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# Age Differences of Gaze Distribution during Pedestrian Walking in a Virtual-Reality Environment

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**Abstract** The gaze pattern changes in old age, not only during artificial laboratory tasks but also during quasi-natural behavior. We have recently reported that older adults, walking in a virtual reality pedestrian precinct, spent longer time looking at pedestrian traffic lights than young adults did (Bock et al, 2015). We have interpreted this age-related change as a compensatory strategy, and we now analyze whether this strategy might be potentially hazardous in that it withdraws gaze from other regions that are critical for safe walking. Seventeen young and 16 older adults walked on a non-motorized treadmill linked to the 3D model of a pedestrian precint. The model was displayed on a monitor ahead, such that participants felt as if walking through the simulated world. Along their way, participants met a range of familiar objects such as pedestrian traffic lights, oncoming pedestrians and cats crossing their path. Eye position was recorded by a video-based system. We found that compared to young adults, older ones looked longer at regions of high behavioral relevance and less long at regions of low behavioral relevance. We conclude that looking longer at relevant regions might be a strategy for compensating central processing deficits, but this strategy may not pay off when an unexpected threat emerges in a seemingly irrelevant region.

**Keywords** Gaze, Aging, Seniors, Walking, Obstacle avoidance

## 1. Introduction

Visual information plays an important role for locomotion: it allows us to navigate through the environment (Patla, Niechwiej, Racco, & Goodale, 2002) and to detect potential hazards along the way (Zietz & Hollands, 2009) (Land & Tatler, 2009). This seems to be particularly relevant in old age, where the risk of falls and fractures increases (Lord, 2006; Owsley & McGwin, 2004), especially during locomotion (Berg, Alessio, Mills, & Tong, 1997; Kelsey et al., 2010). However, visual inspection of the environment might be degraded in old age because of impaired gaze control: Saccades slow down and become less accurate (Bono et al., 1996; Paquette & Fung, 2011), more time is spent looking at fewer objects (Maltz & Shinar, 1999; Bao & Boyle, 2009), and it becomes more difficult to suppress undesired saccades (Butler et al., 1999; Beurskens & Bock, 2012). These ge-related impairments are not limited to artificial laboratory tasks since they can also be observed under quasi-natural conditions, when walking while avoiding obstacles on the floor (Keller Chandra et al., 2011; Chapman and Hollands, 2006b; Di Fabio et al., 2003; Paquette and Vallis, 2010), climbing stairs (Zietz and Hollands, 2009; Di Fabio et al., 2003) or walking while observing pedestrian traffic lights (Bock, Brustio, & Borisova, 2015).

In the latter study, young and older participants walked at a self-determined speed through a shopping precinct rendered in virtual-reality; they occasionally encountered pedestrian traffic lights that either remained green or turned red. We observed that compared to young persons, older ones directed their gaze at the traffic lights for longer periods of time and more frequently, such that the proportion of time spent looking at the traffic lights rather than elsewhere was higher than in young persons. Specifically, that proportion gradually increased from about 25% to about 50% as young persons approached the traffic lights, but it was steadily about 50% in older ones. We interpreted the prolonged fixation of traffic lights in old age as a compensatory strategy, to overcome deficits of spatial orientation and movement inhibition (in case the lights turn red). We further argued that this strategy carries a potential hazard, since prolonged fixation of traffic lights may prevent older pedestrians from noticing other visual information that might be relevant for walking, such as uneven pavement or fellow pedestrians on a collision course. The purpose of the present work is to scrutinize this view. Rather than collecting new data, we decided to re-analyse the existent data but this time consider the distribution of gaze in areas of visual space other than the traffic lights. Our working hypothesis was that older persons direct their gaze for a shorter time not only at regions of

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space that are irrelevant, but also at regions that are critical for safe walking.

## 2. Methods

Seventeen young (age range 20-30, mean 24.51, s.d. 3.58, 8 females) and sixteen older persons (age range 60-80, mean 66.15, s.d. 5.73, 6 females) participated. All were naïve to the purposes of our study, lived independently in the community and reported to be free of musculoskeletal, sensorimotor, cognitive or visual impairments, except for corrected vision. Since all arrived at the university campus unaccompanied, reached our research facility at the agreed-upon day and time, navigated through the facility hallways and staircases without help, and properly followed our verbal instructions, we concluded that they were in good physical and mental health (cf. Beurskens & Bock, 2013; Bock et al., 2015). All participants signed a written informed consent which was pre-approved by the Ethics committee of the German Sport University.

