabilize gaze on targets of interest (Patla, 1997). When locomotion is

584 performed at a higher speed (e.g., under time-pressure), there will be more head movement in the

585 anterior-posterior direction, which places a higher demand on vestibulo-ocular reflex

586 cancellation. Consequently, impairments in cancellation might become more apparent under

587 time-pressure and AMD participants will acquire less accurate visual information from the

588 central and peripheral visual field. The lack of visual information under time-pressure together

589 with a compromised vestibular system, which is challenged more under time-pressure when the

590 step-up movement is performed at higher speed, might explain why AMD participants adopted a

591 more cautious landing strategy under time-pressure. The more cautious landing strategy allowed

592 more input from the somatosensory system (e.g., kinaesthetic information) and better balance

593 control in the anterior-posterior direction.

594

595 The landing mechanics of the lead foot in the medial-lateral direction were affected by age and

596 time-pressure but not by vision loss. The loading rate in the medial-lateral direction was lower in

597 older visual normals and AMD participants compared to young visual normals, and only the

598 young visual normals increased their medial-lateral loading rate under time-pressure. This

599 finding supports the earlier idea that age-related functional decline and age-related deficits in the

600 somatosensory and vestibular system require a more controlled landing of the lead foot when

601 stepping up a curb. The medial-lateral loading rate at initial foot contact is important for balance

602 control as it regulates the trajectory of the CoM so that it remains within the lateral borders of the

603 base-of-support (MacKinnon, Winter, 1993). The higher medial-lateral loading rate for young

604 visual normals suggests errors in foot placement due to the less controlled landing, especially

605 under time-pressure. The errors in foot placement required a higher medial-lateral loading rate to

606 prevent the CoM from traveling outside the lateral borders of the base-of-support (i.e., initiating

607 medial-lateral imbalance).

608

609 Balance control during the step-up of the trail foot (i.e., single support phase) was affected by

610 time-pressure and vision loss but not by age. Stepping up to a new level under time-pressure

611 increased the CoP displacement and velocity in the anterior-poster direction for young and older

612 visual normals but not for AMD participants. During the single support phase of the trail foot,

613 the CoM is propelled forwards and the forward momentum needs to be counteracted to prevent a

614 forward fall (Winter, 1995). All groups showed shorter single support times under time-pressure,

615 which indicates that participants moved faster forward and that the CoM was traveling at a

616 higher velocity. Greater muscular effort is necessary to counteract the forward movement of the

617 CoM in order to prevent a fall forward (Hahn, Chou, 2004). The increased muscular effort causes a

618   greater CoP displacement and velocity opposing the displacement of the CoM. Indeed, young

619   and older visual normals increased their CoP displacement and velocity under time-pressure but

620   AMD participants used a different strategy to counteract the forward displacement of the CoM. It

621   might be that AMD participants adjusted their movement mechanics during step negotiation to

622   keep the horizontal position of the CoM close to the centre of the base of support (i.e., increased

623   balance control), as seen in healthy older adults with simulated blur (Heasley et al., 2004).

624

625   Time-pressure and vision loss did also affect balance control in the medial-lateral direction

626   during the step-up of the trail foot. In the no-pressure condition, AMD participants showed more

627   CoP displacement and a higher CoP velocity (i.e., reduced balance control) than the young and

628   older visual normals. However, under time-pressure, AMD participant reduced their CoP

629   displacement and velocity (i.e., increased balance control) while young and older visual normals

630   did not show a change in these balance control parameters. These results suggest that AMD

631   participants altered their movement mechanics under time-pressure to also improve balance

632   control in the medial-lateral direction. The reduced medial-lateral balance control of AMD

633   participants in the no-pressure condition supports the findings of healthy older adults who

634   stepped up to a new level with simulated blur (Buckley et al., 2005b). It might be that due to the

635   nature of the task AMD participants adjusted their movement mechanics to not fall forwards,

636   thereby accepting more deviations in medial-lateral balance control ('minimal intervention

637   principle') (Todorov, Jordan, 2002).

