

The affect of visual acuity on driving ability

A simulator study

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Kort sammanfattning

Flera synförmågor tenderar att försämrars med ökad ålder. Trots detta kontrolleras synförmågan i Sverige endast i samband med ansökan om körkortstillstånd. Denna studie genomfördes med syftet att undersöka synens påverkan på körförmåga, oavsett ålder. Totalt deltog 89 personer (36 män) i åldrarna 18–77 år i studien. Deltagarna var uppdelade i fem grupper: två yngre grupper med godkänd ($\geq 0,5$) respektive nedsatt syn (nedsatt till minst 0,4), två äldregrupper med godkänd ($\geq 0,5$) respektive nedsatt syn (nedsatt till minst 0,4) samt en grupp personer med ögonsjukdom (glaukom, katarakt och AMD). Med tanke på att tidigare forskning har visat att det behövs fler syntester än enbart synskärpa (visus) för att bedöma bilkörning kompletterades visus med kontrastseende och testet Useful Field of View (UFOV) samt simulatorkörning. Datainsamlingen, i en körsimulator från VTI, genomfördes av studenter på Optikerprogrammet vid Karolinska Institutet i Stockholm. Körsimulatorens var en stationär simulator utan rörelseplattform som var utrustad med automatlåda och tre skärmar. Inga skillnader mellan grupperna framkom när det gäller antal krockar, men däremot fanns signifikanta skillnader vid flera händelser under simulatorkörningen. För de två yngre grupperna fanns skillnader för totalt 5 av 12 händelser. De med nedsatt synskärpa såg fotgängare eller fordon senare än de med bättre synskärpa. Detta resulterade i ett riskfyllt körbeteende eftersom de reagerade för objektet, det vill säga bromsade eller stannade, senare eller hade högre hastighet än vad som var lämpligt. För de äldre framkom skillnader mellan grupperna i 3 av 12 händelser. De äldre förarna med god syn upptäckte fordonet och fotgängarna tidigare, vilket betyder att de uppvisade en bättre reaktionsförmåga och därmed ett säkrare körbeteende. Studien visade således att körsimulator är ett användbart verktyg för att bedöma körförmåga och att synfunktioner spelar en viktig roll för säker bilkörning. Dock behöver detta studeras ytterligare för att öka förståelsen för exakt vilken grad av nedsättning kopplat till varje typ av synförmåga som försämrar körbeteendet och leder till minskad trafiksäkerhet.

Nyckelord

Körförmåga, synskärpa, trafiksäkerhet

Abstract

As we age, visual abilities tend to worsen. Despite this, in Sweden vision is only checked when applying for a drivers' licence. This study was performed to investigate the impact of vision on driving ability, regardless of age. Eighty-nine people (36 men) between the ages of 17 and 77 participated in the study. Participants were divided into five groups: two younger groups with good (≥ 0.5) and impaired visual acuity (impaired to at least 0.4), two older groups with good (≥ 0.5) and impaired visual acuity (impaired to at least 0.4), as well as a group with people with eye disease (glaucoma, cataracts and AMD). Considering that previous research has shown that there is a need for more vision tests than just visual acuity (visus) to determine driving ability, contrast vision, the Useful Field of View (UFOV) test and simulator driving were also used in this study. Data collection, in a driving simulator from VFI was performed by optometry students from the Karolinska Institute in Stockholm. The driving simulator was a stationary simulator with an automatic gearbox and three screens, but no moving platform. There were no differences between groups when it came to collisions, but there were several significant differences during different events while participants were using the simulator. For the two younger groups, there was a difference in 5 out of 12 events. Pedestrians and other vehicles were seen later by those with an impaired visual acuity compared to those with good visual acuity. This resulted in risky driving behaviour because they reacted to the object, either braked or stopped, later or had a higher speed than was appropriate. For the older groups, there are differences between 3 out of 12 events. The older drivers with good visual acuity saw the vehicle and pedestrian sooner, which meant that they were able to react better and drive more safely. The study showed that a driving simulator is a useable tool to determine driving ability and that visual ability plays an important role in safe driving. However, this does need to be studied further to increase our understanding of exactly the degree of impairment associated with each type of visual impairment that impairs driving behaviour and leads to reduced road safety.

Keywords

Driving ability, visual acuity, traffic safety

Preface

The National Society for Road Safety (NTF in Swedish) has commissioned this simulator study to investigate whether visual acuity has an affect on the ability to drive safely. Data collection was performed with the help of optometry students and their supervisor Marika Wahlberg Ramsay from the Karolinska Institute, and we would like to thank them for their help. Data analysis, collation and writing was performed by the researchers, Helena Selander, Per Henriksson and Birgitta Thorslund at The Swedish National Road and Transport Research Institute (VTI). Help with the simulator and adjustments to the program were provided by Andreas Jansson at VTI. Translation of this report to English was performed by Kate Bramley-Moore.

We would also like to thank all of the participants who have contributed to the data collection.

Gothenburg, January 2020.

Helena Selander
Project leader

Granskare/Examiner

Björn Lidestam, VTI.