As described in detail elsewhere (Bock et al., 2015), participants walked on a non-motorized treadmill (Christopeit Pro Magnetic) at their self-selected speed. Treadmill movement was registered, and the signal was used to drive the rendering of a 3D virtual pedestrian precinct displayed on a 60' TV screen located a t eye level 130 cm ahead. Thus, the virtual environment moved fast, slow or stopped as the participants walked fast, slow or stopped, respectively. The participants' field of view and gaze direction were registered with a head-mounted tracking system (Mobile Eye XG, Applied Science Laboratories, Bedford, USA) with a sampling rate of 30 Hz and accuracy of 0.5 to 1.0 deg.

To make the virtual walk more realistic, participants encountered a variety of objects in the virtual precinct such as pedestrian traffic lights, oncoming pedestrians, trees, mailboxes, oncoming and crossing cats, windblown newspapers and shops with various window displays. Some of these objects required a locomotor response (e.g. stop if pedestrian traffic lights turned red or if a cat crossed the path), others required another response (e.g., spell out the gender of oncoming pedestrians), and yet others required no response (e.g. mailboxes along the way). The layout and length of the virtual precinct, as well as the location of objects encountered along the way, was identical for all participants. Depending on individual walking speed, it took participants up to eight minutes to complete the walk. The following time intervals were selected for gaze analysis:

- TL: time starting when green pedestrian *traffic lights* became visible ahead (size > 10 mm on the screen) and ending when the green lights disappeared in the visual periphery. The length of this interval was 8.48 ±1.66 s, in dependence on walking speed. There were three TL per participant, intermixed with three encounters of traffic lights which turned red as participants approached (analyzed in our earlier study).
- OP: time starting when an *oncoming pedestrian* became well discernible (size > 10 mm) and ending 2 later. There were two OP per participant; both times, the oncoming pedestrians passed by without crossing the participants' path.
- CC: time starting when a *cat crossing* the participants' path suddenly appeared on the left and ending 2 s later, when the cat had completed its crossing. There were four CC per participant.

In each analysed video frame, we defined a main region of interest (MRI), which was the traffic lights in TL, the oncoming pedestrian in OP and the cat in CC. The top part of Fig. 1 shows MRI in black. We further defined an additional region of interest (ARI), which consisted of the pavement in all analysed intervals, and additionally of an oncoming pedestrian who passed by during two of the three TL intervals. ARI is shown in grey at the top of Fig. 1. The remaining part of the scenery constituted the excess region of interest (ERI), left while at the top of Fig. 1.

We calculated the following gaze parameters for each of the above intervals and regions:

- Total gaze time (cumulative duration of all glances at the specified region);
- Relative total gaze time (100* (Total gaze time / duration of registration)).

For a more detailed analysis of the gaze in regions of behavioral relevance, we also calculated the following gaze parameters for MRI and ARI:

- Longest glance time (duration of the longest glance at the specified region);
- Number of re-glances (count of gaze returns from elsewhere to the specified region);
- Mean glance time (Total gaze time / (1 + number of re-glances));

All parameters were averaged across repetitions, and the outcome was submitted to analyses of variance (ANOVAs) with the between-factor Age (young, older) and the within-factors Interval (TL, OP, CC) and Region (MRI, ARI, ERI).

## 3. Results

The means and standard deviations of gaze parameters from young (black lines) and older participants (grey lines) during their encounters with traffic lights, an oncoming pedestrian and a crossing cat are plotted in Figure 1 A. Total gaze time in MRI was higher in older than in young adults during TL, but not during OP or CC; no substantive age differences of total gaze time in ARI and ERI can be discerned. Findings are similar for gaze time percentage, longest glance time, number of re-glances and mean gaze time. The ANOVA outcome is summarized in Table 1.