638

639   Age did not cause additional balance deficits when stepping up to a new level. The absence of

640   age-related deficits in balance control during step ascent are in accordance with previous

641   research (Reid et al., 2011; Lee, Chou, 2007). The present study is unique in measuring balance

642   control in AMD participants during a dynamic task. Previous studies in AMD participants

643   reported deficits in standing balance (Wood et al., 2009; Elliott et al., 1995; Willis et al., 2013; Chatard

644   et al., 2017; Kotecha et al., 2013) but everyday activities are often dynamic rather than static. The

645   dynamic situation in the present study did reveal deficits in medial-lateral balance control, but

646   none of the AMD participants actually lost their balance during the step-up task.

647

648   It is important to highlight that fit and healthy individuals were recruited for the present study

649   who did not have a history of falling. The present findings suggest a very positive picture for

650   older adults with and without AMD, however, these population groups are at an increased risk of

651   falling (Szabo et al., 2010; Soubrane et al., 2007; Rubenstein, 2006). Future research should consider

652   recruiting vision impaired fallers to understand whether their balance and adaptive gait

653   characteristics are different to the population group recruited to the current study. Also

654   interesting is to look at vision metrics as predictors of balance and adaptive gait metrics, using a

655   large dataset that includes a wide range of datapoints from no visual impairment to severe visual

656   impairment.

657

658   **Limitations**

659   In the current study, we were unable to measure the contribution of the trail foot towards

660   maintaining balance control when stepping up to the floor-mounted force plate because only one

661   force plate was used. The mechanics of the trail foot play an important role in maintaining

662   medial-lateral stability during a stepping movement (Lyon, Day, 1997), especially when vision was

663   acutely impaired (Buckley et al., 2005b). Future research is needed to determine how the

664 mechanics of the trail foot also help older adults with chronic vision loss to maintain medial-

665 lateral stability.

666

667 The step height in the present study was low (4.5 cm) compared to the step heights used in

668 previous vision loss research (7.2 to 23.5 cm) (Heasley et al., 2004; Buckley et al., 2005a; Buckley et

669 al., 2005b; Timmis et al., 2014; Alexander et al., 2014). These previous studies used step heights that

670 people would usually encounter in buildings (Billington et al., 2017), while the step height in the

671 current study was meant to reflect the height of a pavement curb. Pavement curbs at pedestrian

672 crossing points can be as low as a few millimetres. In addition, curbs below the height of 6.0 cm

673 are especially difficult for blind and partially sighted to detect the edge of the footway (Thomas,

674 2011). Following previous research (Buckley et al., 2005b; Timmis et al., 2014), it is expected that

675 higher step heights will further emphasize the differences in landing mechanics and balance

676 control observed in the present study.

677

678 **Conclusions**

679 The present study demonstrates the effects of age and vision loss on landing mechanics and

680 balance control when stepping up to a new level under time-pressure. Individuals with AMD did

681 not adapt their landing mechanics under time-pressure (i.e., remained more cautious), while the

682 landing strategy of young and older visual normals became more forceful (i.e., increased loading

683 rates and ground reaction forces) with the young showing the most forceful landing. Retaining

684 less forceful landing mechanics might be a safety strategy for older adults with and without

685 central field loss to maintain balance control during adaptive gait. Especially during time

686 pressured situations when balance control in the anterior-posterior direction is challenged more.

687

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693

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852

Figure 1

Experimantal setup and force plate data

Schematic representation of the step-up action (A) and a representative trace of the ground reaction force from a single participant in the vertical direction (B), anterior-posterior direction (C), and medial-lateral direction (D) when lading onto the floor-mounted force plate. Of note, the left foot was the lead foot in this example. AP, anterior-posterior; ML, medial-lateral.

