Hemianopia and Visual Scanning Behavior during Cycling

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PSB3E-BT15: Bachelor Thesis

2223_2a_20 NL/EN

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July 7, 2023

Abstract

Introduction. People with hemianopia find it difficult to participate in traffic such as during cycling. They can use compensatory scanning strategies to limit these difficulties. There might be differences in visual scanning behavior between people who experience hemianopia for the first time and people who have had hemianopia for longer. The aim of this study was to research how visual scanning behavior during cycling differs between people with hemianopia, people who experience hemianopia for the first time and people without hemianopia. We also compared these three groups on the safety of their cycling behavior.

Method. To study this we set up a virtual reality experiment in which participants were asked to cycle through a virtual environment and brake in time for other road users. We compared people with hemianopia, people with unimpaired vision and people with simulated hemianopia (N = 12 for each group) on number of saccades per minute, mean saccadic amplitude, number of saccades per minute towards the blind hemi-field and time to collision.

Results. No significant differences in scanning behavior were found between the three groups, although the hemianopia group and simulated hemianopia group contained more variance than the unimpaired vision group. A trend in the simulated hemianopia group indicated that they employed more cautious cycling behavior.

Conclusion. People who experience hemianopia for the first time are more cautious during cycling. The lack of difference in scanning behavior could have been caused by the large variance within the groups or the lack of realism of the virtual reality environment. It could also be that less compensatory scanning is required during cycling than during other types of tasks. Compensatory training should take into account individual differences in hemianopia type and learning and should also focus on increasing confidence.

Keywords: hemianopia, scanning behavior, cycling, virtual reality

Hemianopia and Visual Scanning Behavior during Cycling

Introduction

Homonymous hemianopia is a visual field defect caused by brain damage in which people experience partial or full blindness in one part of their visual field in both eyes. People with hemianopia find it difficult to anticipate on obstacles or objects on the side of their visual field defect (De Haan et al., 2015), causing difficulties when participating in traffic such as during cycling. Cyclists with a visual field loss, such as people with hemianopia, find it particularly difficult to see other road users (Jelijs et al., 2019). Some people with hemianopia drive unsafely (Wood et al., 2009). They also have higher collision rates during driving (McGwin et al., 2016). Despite these possible safety issues people with visual field deficits still want to use the mode of transport that is perceived as most normal (Ball & Nicole, 2015). In some countries like the Netherlands, in which 25% of trips were made with a bycicle in 2021 (Centraal Bureau voor de Statistiek), cycling is perceived as a normal form of transportation. So to ensure that people can choose the mode of transport that is perceived as most normal, while also ensuring their safety it is important to study cycling behavior in people with hemianopia.

An important part of participating in traffic such as during cycling is visual scanning behavior, since scanning the environment is necessary for detecting other road-users. Consequently, they can appropriately react on them. To adapt to their visual field defect people with hemianopia can develop compensatory scanning strategies (Machner et al., 2009). When driving a car people with hemianopia have shown to employ different scanning behavior than people with unimpaired vision. They tend to make more and larger scans into the blind side of their visual field and fixate longer on cross-traffic cars in their blind hemisphere (Xu et al., 2022; Wood et al., 2011). This seems to suggest that people with hemianopia are biased towards the blind side of their visual field and make longer scans into their blind hemi-field. These compensatory scanning strategies can improve performance. Previous research has found that people with hemianopia who make longer saccades and more saccades into the blind hemi-field perform better on driving tasks (Bahneman et al., 2015; Papageorgiou et al, 2012; Xu et al., 2022).

Compensatory training can also help improve visual scanning behavior in people with hemianopia (De Haan et al., 2016). Compensatory scanning behavior is specific to certain tasks however and it is therefore important that compensatory training specifically for cycling is further developed (Schuett et al., 2009). Compensatory training also results in people with hemianopia making longer scans with the number and amplitude of saccades significantly increased (Keller & Lefin-Rank, 2010).

