International Journal of Applied Psychology 2015, 5(1): 13-19
DOI: 10.5923/j.ijap.20150501.03

Age-Related Differences of the Gaze Pattern in a Realistic Pedestrian Traffic Task

Otmar Bock[1,*], Paolo Riccardo Brustio[2], Steliana Borisova[3]

[1]Institute of Physiology and Anatomy, German Sport University, Cologne, Germany
[2]Department of Psychology, University of Torino, Torino, Italy
[3]Institute of Neurobiology, Bulgarian Academy of Sciences, Sofia, Bulgaria

Abstract Laboratory studies suggest that the gaze pattern changes in older age, both in seated and in walking persons. Here we investigate the gaze pattern in a more complex and realistic scenario: walking in a virtual-reality shopping precinct. Seventeen young and sixteen older adults walked at their preferred speed on a treadmill driven by their leg movements, thus controlling the presentation of a virtual 3D world on a screen 130 cm ahead. The screen showed a shopping street with stationary and moving objects, and with six pedestrian traffic lights of whom three turned red upon approach. Gaze direction was registered by a video-based system. We found that each glance at a traffic light took longer in older than in young persons, and the sum of all glances at a traffic light was longer as well. In effect, older persons looked at the traffic light equally long throughout all three light phases, while young ones gradually increased their inspection of the traffic light as the green phase went on. The observed change of the gaze pattern in older age could represent a compensatory strategy to facilitate spatial orientation and/or movement preparation, or it could reflect a deficit of gaze disengagement. Future research should disambiguate these alternatives. In any case, the observed change is detrimental for seniors' sensorimotor performance in everyday scenarios.

Keywords Virtual reality, Locomotion, Fixation, Ecological validity

1. Introduction

It is well established that the human gaze pattern changes with advancing age. The latency of saccadic eye movements increases while their speed and accuracy declines [1-3]. The visual inspection of static and dynamic displays takes a longer time as the number of saccades increases, with no change of saccadic frequency [4, 5]. Older observers spend more time looking at fewer objects [4, 6], they refixate already inspected objects more often [4, 5, see however 7], and their ability to suppress undesired automated saccades is degraded [8-10].

The above findings were yielded in well-controlled laboratory settings, where subjects sat in front of a computer display and were instructed to perform one given task. The outcome may not necessarily be replicable under situations of everyday life where persons move about, interact with an ever-changing environment, keep track of multiple concurrent tasks, produce self-initiated, complex actions and pursue ecologically valid goals rather than obeying experimenter instructions. Previous work has shown that age-related changes of manual performance [11, 12], locomotion [13] and cognitive skills [14] are dramatically different in an everyday-like context and in a typical laboratory context, and age-related changes of the gaze pattern may therefore be different as well.

Only few studies investigated the gaze pattern of young and older persons in a natural or in a close-to-natural context. This work documented that older persons, standing at a curbside, lower their gaze for longer time to the walkway than young persons do [15]; furthermore, when older persons approach stairs or other obstacles, they direct their gaze earlier and for a longer time at the upcoming stair or obstacle [16-20]. Both findings have been interpreted as evidence for a compensatory strategy, which helps to overcome age-related deficits of postural control [15, 17, 18]. However, this strategy might defeat its own purpose: when seniors keep their gaze for a longer time on one given object, they may miss other relevant objects around them. As a consequence, seniors' ability to observe oncoming traffic [21, 22] and to negotiate complex obstacled terrains [23, 24] might be compromised.

The present study investigates whether the gaze of older persons is drawn specifically to objects that threaten their postural stability, such as stairs and obstacles, or rather is attracted by other objects as well. Specifically, we evaluate whether it also is attracted by pedestrian traffic lights. We test young and older subjects in a virtual-reality scenario that approximates a realistic everyday activity: subjects

* Corresponding author:
Bock@dshs-koeln.de (Otmar Bock)
Published online at http://journal.sapub.org/ijap

walk down a shopping precinct, interact with various events and meet pedestrian traffic lights that may or may not turn red. We document that the gaze of older persons dwells longer on those traffic lights than that of young ones. Since traffic lights are not specifically relevant for postural control, our finding doesn't support the posture-first interpretation.