A

Vertical ground reaction force (Fz)

+

+ AP ground reaction force (Fy)

+

ML ground reaction force (Fx)

Lead foot

Trail foot

Lead foot

Trail foot

Force plate

B

Lead foot contact

Toe off trail foot

Trail foot contact

Trial end

Peak landing force

Y

Loading rate = Y/X

X

Vertical ground reaction force (N)

Time (s)

C

X

Y

Peak landing force

AP ground reaction force (N)

Time (s)

D

X

Y

Peak landing force

ML ground reaction force (N)

Time (s)

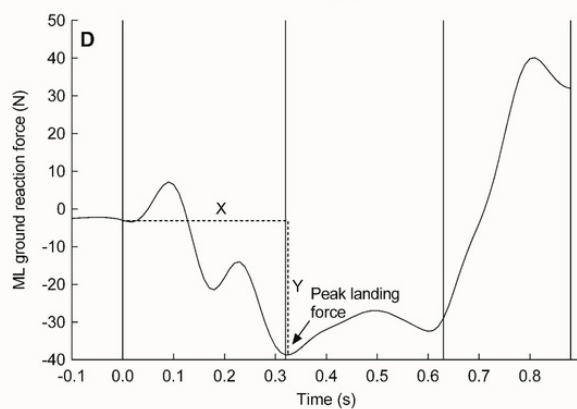
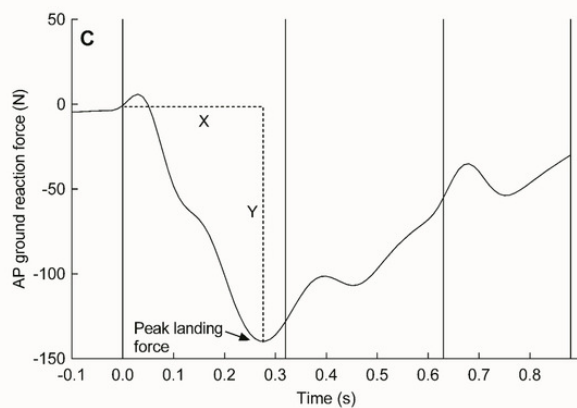
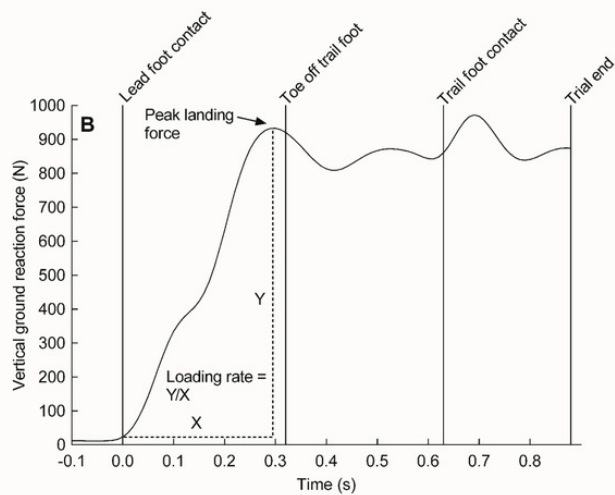
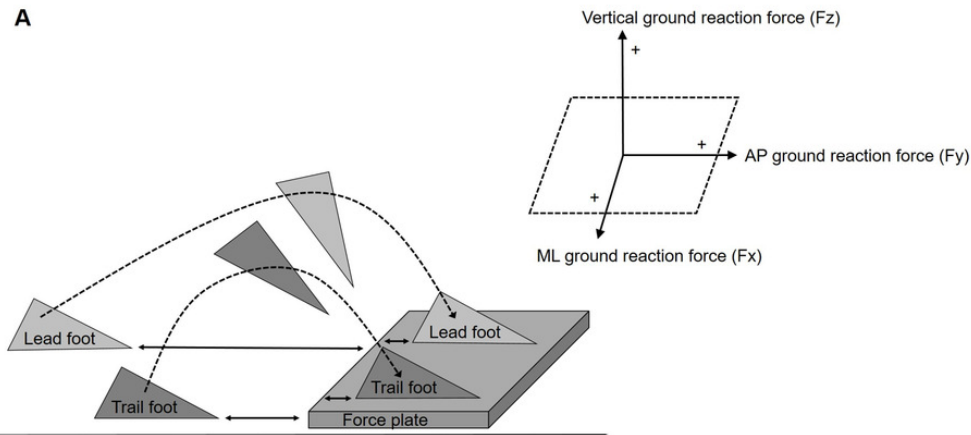



Figure 2

A representative trace of the centre-of-pressure displacement and velocity

A representative trace of the centre-of-pressure displacement (A) and velocity (B) from a single participant when stepping onto the floor-mounted force plate. Of note, the left foot was the lead foot in this example. Postural control parameters were calculated from the centre-of-pressure data (see text for details).