People who experience hemianopia for the first time might employ different compensatory scanning strategies than those that have had hemianopia for a longer time. When people with unimpaired vision perform visual search tasks with a simulation of hemianopia, they show similar scanning behavior as that of people with hemianopia (Tant et al., 2002; Schuett et al., 2009). However, people in which hemianopia is simulated do not spontaneously adopt efficient compensatory strategies (Nowakowska et al., 2016). In the beginning people with simulated hemianopia are mainly focused on the blind hemi-field and only after some time do they develop more efficient compensatory strategies (Simpson et al., 2011). It is useful to look at how visual scanning behavior differs in people who experience hemianopia for the first time as this could reveal how people differ in their scanning behavior before they have learned to adapt to their visual field defect. It could also help in knowing which scanning behavior needs to be targeted by compensatory training in the early stages of hemianopia.

Simulating hemianopia in real life is difficult and could create unsafe situations. A much safer option is the use of virtual reality. Virtual reality can also combine a high degree of experimental control with a high degree of ecological validity (Bohil et al., 2011; Bell, 2020). Developing and maintaining virtual reality applications is, however, complicated, costly and more research on the reliability and validity of virtual reality experiments is needed

(Bell, 2020). Eye strain and virtual reality sickness can also often occur (Bell, 2020). Although virtual reality has some potential problems with validity and reliability and it can induce simulation sickness, it can also be valuable due to its safety and high degree of experimental control, which in this case is especially useful for simulating hemianopia.

The aim of this study will be to research how visual scanning behavior during cycling differs between people with hemianopia, people who experience hemianopia for the first time and people with unimpaired vision. We will study visual scanning behavior by looking at the difference in exploration and length of scans between these three groups during cycling in virtual reality. We will measure this with the number of saccades per minute, the number of saccades per minute to the blind side and the saccadic amplitude. We will also be looking at how safe the cycling behavior of the participants was and how long it would have taken before a collision would have happened after they braked as measured by the time to collision. That could tell us if differences in scanning strategies are related to differences in safe cycling behavior. Taken together these results could help to give a better understanding of the compensatory strategies that people with hemianopia use during cycling. This knowledge can be used to improve compensatory training by providing information on which characteristics of visual scanning behavior need to be targeted.

Methods

Participants

There were 48 participants which took part in this study of which 16 had hemianopia and 32 had normal vision. Of the 48 initial participants 4 with hemianopia and 8 with normal vision dropped out due to symptoms of nausea during the experiment. The participants were divided into three groups of 12 participants consisting of a group with people with hemianopia, a group with people with unimpaired vision who were subjected to a hemianopia simulation and a group with people with unimpaired vision who did not receive a hemianopia simulation. Participants in all three groups were matched with each other based on similar age and gender. The demographics of these groups are presented in table 1.

Participants with hemianopia were recruited through Royal Dutch Visio Netherlands. Those without hemianopia were recruited through a convenience sample by social media resources. Inclusion/exclusion criteria for all participants were an age of 18 years and older, no signs of neglect, no (other) visual or neurological disorders, no eye- or head-movement impairments and no severe psychiatric, cognitive, balance, orientation and language or communication impairments. All participants took the Mini-Mental State Examination (MMSE) and were only included if they had a score higher than 24. Inclusion/exclusion criteria specifically for participants with hemianopia were a homonymous visual field defect of at least quandrantopia level with a neurological cause without a visual field defect on the ipsilesional side, the time since onset longer ago than 3 months and a visual acuity above 0.5. All participants also took part in two related studies on street crossing and walking. All participants signed an informed consent form and the study was ethically approved by the medical ethical committee of the Universitair Medisch Centrum Groningen.

Table 1. *Demographics participants (N=54)*

		HH	UN	SH
Age (M [SD])		57.5 (19)	57.9 (19)	59.6 (21)
Gender Male (%)		83.3%	83.3%	83.3%
Time of onset (M [SD])		25.2 (16)		
Side Left (%)		58.3%		
Macula Sparing Yes (%)		50%		
Quadrant	**Upper (%)**	16.7%		
	Both (%)	75%		
Cause	**Stroke (%)**	66.7%		
	Traumatic brain injury (%)	25%		
	Tumor (%)	8.3%		
Training	**Finished (%)**	41.7%		
	Practicing cycling last stage (%)	8.3%		
	Practicing walking inside (%)	8.3%		
	Not started (%)	16.7%		
	Not necessary (%)	25%		

Note. HH: homonymous hemianopia, UN: unimpaired vision, SH: simulated hemianopia.