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1. Introduction

Several visual abilities tend to worsen with increasing age, such as visual acuity, contrast vision, the ability to change between different distance viewing and the ability for pupil's to change according to light conditions. Despite this, in Sweden vision is only checked when applying for a drivers' licence. The required binocular visual acuity for passenger vehicle drivers has been set at least 0.5 (central, with/out corrective lenses) since 1984 (1). For those who drive for a living (group 2 licences), the binocular (both eyes together) visual acuity requirement is 0.8, and every five years the professional driver is required to have both a doctor's and vision test certificate (1). Before 1984, the visual acuity requirement was higher for passenger vehicle drivers, but was changed because it was determined that "passenger vehicle drivers can decide for themselves if driving a car is appropriate or not" (2).

In contrast to some other countries within the EU, Swedish doctors are required to report drivers with insufficient vision to the Transport Agency (Transportstyrelsen). If visual acuity for passenger vehicle drivers is below 0.3 and the worsening of vision has happened suddenly, a 6 month adjustment period is required before the licence can be renewed (1). This is due to the need for the driver to adjust and become familiar with different ways of assessing distance and depth.

For a passenger vehicle licence, vision testing is performed by a doctor, optometrist, eye nurse, orthoptist etc. In order to measure visual acuity a 4 or 5 meter eye chart should be used. All of the optotypes (letters) should be able to be read without error. For group 2 licences the eye test can only be performed by a doctor and visual acuity should be at least 0.8 in the best eye and a minimum of 0.1 in the worse eye with the best correction. There is an exception for taxi driver registrations, which can be given even if the worse eye's visual acuity is lower than 0.1, as long as the binocular visual acuity is at least 0.8 (and the other visual requirements are met) (1).

It's common that visual acuity begins to worsen between the ages of 40 and 50, and is compensated with the use of glasses or contact lenses. With increasing age the need for light increases and there is a reduced adjustment ability, which can be relevant when driving in the dark or when driving in and out of a tunnel during the darker hours of the day. In contrast to other countries in both the Nordic region and the EU, Sweden doesn't require assessment to ensure that passenger car drivers have sufficient vision after a certain age (3). Drivers with low visual acuity can therefore continue to drive as long as they don't seek healthcare (3). Opinions surrounding Sweden's visual acuity requirement levels and aged based health checks have been discussed and recently a study was performed, looking at the connection between being involved in an accident and 'traffic dangerous' illnesses amongst older drivers (4). The report included different diagnoses from the Traffic Agency's regulations and general advice about medical requirements for possession of a driver's licence (TSFS 2010: 125). According to the report, drivers with illnesses common amongst the elderly, such as cardiovascular illness, and reduced visual function had an increased likelihood of being in an accident, compared to drivers with a diagnosis (4). Individuals with a reduced visual function had had some kind of contact with the healthcare system (not primary care) because of an eye disease or other diagnosis that had affected their vision were included in the study. Excluded from the study were individuals who had 'only' reduced visual acuity or reduced contrast vision because of their age.

Winter in Sweden is long, and it can be difficult for all of us to drive during the long dark months. The ability to see contrast reduces as we age. Contrast vision is important to be able to see and recognise small details and is important for safe driving, because it requires a person to be able to see objects both when it is dark as well as light (5).

For example, a curb can appear diffuse and difficult to see for someone with reduced contrast sensitivity (see Image 1 below). However, people with reduced contrast sensitivity can still have good visual acuity. Some age related illnesses, such as cataracts, primarily affect contrast sensitivity. People who have reduced contrast sensitivity can have difficulty in several different daily activities, such as reading and driving (6). In studies that have specifically investigated driving, contrast sensitivity

impairment has been shown to result in a reduced capacity to recognise road signs and dangers in traffic (7), manoeuvring (8), and driving in the dark (9,10).



Image 1. Photo from www.medicinskoptik.se/.

Vision, cognition and motor skills are all important components in safe driving and vision and attention are significant factor in good driving ability (11). However there has yet to be found an unambiguous connection between vision and traffic safety (12,13). The way in which Sweden measures visual acuity has been criticised as it is done statically and not dynamically. The reason that vision is not reassessed as being sufficient after someone has a driver's licence is most likely one of monetary but also time cost, or for safety's sake (eg driving tests). Using a simulator has been discussed as a tool to assess the importance of vision in safe driving. Simulator programs contain specific variables that pose a risk when driving, such as a child or an elk running out into the road. A driving simulator is a safe alternative to driving assessment performed on roads, which minimises the risks and makes it possible to assess reproducible driving conditions (13). In summary, our aim with this study was to investigate, using a driving simulator, if vision affects safe driving ability. If a driver with reduced visual acuity (<0.4) was a less safe driver than one with a better visual acuity (>0.5).

2. Methods

2.1. Data collection and participants

Data collection was performed by students from the optometry programme at the Karolinska Institute in Stockholm. Participants were recruited using the students' network, NFT's network, and advertising at St Göran's Eye Clinic. Participants received both verbal and written information about the study, and that their participation would not affect their licence status. Eighty nine people (36 men) between the ages of 18 and 77 participated in the study and all of them had a valid driver's licence. Before testing began participants answered a few questions about their driving habits.