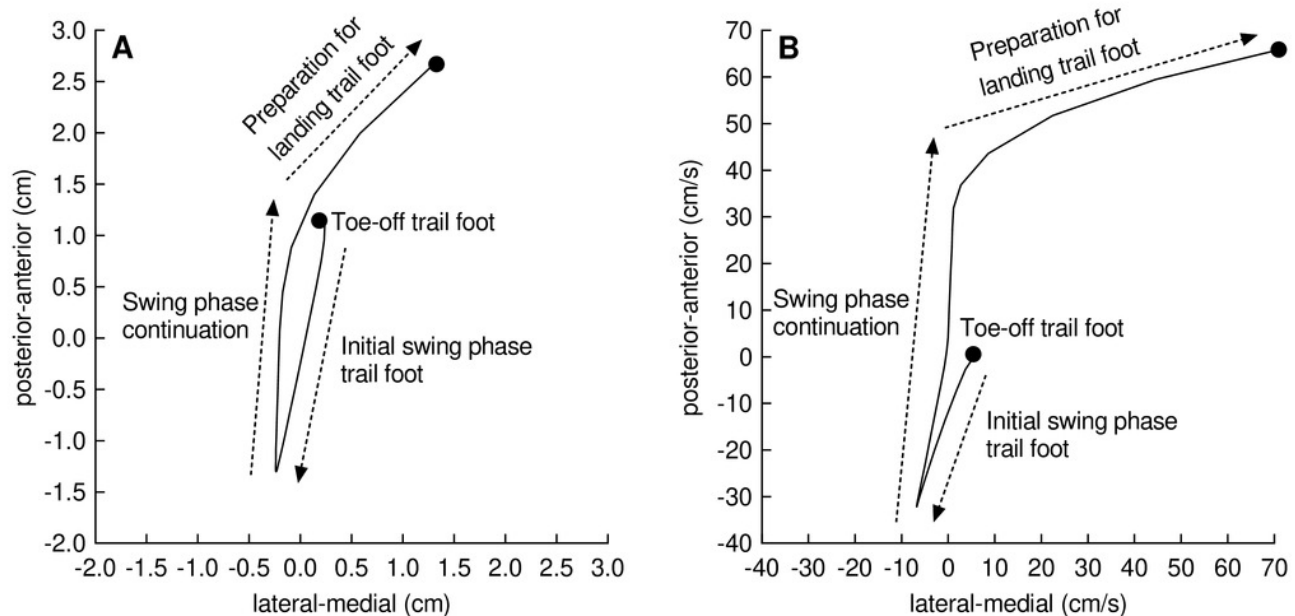



Figure 3

Rate of force development when stepping up to the force platform with the lead foot in the time-pressure and no-pressure condition

Rate of force development in the vertical direction (A), anterior-posterior direction (B), and medial-lateral direction (C) in the two different conditions when stepping up to the force platform with the lead foot. ‡, between group difference ($p < 0.05$); *, group by condition interaction between the time-pressure and no-pressure condition ($p < 0.05$).

A

Rate of force development in vertical direction (N/s)

AMD participants
Older visual normals
Young visual normals

No-pressure   Time-pressure

B

Rate of force development in AP direction (N/s)

No-pressure   Time-pressure

C

Rate of force development in ML direction (N/s)