Materials

To display the virtual environment we used the HTC Vive Pro eye, which has a horizontal and vertical field of view of approximately 90 degrees, a sampling rate of 90 Hz and a 1440 x 1600 pixels resolution. The HTC Vive Pro eye has a Tobii XR build in eye-tracker, which has an accuracy of 0.5-1.1 degrees with 5-point calibration. The Vive SRanpial SDK software was used to access the tracking data at a 90 Hz sampling rate. We also used a bicycle of which the front wheel was blocked. The movement information of the back wheel was sent to the virtual reality headset to create a corresponding movement in the virtual world by using the TUO cycling trainer (Elite, Fontaniva, Italy). Figure 2 shows the setup used for this.

The virtual environment was created in Unity by The Virtual Dutch Man Corporation. In the virtual environment, you bike along a neighborhood street on which cyclists cross the street in front of you during 8 events as shown in table 2. Cyclists either crossed on an intersection or at an unexpected part of the road without crossing markings. Distractions were also present, consisting of crowds of noisy people stationed along the way. Figure 1 shows an example of what the virtual environment looked like.

During the experiment we made use of the Motion Illness Symptoms Classification (MISC) scale (Reuten et al., 2021) to monitor motion sickness symptoms in the participants. People were asked if they felt discomfort with no specific symptoms or if they had symptoms such as dizziness with no nausea and to what degree or if they experienced nausea and to what to degree. Based on their answers their level of motion sickness was rated from 0 to 10, where 0 indicated no problems, scores between 2 and 5 indicated symptoms of motion sickness but no nausea and scores above 6 indicated degrees of nausea.

Table 2. *Events during cycling in the virtual reality environment*

Event	**Coming from the left or right side**	**Location**	**Distraction present**
1	Right	Crossroad	No
2	Right	Unexpected	Yes
3	Right	Unexpected	No
4	Left	Unexpected	No

5	Left	Crossroad	Yes
6	Left	Unexpected	Yes
7	Left	Crossroad	No
8	Right	Crossroad	Yes

Note. Crossroad means that a cyclist crossed the road on a crossroad while unexpected means that a cyclist crossed the road on an expected location instead of at a crossroad as expected. Distraction present means that while the cyclist crossed the road a distraction was present in the form of a crowd of noisy people.

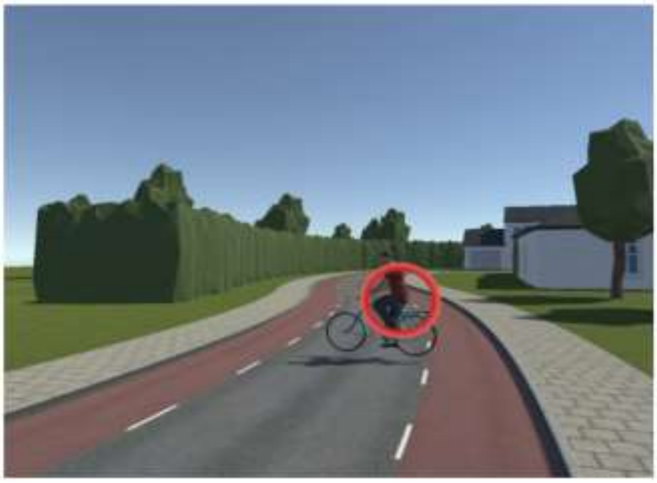

Figure 2. The virtual reality cycling environment. The red circle represents the location of eye movements.

Figure 1. Setup for the bicycle and virtual reality headset.

Protocol

During the experiment a window was opened to provide participants with fresh air and to mitigate nausea symptoms. After the participants were seated on the bike, they had to put on and adjust the headset. The eye-tracker was calibrated by having participants make eye movements towards five different dots. Participants began with a practice round to get familiar with the virtual environment. They were told to practice braking by stopping for every stop sign. When they were done practicing, scenario 1 was activated.

The participants were instructed to brake timely for other crossing road users coming from the left or right side. In scenario 1, cyclists crossed the road during 8 events as described in table 2 in the order of 1 to 8. After this scenario 2 was started, which was similar to scenario 1, but now the events were in reverse order from 8 to 1. Then the headset was removed and the experiment was finished. Both after the practice round and after scenario 1 the MISC scale was administered and participants were only allowed to continue if they had a score lower than or equal to 6.