Considering that previous research has shown that more than just visual acuity tests are required to assess driving (14), visual acuity testing was complemented with a test to look at contrast vision, the test Useful Field of View (UFOV), as well as driving in the simulator. UFOV is a data based visual and cognitive test that measures visual processing speed (part 1), divided attention (part 2) and selective attention (part 3) (15). The result for each part is presented in the form of milliseconds (ms) and can vary between 13-1500 ms (a lower value means a better result). A UFOV result generates an estimated risk (risk category 1-6), which establishes what the risk is that a driver may cause a collision (for example, risk category 1 = a very low risk). The test has repeatedly shown to be correlated with driving and demonstrated good validity and reliability (15,16). Visual acuity was measured monocularly (one eye at a time) as well as binocularly (both eyes together) on a LogMar chart with high contrast and also with low contrast, 10%. All measurements were performed in the same light conditions in the same room for all participants. A binocular sight test (Titmus) was performed to ensure that participants could see with both eyes simultaneously. For the tests performed, all participants used their own corrective lenses for distance. Once vision had been tested, half of each group had their binocular visual acuity reduced by fogging to 0.4. This was to ensure that participants were not able to see better than 0.5 binocularly. The reduction was achieved by adding plus lenses while participants were looking at a sight chart until the desired reduction was achieved. This was done at a measured distance to each test respectively; UFOV, 60cm and 100cm for the driving simulator.

2.2. The simulator

The driving simulator was a stationary simulator without a moving platform and was fitted with an automatic gearbox and three screens (see Image 2 below). The program had been developed for a previous vision project (17) and began with a practice section of around 5 minutes so that participants could familiarise themselves with the simulator. After this the 'test driving' began (approximately 15 mins), which consisted of a driving scenario in which there were close to 20 or more or less critical situations, such as vehicles or pedestrians which suddenly drove/walked out in front of the driver. The situations were evaluated with a selection of measurements such as collisions, position, distance, speed and reaction time.



Image 3. The simulator used in the project.

3. Results

Participants were divided into five groups: two younger groups with good (≥ 0.5) and impaired (reduced to at least 0.4) visual acuity, two older groups with good (≥ 0.5) and impaired (reduced to at least 0.4) visual acuity, as well as a group of people who had eye disease (glaucoma, cataracts and AMD). The first four groups consisted of 20 people, and the final group, with eye disease, consisted of 9 people (Table 1). The two younger groups were compared separately (t-test or Chi²-test), and the older groups, as well as the group with eye disease, were compared with each other (ANOVA and Tukey's post hoc test). Significance was set at 5%.

3.1. Background data, sight status and summarised simulator performance

In the table presented below, background data, results of the vision tests and a few general measurements of behaviour during the simulation. Two older people were forced to stop the simulation because of nausea (simulator sickness).

*Table 1. Gender distribution, age, visual performance and summarised measurements from the simulated driving. *One person in each age group stopped because of simulator sickness and no result from the simulated driving was registered. ** Two people didn't answer this question.*

	Young, good vision	Young, impaired vision	Older, good vision	Older, impaired vision	Participants with eye disease(s)
Number of people	20	20	20*	20*	9
Percentage women, %	85	60	45	50	56
Age, mean	25	26	68	68	67
Age range	19–30	18–34	60–76	60–77	62–72
Average number of years holding licence	5	6	49	47**	46
Binocular visus	1,71	1,67	1,30	1,26	0,66
Binocular low contrast visus	1,13	1,18	0,91	0,78	0,43
UFOV 1, ms	13,8	14,8	15,8	24,5	21,2
UFOV 2, ms	19,8	19,1	61,5	65,0	48,3
UFOV 3, ms	46,3	65,0	135,9	176,9	143,8
UFOV risk 1, number of people	20	20	14	15	7
UFOV risk 2, number of people	0	0	6	3	2
UFOV risk 3, number of people	0	0	0	2	0
Average number of side line crossings	1,1	1,7	1,5	1,3	2,6
Average number of collisions with another vehicle	0,2	0,2	0,3	0,4	0,0
Average number of collisions with pedestrians	0,4	0,5	0,3	0,6	0,7
Average number of exceeding the speed limit	3,8	4,2	3,7	4,1	3,9

The values measured for visus (visual acuity) and low contrast visus were not different within age groups, but there were significant differences between age groups. The group with eye disease were significantly different to all other groups. Older participants with reduced vision had a longer UFOV-1 result than both the younger groups and the older group with good vision. The performance of the

participants with eye disease was at the same level as the older participants with reduced vision, but there were no significant differences when compared to the other groups. The results for UFOV-2 were about three times longer for the older versus the younger groups. There were no significant differences for UFOV-2 within the groups, younger groups compared with each other and older groups compared with each other. UFOV-2 was not significantly different when comparing the participants with eye disease to the other groups. Both the older groups and the eye disease group had significantly longer UFOV-3 times than the younger participants, but the differences between the older groups and the eye disease groups were not significantly different from one another. There was not a significant difference in the UFOV-3 result between the younger groups when compared to one another. The participants with a higher UFOV risk than 1 were in the older age group and amongst those with eye disease.

There were no significant differences between groups with regards to the number of “side line crossings” (ie when the driver drove over the middle line in the road or the line at the edge of the road), collisions with vehicles or pedestrians as well as the incidence of speeding. The younger participants drives less frequently than the older groups, see Figure 1.