No-pressure   Time-pressure

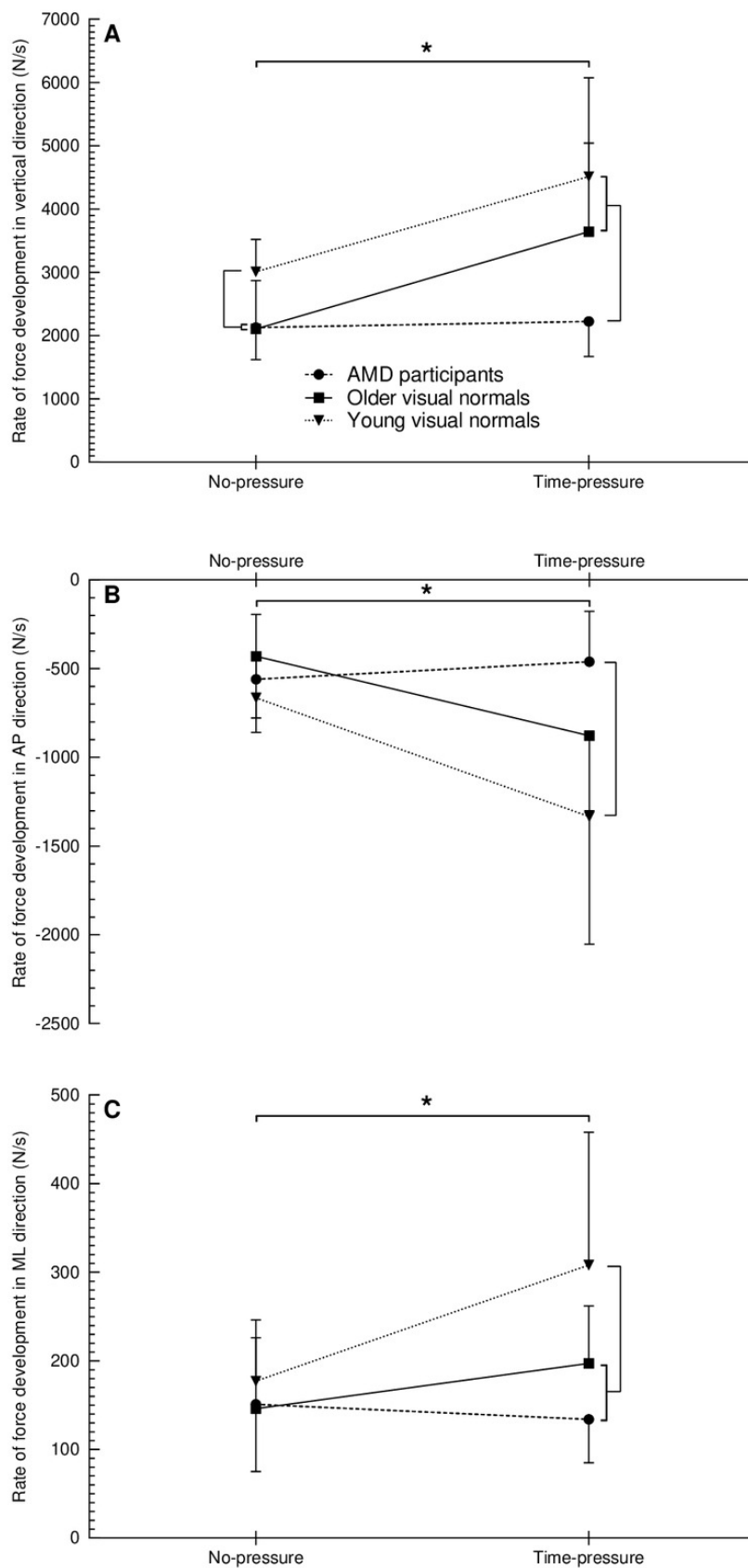
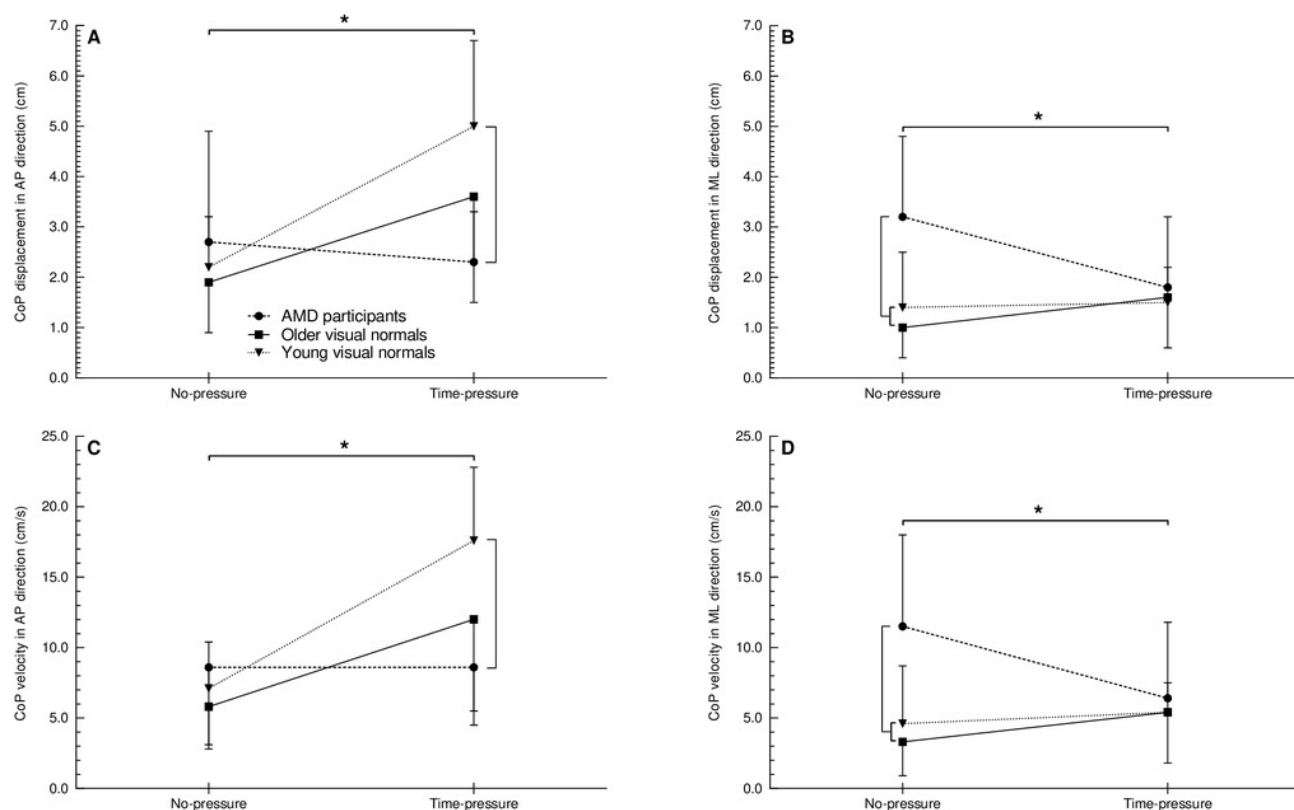