2. Methods

Seventeen young (age range 20-30, mean age 24.51 ±3.58, 8 females) and sixteen older persons (age range 60-80, mean age 66.15 ±5.73, 6 females) participated. All were naïve to the purposes of our study, had no sensorimotor or cognitive deficits by inspection and self-report, and had normal or corrected-to-normal vision. All subjects lived independently in the community, found their way to the university campus and to our research facility at the agreed-upon day and time, navigated through the facility's hallways and staircases without need for help, and followed our verbal instructions without need for lengthy explanations or reminders. From this we concluded that they were in good physical and mental health, and decided to spare them lengthy screening tests (MMSE, leg force, O_2-kinetics) which they would have passed anyways. The study was pre-approved by the Ethics committee of the German Sport University, and all participants signed an informed consent statement.

A computer-generated, three-dimensional world representing a pedestrian precinct was displayed on a 106 cm wide and 110 cm high screen, located at eye level about 130 cm ahead of the participant. The displayed vantage point travelled through the 3D world at a speed that was proportional to the speed of a treadmill placed in front of the screen. This was a simple non-motorized treadmill, driven by the participants' legs, whose momentary position was registered by a potentiometer and passed on to the graphics software. Thus in effect, subjects walked on the treadmill at their self-selected speed and saw the virtual shopping precinct moving by at a commensurate speed. When they slowed down, the virtual world slowed down as well; when they stopped, the virtual world also stopped. Participants reported this to be a realistic and immersive experience.

To avoid physical and mental fatigue, we decided to keep the experiment short. The duration of a session varied in dependence on the participants' individual walking speed, but it didn't exceed 8 minutes for any participant. During the session, participants walked by trees, bushes, benches, hydrants, mailboxes, cats, windblown newspapers and shops with various window displays. These events required no response, but other events did:

– When they encountered an oncoming pedestrian, participants should verbally indicate that person's gender.
– When they approached a cat crossing the walkway, participants should slow down and let the cat pass (an angry cry was issued when they didn't slow down).
– When they approached an intersecting road, participants had to obey the pedestrian traffic light located on the opposite side of the road, i.e., they were allowed to walk on if the light remained green, but had to stop and wait for the next green phase if the light turned amber and red.

The sequence of events was the same for all subjects. There was a total of 30 events, among whom the 4th, 8th and 20th event was a traffic light that changed color while the 11th, 12th and 26th event was a traffic light that remained green. The present study deals with the participants' eye movements before and after a traffic light changed color.

Eye position was registered with a head-mounted tracking system (Mobile Eye XG, Applied Science Laboratories, Bedford, MA, USA) with a sampling rate of 30 Hz and accuracy of 0.5 to 1.0 deg. The system was individually calibrated for each participant at the onset of the experiment. Because of technical problems, no useful eye data were available from one older subject during the first, and another older subject during the third presentation of a traffic light that changed color. We decided not to exclude these subjects, and rather to base our analyses on scores averaged across all available (two or three) presentations. As a safeguard, we replicated the analyses after excluding the two older subjects and we still yielded the same significance pattern.

The eye tracker provided video footage of the screen located in front of the participant, superposed with symbols representing the location of each gaze fixation. We defined in each video frame a region of interest (ROI) that coincided with the traffic light, and determined the following parameters for each event on which a traffic light changed color:

– total gaze time (cumulative duration of all fixations within the ROI)
– number of glances (number of gaze changes from elsewhere into the ROI)
– mean glance duration (total gaze time / number of glances)

All three parameters were calculated separately for two time intervals, once for the last 1.75 s before the onset of amber, and once for the first 1.75 s after the onset of amber (1.75 s was the longest interval for which valid data from all subjects were available). The outcome was then averaged across the three presentations of a color-changing traffic light. We then submitted the data to analyses of variance (ANOVAs), using the between-factor Age (young, older) and the within-factor Interval (before amber onset, after amber onset).