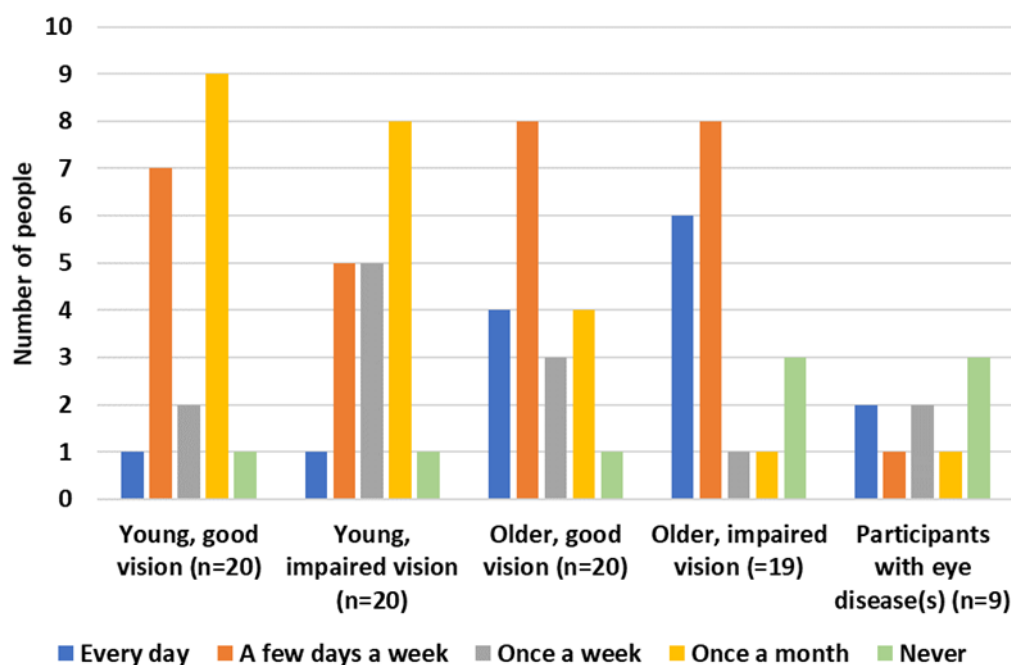


Figure 1. How often participants drove.

And finally participants were able to describe how well they thought they saw driving in daylight and in the dark. Only one person, who had eye disease, said that their sight was not satisfactory driving in daylight. With regards to driving in the dark, mostly those with eye disease, but even the older groups were not satisfied with their sight in dark conditions, see Figure 2.

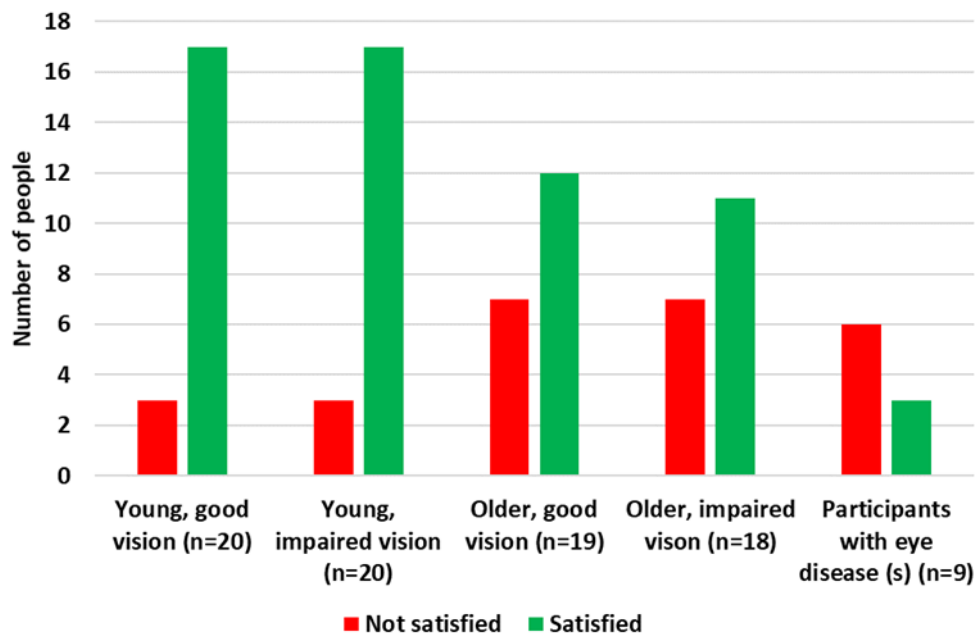


Figure 2. Answer distribution for the question “How is your vision when driving in the dark?”.

3.2. Driving in the simulator

The scenario in the simulator included a number of events and behaviour during these events has been analysed in this section. The measurements that were compared between groups were: distance, TTC (Time To Collision), reaction time, reaction distance, speed, if the brake was pressed and if way was given to pedestrians. All these measurements have not been relevant in all situations. TTC means the time it takes until the driver crashes into an object (car or pedestrian) if they continue in the same direction at the same speed.