Data Analysis

The data analysis was performed in Matlab version 2022b. Invalid data from the eye-tracker was excluded and some of the missing data was filled in using the Piecewise Cubic Hermite Interpolating Polynomial with a maximum data gap of 0.1s. Afterwards the normalized vectors of the eye-tracker data were translated into degrees, using the x-axis for horizontal eye movements and the y-axis for vertical eye movements.

The first variable we calculated was the number of saccades per minute. This is the number of rapid eye movements a person makes to explore a visual scene. The detection of saccades was performed by looking at the velocity of eye movements and making use of the variable velocity threshold of Hooge & Camps (2013) to distinguish them from other types of eye movements. The second variable we calculated was the number of saccades per minute towards the blind side of the visual field. The third variable we calculated was the amplitude of saccades. This variable measures the length of an eye movement that people make to scan their environment. This was calculated by using the distance between the beginning and end of a saccade for both their vertical and horizontal eye orientation combined, using the Pythagoras theorem. The fourth variable we calculated was time to collision. This variable is the time it would have taken after participants braked before they would have crashed into another cyclist. A time to collision of 0 would indicate a crash and higher times to collision indicate a safer braking time than lower times to collision.

Statistical Analysis

The statistical analysis was performed in SPSS version 28.0.1.1. We wanted to compare the groups with hemianopia, without hemianopia and with simulated hemianopia on visual scanning behavior by analyzing saccadic exploration and the length of saccades. In this study the number of saccades per minute and number of saccades per minute towards the blind side were used as measures of exploration and the saccadic amplitude was used as a measure of the length of scans. We also examined the safety of braking decisions between groups, which we measured by using time to collision. A 4x3 ANOVA was performed with the dependent variables number of saccades per minute, saccadic amplitude, number of saccades per minute towards the blind side and time to collision and the three different groups as between group factor. If differences were found the Tukey HSD test was used to see which groups differed from each other. A difference between the hemianopia group and the unimpaired vision group on exploration would indicate that people with hemianopia use compensatory scanning behavior during cycling. A difference between the hemianopia group and simulated hemianopia group would mean that people experiencing hemianopia for the first time use different compensatory scanning strategies than people who have had hemianopia for a longer time. A difference between the simulated hemianopia group and the unimpaired vision group would imply that people who experience hemianopia for the first time use different visual scanning behavior during cycling than people without hemianopia. We used an alpha value of 0.05 and Eta squared to measure effect sizes with effect sizes below 0.01 considered small, between 0.1 and 0.3 medium and above 0.5 large (Iacobucci, 2023). Results with a p-value between 0.05 and 0.1 and a large effect size were taken as an indication for a trend.

Results

There was little difference between people with hemianopia, people with simulated hemianopia and people with unimpaired vision on saccadic exploration and length of scans. This is indicated by no significant group effect on the variables number of saccades per minute, number of saccades per minute towards the blind side and saccadic amplitude as shown in table 3 and figure 3, 4 and 5. For saccades per minute there was a medium effect size and for saccades towards the blind side and saccadic amplitude a small effect size. Although there was no statistically significant difference on these variables between the three groups, table 3 does show that the standard deviations for the hemianopia and simulated hemianopia groups were much larger than in the unimpaired vision group, indicating a lot of variance within these groups.

Although the difference between the three groups was not statistically significant with an alpha-value of 0.05, there was a trend for a difference between the simulated hemianopia group and the other two groups on time to collision. This is indicated by the large effect size between the three groups and a p-value between 0.05 and 0.1 as shown in table 3. When looking at figure 6 we can also see that the time to collision of the simulated hemianopia group was higher than the other two groups. This is confirmed by the results of a post-hoc test as shown in table 4, which indicates that the difference between the simulated hemianopia group and the other two groups would have been significant with an alpha-value of 0.1.

Table 3. *Descriptive statistics and results ANOVA*

	M(SD)			F(df)	p	η^2
	HH (N=12)	**UN (N=12)**	**SH (N=12)**			
Number of Saccades	114 (25)	114 (10)	104 (20)	1.049 (33)	.362	.060
Number of Saccades Blind Side	55.2 (11)	57.0 (6.7)	52.9 (13)	.461 (33)	.635	.027
Saccadic Amplitude	9.57 (2.2)	9.33 (1.5)	8.76 (3.9)	.282 (33)	.756	.017
Time to Collision	1.57 (.64)	1.86 (.60)	2.24 (.85)	2.687 (33)	.083	.140

Note. HH: homonymous hemianopia, UN: unimpaired vision, SH: simulated hemianopia.