For a more detailed view on the registered time-series of gaze positions, we calculated the percentage of subjects that fixated the traffic light in each video frame, starting with the frame registered 1.75 s before the onset of amber and ending with the frame registered 1.75 s after the onset of amber. We did this separately for each age group and each of the three traffic lights. Other data from this experiment will be analysed and communicated later.

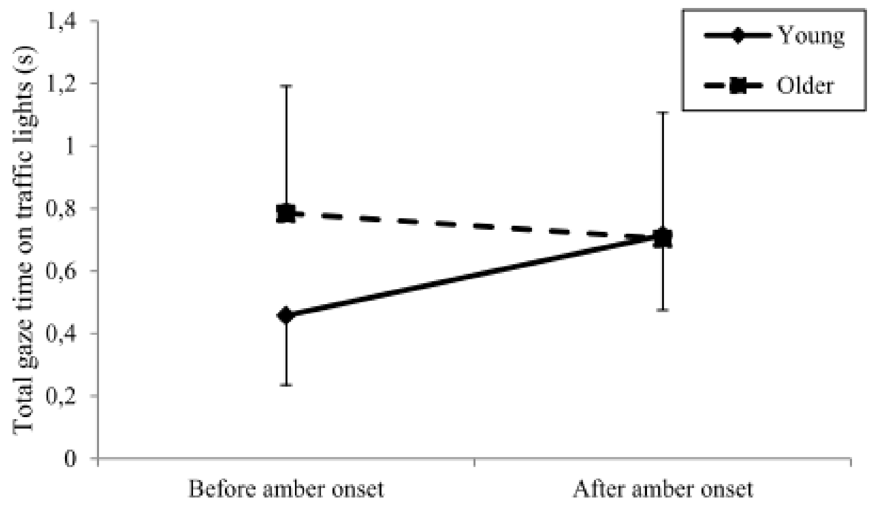
3. Results

With total gaze time as dependent variable, ANOVA yielded no significance for Age ($F(1,31) = 3.079$; $p > 0.05$) and Color ($F(1,31) = 1.614$; $p > 0.05$). However, significance emerged for the interaction term, Age * Color ($F(1,31) = 5.885$; $p < 0.05$). Fig. 1 (a) illustrates that total gaze time was consistently high in older participants while in young ones, it was low during the green interval and increased thereafter.

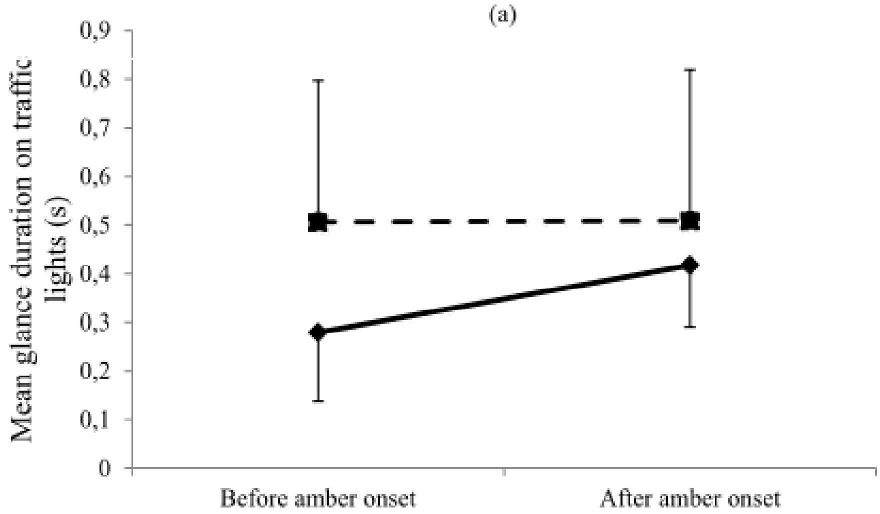
With mean glance duration as dependent variable, ANOVA yielded significance for Age ($F(1,31) = 7.381$; $p < 0.05$), but not for Color ($F(1,31) = 1.650$; $p > 0.05$) or Age * Color ($F(1,31) = 1.533$; $p > 0.05$). Fig. 1 (b) shows that on the average, each glance at the traffic light took about 50% longer in the older as compared to the young participants.