Before analysis of the simulator data, values that were as a result of participants reacting in a way that doesn't give useable data were excluded. For example, if the driver has let a pedestrian pass at a crossing before values were able to be registered. For several events, the dropout rate becomes large due to this and these events are excluded. Thus, 12 events remain in this report.

3.2.1. Event 1. Pedestrian approaches from the right



Young people with good vision reacted at a significantly greater distance from the pedestrian than young people with impaired vision. Those with the impaired vision were closer to the pedestrian before they reacted, see Figure 3. There were no significant differences for the other measurements.

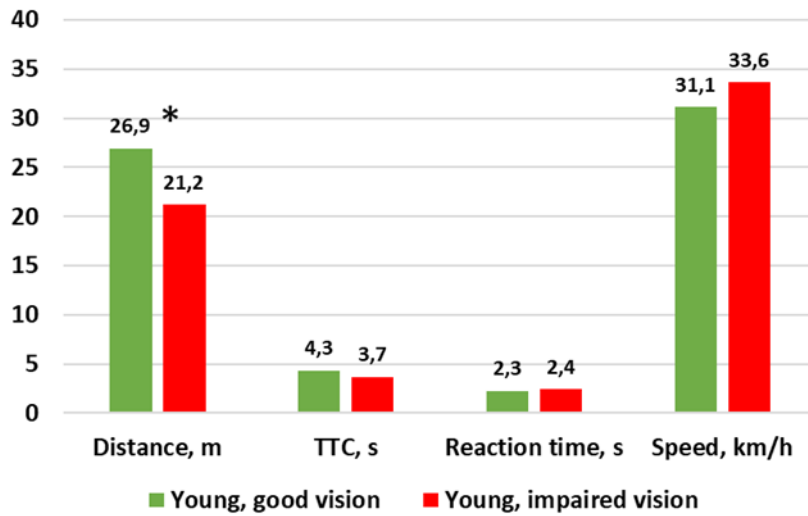


Figure 3. Driving behaviour in the situation “Pedestrian approaches from the right” in the two younger groups (*= $p < 0,05$; t-test).

The two older groups and the group with eye disease performed at around the same level in this event, there were no significant differences, see Figure 4.

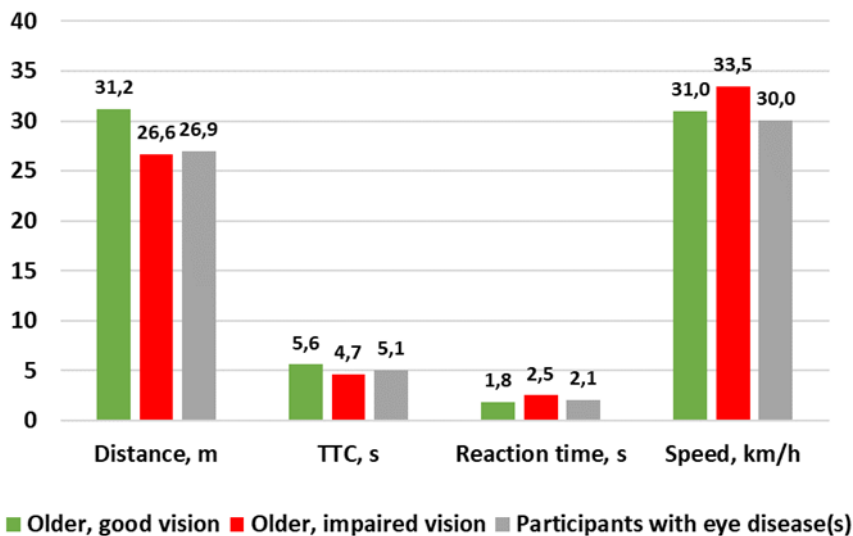


Figure 4. Driving behaviour in the situation “Pedestrian approaches from the right” in the two older groups and the group with eye disease.

3.2.2. Event 2: A parked green car merges



When the parked car began to merge, young people with good vision had a TTC that was a second longer than the young people with impaired vision, which means that those with good vision reacted significantly earlier, see Figure 5. There was no significant difference for the other measurements, but data from half of the cases is missing regarding reaction time because the drivers did not react.

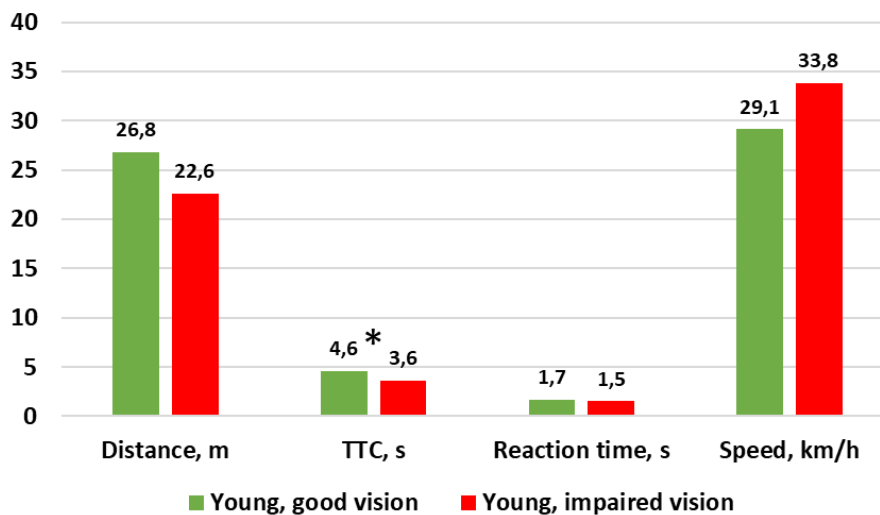


Figure 5. Driving behaviour in the situation “A green car merges” in the two younger groups (*= $p < 0,05$; t -test).