Figure 4

Centre-of-pressure displacement and velocity when stepping up to the force platform with the trail foot in the time-pressure and no-pressure condition

CoP displacement in the AP direction (A), CoP displacement in the ML direction (B), CoP velocity in the AP (C), and CoP velocity in the ML direction (D) in the two different conditions when stepping up to the force platform with the trail foot. AP, anterior-posterior; CoP, centre-of-pressure; ML, medial-lateral; ‡, between group difference ($p < 0.05$); *, group by condition interaction between the time-pressure and no-pressure condition ($p < 0.05$).

Baseline characteristics of the participants

Baseline characteristics of the participants (mean ±SD).

1   Table 1. Baseline characteristics of the participants (mean ±SD).

	AMD participants (n = 8)	Older visual normals (n = 8)	Young visual normals (n = 8)
Age (years)‡	76 (9)	70 (4)	27 (5)
Sex (male / female)	3 / 5	4 / 4	2 / 6
Mass (kg)	71 (12)	68 (12)	68 (13)
Height (cm)	164 (9)	169 (10)	170 (13)
Visual acuity (logMAR)*	0.79 (0.15)	0.02 (0.12)	-0.18 (0.10)
Contrast sensitivity (logCS)*	0.62 (0.27)	1.69 (0.07)	1.95 (0.00)
Visual fields (dB)†	22 (5)	31 (0)	32 (1)
Sedentary behaviour (min/day)†	2048 (1284)	1916 (789)	4305 (1706)
Moderate-to-vigorous physical activity (min/day)	826 (867)	834 (505)	512 (362)

2   * significant group difference between each group ($p < 0.05$); † Significant group difference between AMD
3   participants and the other two groups ($p < 0.05$); ‡ significant group differences between young visual normals and
4   the other two groups ($p < 0.05$).