With the number of glances as dependent variable, ANOVA revealed no significance for Age ($F(1,31) = 0.906$; $p > 0.05$), Color ($F(1,31) = 0.189$; $p > 0.05$) or Age * Color ($F(1,31) = 0.906$; $p > 0.05$). The mean number of glances across age groups and colors was 1.64 ± 0.38.

For a more detailed view of the gaze pattern before and after a change of color, Fig. 2 illustrates the percentage of participants who fixated the traffic light in each video frame. Relatively few young subjects did so 1.75 s before the onset of amber, but their percentage increased as the change of color drew nearer (see Fig. 2 a). The percentage remained high for about 0.5 s after the onset of amber, and then it rather quickly decreased again (see Fig. 2 b). This general pattern prevailed across all three encounters with a color-changing traffic light. Older participants exhibited a somewhat different gaze behavior: a higher percentage of persons watched the traffic light already 1.75 s before the onset of amber (see Fig. 2 c). No overt age differences emerged after the onset of amber (see Fig. 2 d). Again, the general pattern prevailed across all three encounters with a color-changing traffic light.



(a)



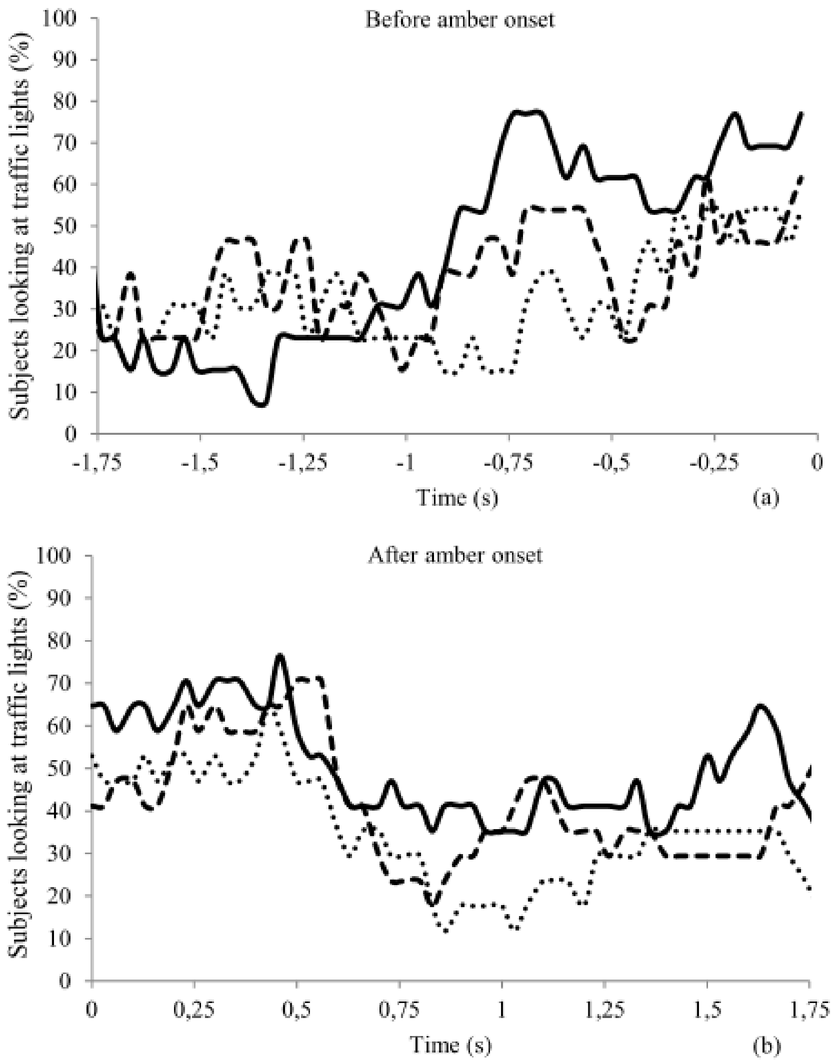
(b)

Figure 1. Total gaze time (a) and mean glance duration (b) of the young (solid line) and the older subjects (dashed line) across the three traffic lights during the last 1.75 s before and the first 1.75 s after the onset of amber light. Symbols represent the across-subject mean of a given age group, and error brackets show the pertinent standard errors.