Both TTC and speed were significantly different in the three other groups. Older people with good vision noticed the vehicle sooner, which means that they had a better reaction capacity and safer driving behaviour, as made evident by their lower speed in this event, see Figure 6.

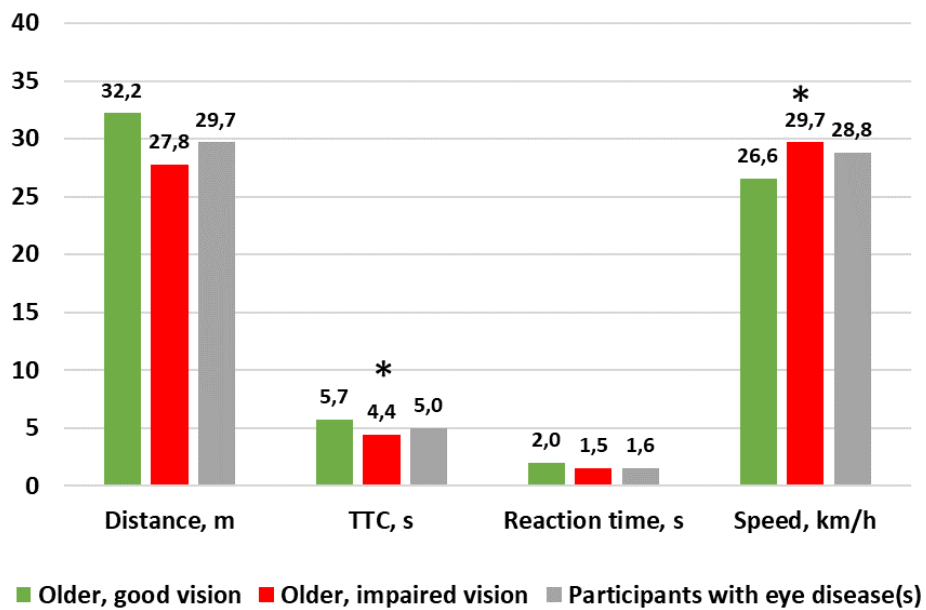


Figure 6. Driving behaviour in the situation “A green car merges” in the two older groups plus the group with eye disease (*= $p < 0,05$; ANOVA).

3.2.3. Event 3: Traffic light controlled intersection



In this situation, the speed that drivers used and whether they braked or not was investigated. The average speed did not differ between the younger groups, nor between the other three groups (see Figure 7).

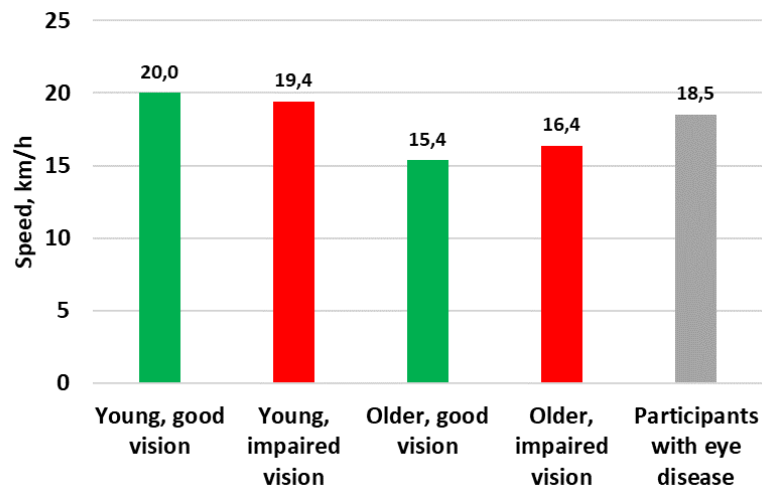


Figure 7. Average speed at the intersection with traffic lights.

Braking behaviour was not significantly different between the two younger groups, nor between the three other groups, see Figure 8.