Task performance variables of AMD participants, older visual normals and young visual normals in the two different conditions

Task performance variables of AMD participants, older visual normals and young visual normals in the two different conditions (mean ±SD).

1   Table 2. Task performance variables of AMD participants, older visual normals and young visual normals in the two different conditions (mean ±SD).

Variables	AMD participants (n=8)		Older visual normals (n=8)		Young visual normals (n=8)		ANOVA
	No-pressure	Time-pressure	No-pressure	Time-pressure	No-pressure	Time-pressure	
Total performance time (s)	10.0 (2.0)	7.8 (1.8)	8.7 (1.9)	6.5 (1.7)	7.0 (0.5)	5.2 (0.7)	G, C
Normalised peak ground reaction forces							
Peak vertical ground reaction force (% body mass)	101 (3)	102 (3)	104 (8)	104 (10)	106 (4)	116 (13)	G
Peak AP ground reaction force (% body mass)	-16 (6)	-15 (3)	-16 (6)	-21 (5)	-21 (4)	-29 (5)	G, C, GxC
Peak ML ground reaction force (% body mass)	6 (1)	7 (1)	6 (2)	6 (1)	6 (0)	8 (2)	ns
Loading rates							
Loading rate in vertical direction (N/s)	2128 (508)	2224 (554)	2107 (764)	3642 (1401)	3011 (510)	4515 (1560)	G, C, GxC
Loading rate in AP direction (N/s)	-560 (365)	-461 (284)	-431 (347)	-878 (423)	-665 (195)	-1334 (719)	G, C, GxC
Loading rate in ML direction (N/s)	151 (76)	134 (49)	146 (100)	197 (65)	177 (49)	308 (150)	G, C, GxC
Temporal variables							
Double support phase prior to step-up (s)	0.19 (0.04)	0.13 (0.03)	0.19 (0.06)	0.12 (0.05)	0.14 (0.03)	0.06 (0.03)	G, C
Single support phase during step-up lead foot (s)	0.42 (0.07)	0.38 (0.05)	0.45 (0.03)	0.39 (0.03)	0.41 (0.03)	0.41 (0.12)	C
Double support phase during step-up (s)	0.32 (0.09)	0.26 (0.09)	0.33 (0.13)	0.22 (0.09)	0.23 (0.04)	0.12 (0.03)	G, C
Single support phase during step-up trail foot (s)	0.31 (0.04)	0.29 (0.03)	0.34 (0.03)	0.31 (0.05)	0.32 (0.03)	0.30 (0.05)	C
Balance control single support phase							
CoP displacement in AP direction (cm)	2.7 (2.2)	2.3 (1.0)	1.9 (1.0)	3.6 (2.1)	2.2 (1.0)	5.0 (1.7)	C, GxC
CoP displacement in ML direction (cm)	3.2 (1.6)	1.8 (1.4)	1.0 (0.6)	1.6 (1.0)	1.4 (1.1)	1.5 (0.7)	G, GxC
Centre-of-pressure velocity in AP direction (cm/s)	8.6 (5.8)	8.6 (4.1)	5.8 (2.7)	12.0 (6.5)	7.1 (3.3)	17.6 (5.2)	C, GxC
Centre-of-pressure velocity in ML direction (cm/s)	11.5 (6.5)	6.4 (5.4)	3.3 (2.4)	5.4 (3.6)	4.6 (4.1)	5.4 (2.1)	G, GxC

2   AP, anterior-posterior; CoP, centre-of-pressure; ML, medial-lateral; G, significant group effect ($p < 0.05$); C, significant condition effect ($p < 0.05$); GxC, significant
3   group by condition interaction ($p < 0.05$); ns, no significant effect.