The data of Fig. 2 are repotted in Fig. 3 in a more compact fashion. The percentage of subjects looking at the traffic light is averaged across blocks of 18 video frames and across all three instances where a traffic light turned red, i.e., we now have three blocks before and three blocks after the onset of amber. The general pattern of Fig. 2 can still be discerned. ANOVA with the between-factor Age and the within-factor Block revealed a significance for Age (F (1,34) = 19.70; $p < 0.001$), Block (F (5,170) = 84.10; $p < 0.001$) and Age * Block (F (5,170)=29.45; $p < 0.001$). Post-hoc decomposition of the interaction term with Tukey's HSD tests yielded highly significant age differences for the first and second block ($p < 0.001$), significant differences for the third block ($p < 0.05$) and no significant differences for the blocks after the onset of amber ($p > 0.05$).

4. Discussion

We investigated the gaze pattern of young and older persons who walked in an everyday-like virtual-reality scenario, encountered various events which required no response ("distractors" in terminology of laboratory research) but also came upon events which required different responses. The present study focuses on one type of event, pedestrian traffic lights that changed color from green to red and thus required participants to stop. We compared the gaze pattern of young and older participants and found that each glance at a traffic light took longer in in the older group (i.e., effect of Age on mean glance duration). This corresponds to earlier data about the gaze pattern when inspecting stationary displays [25, 26], and may reflect a generalized slowing of visual processing in old age. We further found that the sum of all glances at a traffic light was longer in the older group as well; older participants looked at the traffic light intensely throughout the green, amber and red phase, while young participants gradually intensified their inspection of the traffic light as the green phase went on and the likelihood of a color change increased.