Table 4. *A post hoc test comparing the three groups (N=12 each group) on time to collision*

Tukey HSD	Group	p
HH	**UN**	.584
	SH	.068
UN	**HH**	.584
	SH	.397
SH	**HH**	.068
	UN	.397

Note. HH: homonymous hemianopia, UN: unimpaired vision, SH: simulated hemianopia.

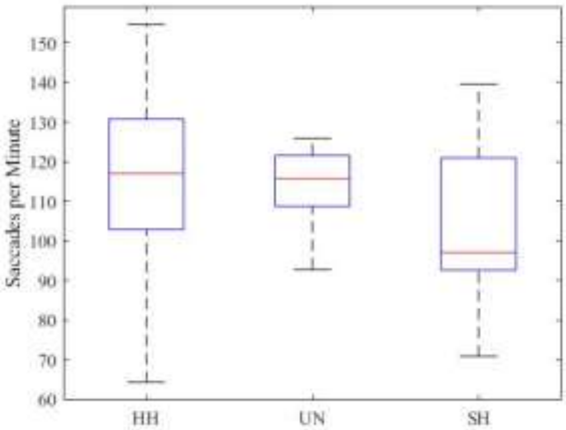

Figure 3. The number of saccades per minute for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal line in the boxplot shows the mean of each group. The vertical black lines show the standard error of each group.

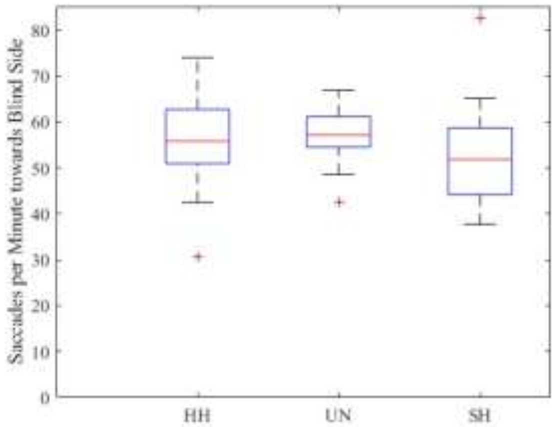

Figure 4. The number of saccades per minute towards the blind side for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal line in the boxplot shows the mean of each group. The vertical black lines show the standard error of each group

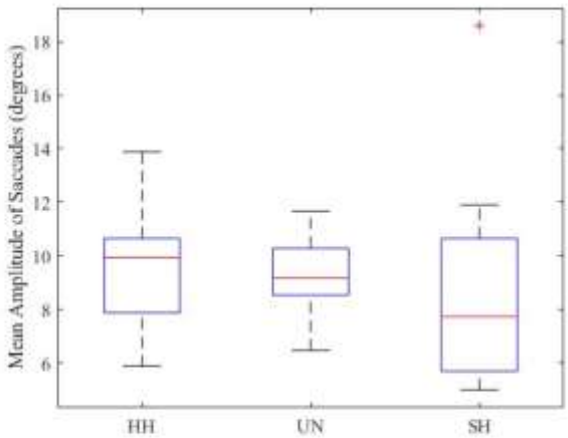

Figure 5. The saccadic amplitude for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal line in the boxplot shows the mean of each group. The vertical black lines show the standard error of each group.

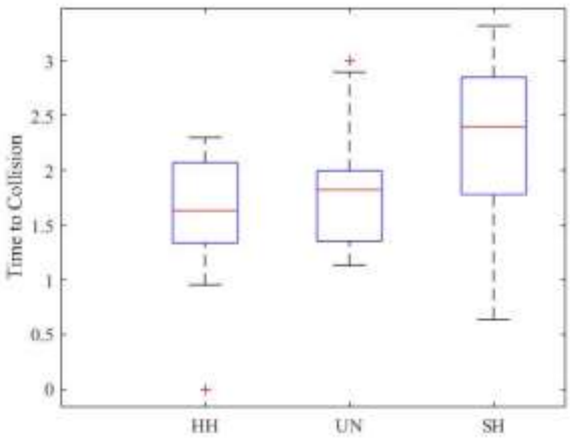

Figure 6. The safety margin in seconds after street crossing for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal line in the boxplot shows the mean of each group. The vertical black lines show the standard error of each group.