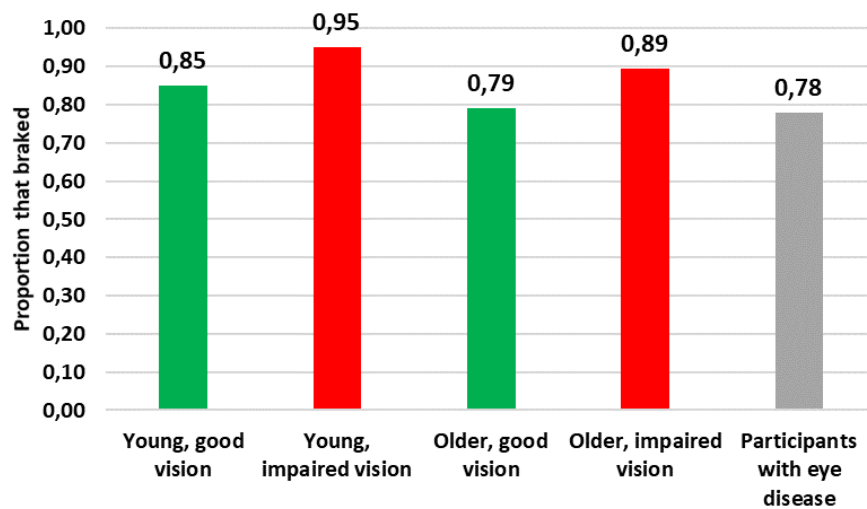


Figure 8. Proportion that braked in the crossing with traffic lights.

3.2.4. Event 4: Pedestrian appears from the left at a pedestrian crossing



There was no significant difference in behaviour between the younger groups in this situation. Distance, TTC and speed were about the same, see Figure 9. All of the younger people gave way to the pedestrian.

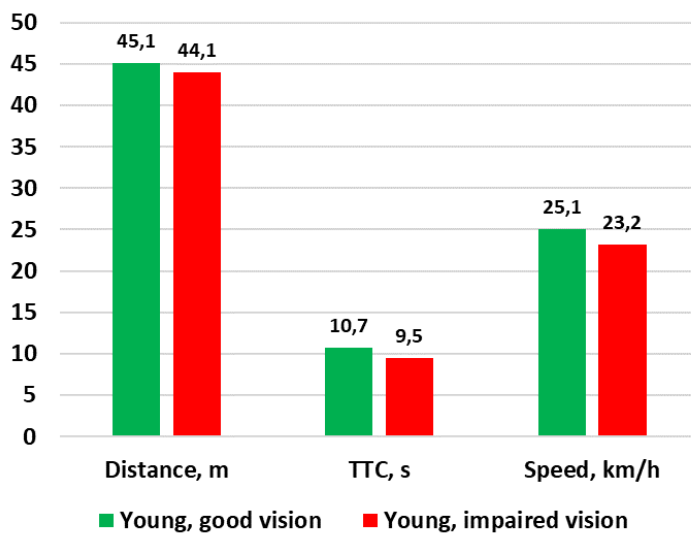


Figure 9. Driving behaviour when a pedestrian crosses at a traffic light regulated crossing, younger groups.

With regards to the three other groups, TTC was significantly different, see Figure 10. Further testing showed that the two older groups were the ones who had significantly different TTC values. The older participants saw the pedestrian and topped, but the older participants with good vision reacted earlier. All participants in these three groups gave way to the pedestrian.

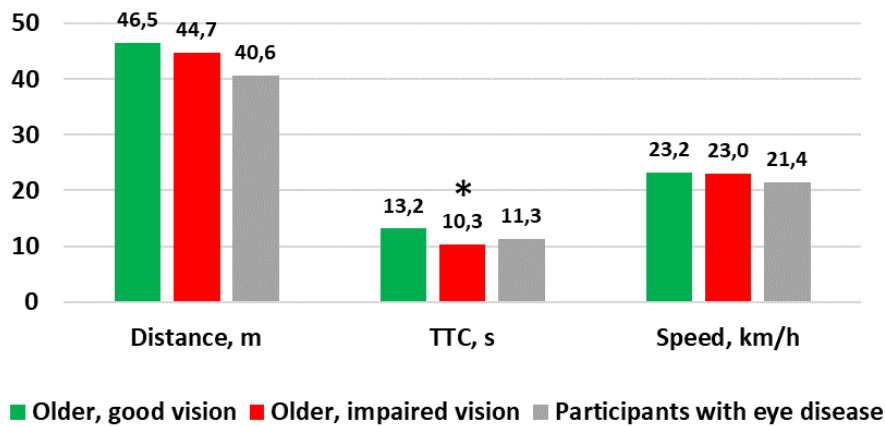


Figure 10. Driving behaviour when a pedestrian crosses at a traffic light regulated crossing, the two older groups and the group with eye disease (*= $p < 0,05$; ANOVA).

3.2.5. Event 5: Green car at an intersection



The distance between the driver and the car in front was the only comparison made in this situation, see Figure 11. The two younger groups kept pretty much the same distance, whereas the older groups and the group with eye disease left more room between them and the car in front, but there were no significant differences between the five groups.