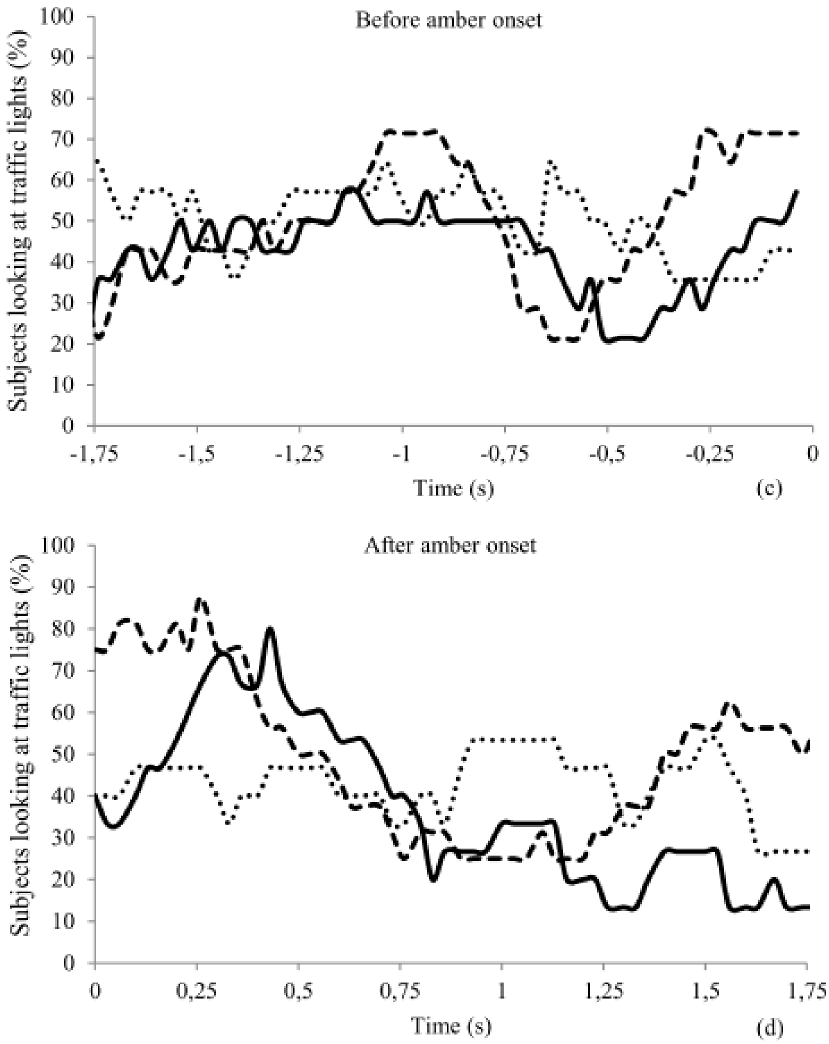


Figure 2. Percentage of young (a, b) and older (c, d) subjects looking at the traffic light during the last 1.75 s before (a, c) and the first 1.75 s after the onset of amber (b, d). Solid lines represent the first traffic light that was encountered changing color, dashed lines the second and dotted lines the third

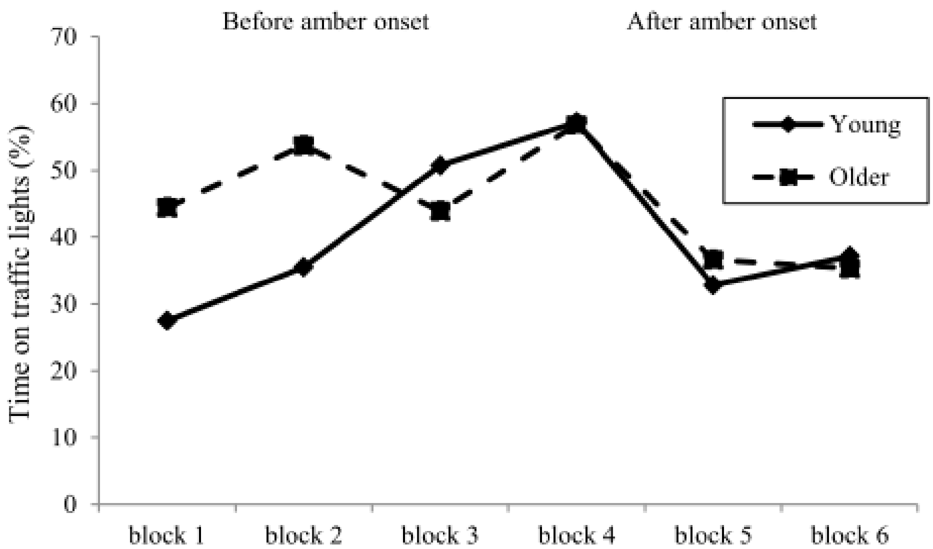


Figure 3. Percentage of subjects looking at the traffic light during three time blocks before and three after the onset of amber. Each symbol is the mean across 18 video frames x three traffic lights, averaged across subjects from an age group

Prolonged viewing of the traffic light in old age could be a sign of disinhibition: elderly persons have problems to suppress automated saccades towards potentially relevant objects [8, 10], possibly because prefrontal shrinkage [30] frees the "visual grasp reflex" of the midbrain [31] from higher-order control. Alternatively, prolonged viewing could be a compensatory strategy: just as longer glances at obstacles along the walking path may prevent trips and falls [17–20], longer glances at the traffic light may facilitate spatial orientation by minimizing eye and head movements [27], and may help preparing to stop by extending the available time [28, 29]. However, prolonged viewing also carries potential hazards: older persons who keep their gaze on the traffic light might miss other important events in their environment, such as uneven pavement or other pedestrians on a collision course. This should be taken into account when offering courses on traffic safety to older persons: it is important to teach participants not only to observe identified critical objects, but also to watch out for those that have not yet been identified.

ACKNOWLEDGEMENTS

Travel to the experimental laboratory was supported by a travel grant to P.R.B. from the Doctoral School in Human Sciences in the field of Anthropological, Pedagogical and Psychological Science at the University of Turin, and to S.B. from the Bulgarian Science Fund [BG051PO001/3.3-05-00 01]. Financial sponsors played no role in carrying out this work. The eye tracking system was kindly provided by a colleague of O.B.

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