Discussion

The aim of this study was to investigate how visual scanning behavior during cycling differs between people with hemianopia, people who experience hemianopia for the first time and people without hemianopia to improve compensatory training by providing information on which characteristics of visual scanning behavior need to be targeted. We also compared these three groups on the safety of their cycling behavior. In our experiment we found little difference on the number of saccades, number of saccades towards the blind side and saccadic amplitude between the three groups. This indicates that people with hemianopia, people who experience hemianopia for the first time and people with unimpaired vision do not employ different scanning strategies during cycling. However there was much more variance within the hemianopia groups than in the unimpaired vision group. For time to collision we found a trend for a difference between the simulated hemianopia group and the other two groups, suggesting that people who experience hemianopia for the first time might be more cautious during cycling.

We could not find a difference in visual scanning behavior during cycling between people with hemianopia and people with unimpaired vision. This is not in line with previous studies which found that people with hemianopia make more saccades per minute towards the blind side than people with unimpaired vision (Elfeky et al., 2021; Xu et al., 2022; Wood et al., 2011). The variance within the hemianopia group was much larger than in the unimpaired vision group, which might be an indication that there are other variables which divide the hemianopia group. It could be that there is more variance in the hemianopia group because the majority of them were engaged in or had already completed compensatory training. People with hemianopia who engaged in compensatory training could have employed more exploration and longer scans as found by Keller & Lefin-Rank (2010) than those who did not follow compensatory training, causing the large variance.

The large variance in the hemianopia group might also be explained by different types of hemianopia leading to different scanning behavior.

The lack of differences in scanning behavior could also be because the task of cycling is too easy to require different scanning strategies. Cycling is slower than driving a car and thus requires less caution and visual exploration of the environment. This could be contradicted however by findings that people with hemianopia employ more exploration of their blind hemi-field and longer scans than people with unimpaired vision during visual search tasks and viewing naturalistic pictures (Pambakian et al., 2000; Jahnke et al., 1995). Such tasks seem easier than cycling and yet they do seem to elicit a difference on these characteristics. Perhaps it is not necessarily the difficulty of tasks which explains the differences in findings between tasks, but merely the fact that they are different tasks. This is supported by the finding that compensatory scanning strategies are highly task specific (Schuett et al., 2009).

Lastly our results could be explained by the limitations of our virtual reality environment. The virtual reality environment could have been not realistic enough. People may have not felt the need to carefully explore the environment as they might do in their everyday life to avoid danger. Another problem could be that they experienced nausea because of the virtual reality headset. Due to this they may have kept their head and eye movements still to avoid feeling more nauseous. The field of view of 90 degrees is another limitation of the virtual reality headset, as normally humans have a field of view of 180 degrees. Participants may have been prevented from properly exploring the parts of the visual field which were blocked by the virtual reality headset.

Despite the hemianopia group not differing in their scanning behavior from the people with unimpaired vision, the safety of their cycling was similar. That is not in line with previous studies, which found that people with hemianopia who make saccades with higher amplitudes and more saccades into the blind hemi-field employ safer behavior during mobility tasks (Bahneman et al., 2015; Papageorgiou et al, 2012; Xu et al., 2022). Our results are also different from research that found that some people with hemianopia drive less safely than people with unimpaired vision and cause more collisions (Wood et al., 2009; McGwin et al., 2016). Our findings suggest that people with hemianopia are just as careful during cycling as those with unimpaired vision. As previously stated, these differences could be caused by the large variance in the hemianopia group due to differences in compensatory training and hemianopia type or the lack of realism of the virtual reality environment. It is also possible that people with hemianopia do not actually need to employ different scanning behavior during cycling to cycle safer. Due to the large variance in the hemianopia group this seems unlikely however. Our findings may at least infer that people with hemianopia can cycle just as safely as people with unimpaired vision.