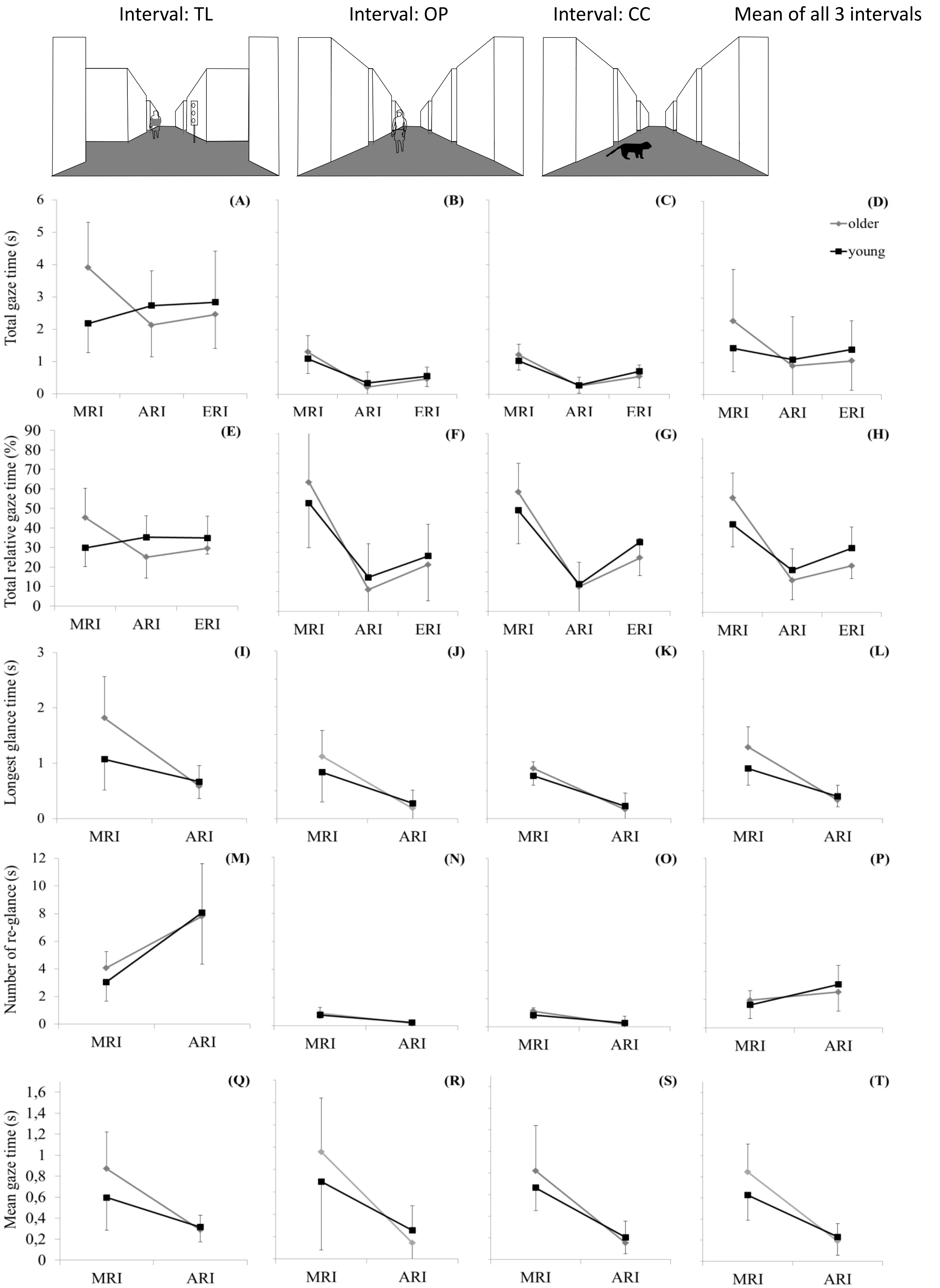


**Figure 1.** Schematic screen shots, as seen a participant who encountered traffic lights (top left), an oncoming pedestrian (top middle) and a crossing cat (top right). The main region of interest (MRI) is shown in black, the additional region of interest (ARI) in grey, and the excess region of interest (ERI) is the remaining area. Graphs show the means and inter-individual standard deviations of gaze parameters in each of the three regions of interest, separately for encounters with traffic lights (left), oncoming pedestrians (middle left), and crossing cats (middle right), as well as jointly across all three types of encounter (right). Data of young participants are plotted in black, and those of older ones in grey

**Table 1.** Outcome of three-way ANOVAS with the factors Interval (TL, OP, CC), Region (MRI, ARI, ERI) and Age (young, older). Rows represent dependent variables, columns ANOVA effects, and cell entries are F-values with degress of freedom in parentheses. Degrees of freedom differ between variables since a different number of data points was analysed. For relative total gaze time, effects of Age and Interval*Age couldn't be calculated as relative time added up to 100% in either age group across all three intervals

| | Interval | Region | Age | I*R | I*A | R*A | I*R*A |
|---|---|---|---|---|---|---|---|
| Total gaze time | 417.11***<br>(2,56) | 25.27***<br>(2,56) | 2.15$^{n.s.}$<br>(1,28) | .55$^{n.s.}$<br>(4,112) | 2.15$^{n.s.}$<br>(2,56) | 13.01***<br>(2,56) | 9.86***<br>(4,112) |
| Rel. total gaze time | -<br>- | 50.70***<br>(2,56) | -<br>- | 16.37***<br>(4,112) | -<br>- | 6.29**<br>(2,56) | 1.04$^{n.s.}$<br>(4,112) |
| Longest glance time | 66.83***<br>(2,54) | 129.56***<br>(1,27) | 9.85**<br>(1,27) | 2.77$^{n.s.}$<br>(2,54) | 7.58**<br>(2,54) | 15.77***<br>(F1,27) | 4.69*<br>(2,54) |
| # Re-glances | 103.11***<br>(2,32) | 5.38*<br>(1,16) | 0.00$^{n.s.}$<br>(1,16) | 23.55***<br>(2,32) | 0.30$^{n.s.}$<br>(2,32) | 0.78$^{n.s.}$<br>(1,16) | 1.20$^{n.s.}$<br>(2,32) |
| Mean gaze time | 1.34$^{n.s.}$<br>(2,54) | 122.28***<br>(1,27) | 3.42$^{n.s.}$<br>(1,27) | 3.06$^{n.s.}$<br>(2,54) | .54$^{n.s.}$<br>(2,54) | 12.56**<br>(1,27) | 1.49$^{n.s.}$<br>(2,54) |

With total gaze time as dependent variable, ANOVA yielded several significant effects. Of interest for the present study are significant effects that include the factor Age, i.e, Region * Age and Interval*Region*Age. The former interaction term was explored by post-hoc decomposition with Tukey`s HSD tests; total gaze time in MRI was significantly higher for older adults compared to young ones ($p < .001$), while total gaze time in ARI and ERI was similar for both age groups (both $p > .05$). The later interaction term arose because age differences during TL were much more ronounced than those during OP and CC (see Fig. 1 A-C).

With relative total gaze time as dependent variable, ANOVA revealed one significant effect of interest, Region * Age. As depicted in Fig. 1H, relative gaze time percentage in MRI was higher in older adults than in young ones, while relative gaze time in ARI and ERI was higher in young adults than in older ones ( Tukey`s HSD: all $p < .001$).

With longest glance time as dependent variable, significance of interest emerged for Age, Interval * Age, Region * Age and the three-way interaction. Fig. 1L demonstrates that older participants looked longer than young ones at MRI but not at ARI and accordingly, Tukey`s HSD tests showed a significant age difference for MRI ($p < .001$) but not for ARI ($p > .05$).

With number of re-glances, ANOVA revealed no significant effects that included Age. Fig. 1P illustrates that the number of re-glances into MRI and ARI was similar in both age groups ($p > .05$). With mean gaze time, ANOVA yielded significance of interest for Region * Age only. As shown in Fig. 1T, mean gaze time of older participants was higher than that of young ones in MRI but not in ARI, as confirmed by Tukey's HSD tests (MRI: $p < .05$; ARI: $p > .05$).