Our findings suggest that people who experience hemianopia for the first time do not employ different scanning behavior during cycling than people who have had hemianopia for a longer time. This is in line with some results from previous research, which found that simulated hemianopia elicits similar scanning behavior as in hemianopia (Tant et al., 2002; Schuett et al., 2009). People who experience hemianopia for the first time may develop similar types of compensatory scanning strategies as those of people who have had hemianopia for longer. This is not in line however with research in which people with a hemianopia simulation did not spontaneously develop efficient compensatory scanning strategies as found in people who have had hemianopia for a longer time (Nowakowska et al., 2016; Simpson et al., 2011). As mentioned earlier the virtual reality environment may not have been realistic enough to elicit compensatory scanning behavior in both groups, which might have prevented us from being able to analyze the difference in compensatory scanning strategies between these two groups.

We found a trend that people who experienced hemianopia for the first time were more careful in their cycling than people with hemianopia. This could be because people who experience hemianopia for the first time are more insecure. It might also be that people with hemianopia who followed compensatory training feel more confident, although this may be less likely because not all of our participants followed such training and the difference in variance between the simulated hemianopia and hemianopia group is minimal.

We found little difference between the simulated hemianopia group and the unimpaired vision group in visual scanning behavior during cycling. This is not in line with previous research which found that people with unimpaired vision who are subjected to a hemianopia simulation show more exploration of the blind side (Simpson et al., 2011). The variance of the simulated hemianopia group being much higher than that of the unimpaired vision group could have been the cause of this. People in the simulated hemianopia group were subjected to simulations of different types of hemianopia, which might have caused the larger variance. The larger variance may also have been caused by individual differences in learning, leading to people developing different compensatory scanning strategies within the group who experienced hemianopia for the first time. Cycling could also have been too different from tasks used in previous studies to find the same results. Maybe the virtual reality environment was not realistic enough to elicit a difference in scanning behavior between these groups as well. Perhaps our results suggest that people who experience hemianopia for the first time do not employ compensatory scanning behavior, but again this seems unlikely due to the aforementioned reasons. We found a trend that people in the simulated hemianopia group were more careful in their cycling than people with unimpaired vision. This might be because people who experience hemianopia for the first time are not used to the hemianopia simulation, which makes them more cautious and less confident of their cycling ability than they would normally be.

The clinical implications of our results can be threefold. First of all our finding that there was a large difference in variance in scanning behavior between the simulated hemianopia and the hemianopia group as compared to the unimpaired vision group suggests that it is important to develop different compensatory training for different types of hemianopia. The large difference in variance between the simulated hemianopia and unimpaired vision group suggests that it may also be necessary to account for individual differences in learning during compensatory training. The clinical implication of our finding that people who experience hemianopia for the first time are more cautious during cycling should be that it is imperative to focus on increasing their confidence during compensatory training to prevent people from being overly careful. It is important to not be overly cautious in traffic, because this might cause irritation in other road users and confusion when someone who is overly careful might give way to other road users who do not have the right of way, which may lead to collisions.

Our greatest limitation was the realism of the virtual reality environment. The lack of realism of the virtual reality environment could have caused people to not perceive the virtual reality world as threatening enough to actually employ compensatory scanning behavior. As mentioned earlier the field of view of the virtual reality headset might have limited scanning behavior. Nausea might have also distracted people and limited their exploration. Another limitation of this study was our sampling method. Our use of a convenience sample might have biased the simulated hemianopia and unimpaired vision groups. As the hemianopia group contained both differences in type of hemianopia and amount of compensatory training that could explain the larger variance within this group in comparison with the unimpaired vision group. Because we did not take these differences within the groups into account by analyzing their effect on scanning behavior, we may have been limited in the interpretation of our results.

So, experiencing hemianopia, whether for the first time or for a longer time, did not change scanning behavior during cycling in our study. The larger variance of the simulated hemianopia and hemianopia group as compared to the unimpaired vision group, the lack of realism of the virtual reality environment or cycling being too different from tasks used in previous research could also explain the difference between our results and those of previous studies. We also found that people with hemianopia may be able to cycle just a safely as people without hemianopia and that people who experience hemianopia for the first time are more cautious during cycling. Future research could use a more realistic virtual environment which induces less nausea or study cycling in a real-world environment to increase ecological validity. Future studies should also divide the hemianopia group and simulated hemianopia group into subgroups to analyze the effects on the results of hemianopia type, compensatory training and individual differences in learning.

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