Summing up, older participants had higher values for all gaze parameters in MRI, when compared to young participants. The age-related increase was 46.52% for total gaze time, 21.97% for relative total gaze time, 42.88% for longest glance time, 16.77% for the number of re-glances, and 30.64% for mean glance time.

# 4. Discussion

The present study re-analysed data on gaze behavior in a quasi-natural setting, where participants interact with their environment to achieve ecologically valid goals. Having shown before that older persons look longer at upcoming green pedestrian traffic lights than young persons do, we now explore whether a similar preference exists for other events besides traffic lights, and whether such a preference reduce the inspection of other, behaviorally relevant regions of visual space.

The analysis shows that older persons look longer than young ones not only at upcoming traffic lights, but also at pedestrians passing by and cats crossing the path; however, the age difference is less pronounced for the latter two events. It therefore appears that age differences are particularly pronounced when an object might suddenly change – the green lights might turn red – and/or when an object has high behavioral relevance – missing the red lights is potentially life-threatening. In either case, longer glances at traffic lights would not be attributable to an age-related enhancement of the "visual grasp reflex" (Rafal et al., 2000; Bos & Machado 2013), but rather to a strategic choice for devoting a higher portion of one's dwindling processing resources to highly relevant objects. In other words, longer glances at traffic lights would signify compensation rather than decay.

The presumed compensation comes at a cost, however, since less time remains to look at other regions of visual space. The main purpose of the present study was to find out whether this reduction of gaze time is limited to regions of little behavioral relevance (ERI), or rather includes regions that are relevant for maintaining balance (ARI). We found that older participants looked slightly less long at ERI and ARI than young ones; however, the age difference didn't reach statistical significance, which suggests that at least part of the increased MRI viewing is compensated not by reducing ERI and ARI viewing, but rather by walking more slowly. Indeed, when total gaze time is expressed as percentage of the registration time, the age difference for gaze time in ERI and ARI became significant.

The above pattern of finding revives a long-known question: should performance of age groups be compared in absolute or rather in relative terms (Somberg & Salthouse, 1982)? We propose the following answer with respect to the present data: older persons compensate the reduction of their processing resources by slowing down (Salthouse, 1996), and therefore need longer than young ones to establish the presence and nature of an obstacle in their walking path. Assuming that walking speed is a valid indicator of this age-related slowing, relative time is a better indicator of older persons' ability for dealing with obstacles in ARI. If so, our data would indicate that older participants compensated their prolonged processing of MRI by abbreviating the processing of both other regions, ERI and ARI. Thus, compensatory extension of MRI processing would indeed carry a behaviorally relevant cost: although older participants had virtually the same time in ms to process information in ARI, they had less time to process that information in the same depth as young ones: young participants spent 24.33% of their gaze time in ARI but older participants only 16.76%, a reduction of (x - y) / x * 100 = 31.26%. This age-related shortage of processing time may contribute towards the increasing incidence of falls in older age (WHO 2008), in particular when it is aggravated by older persons' difficulties for concurrently processing two streams of visual information (Beurskens & Bock, 2012), in this case one stream originating in MRI and the other in ARI. Future research should address these implications of the present study.

Analyses of the remaining gaze parameters indicate that in older participants, both the longest and the mean gaze time in MRI increased in proportion with total gaze time in MRI, while the number of re-glances into MRI didn't change; this outcome suggests that the characteristics of visual inspection were preserved in older age, except for a scaling in time.

Our findings fit well with earlier work on age-related changes of gaze behavior in quasi-natural settings. Older persons were found to glance earlier, and for longer time, at stairs they were going to negotiate (Zietz and Hollands, 2009; Di Fabio et al., 2003) as well as at obstacles they were going to step over or avoid (Keller Chandra et al., 2011; Chapman and Hollands, 2006b; Di Fabio et al., 2003; Paquette and Vallis, 2010). Our data extend those findings to behaviorally relevant objects that are not located on the floor, and therefore argue against the view that age-related gaze changes are due to reduced attention in the lower visual field (di Fabio et al., 2005). It rather appears that the deficit is more general: any objects of behavioral relevance seem to attract older persons' gaze more strongly than that of young ones, and the attraction is more pronounced when behavioral relevance is higher.

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