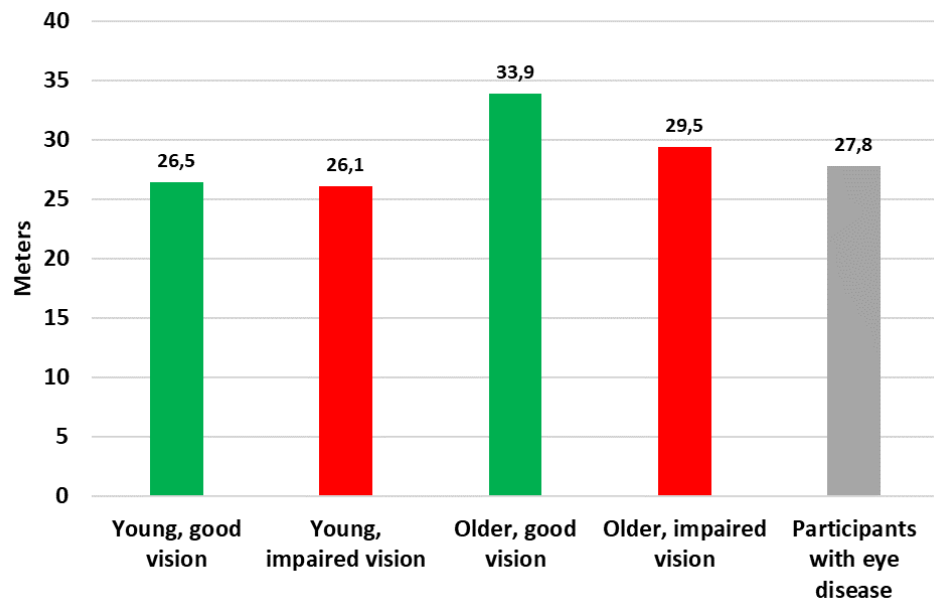


Figure 11. Average distance to a green car that is stationary at an intersection, all groups.

3.2.6. Event 6: A parked bus after an intersection



It was only relevant to investigate speed in this situation, see Figure 12.

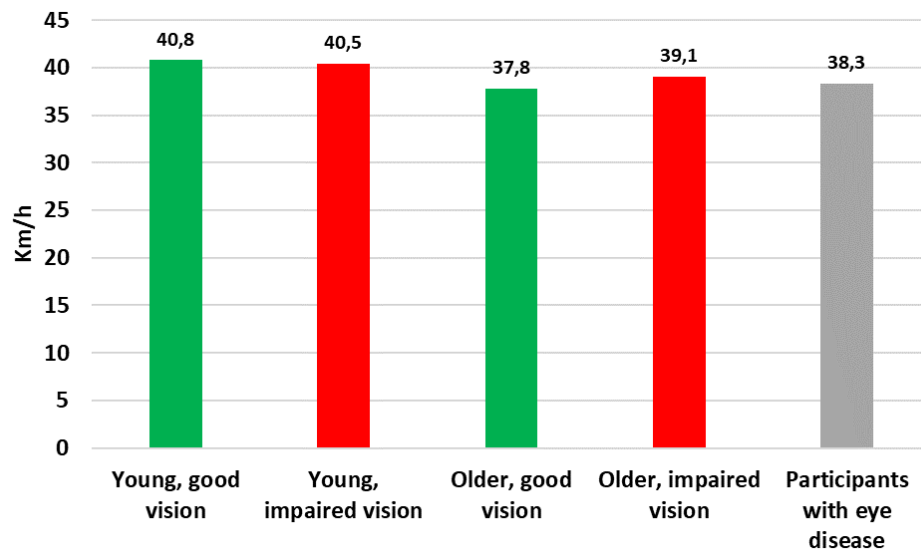


Figure 12. Average speed when passing a bus which is parked after an intersection, all groups.

The two younger groups had very similar behaviour here too. There were no significant differences in speed between any of the groups.

3.2.7. Event 7: Pedestrians approaching from both right and left



Young participants with good vision kept a greater distance to pedestrians and therefore TTC was also longer, see Figure 13. This means that they reacted earlier and had a safer driving behaviour. These differences were significant, but average speed was more or less the same. Both groups gave way to pedestrians at the same rate, that is to say 75% of drivers.

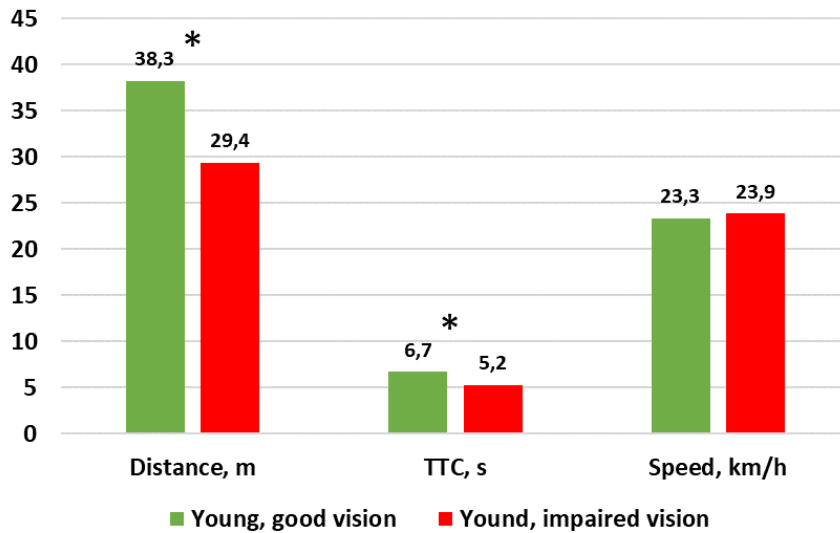


Figure 13. Driving behaviour when two pedestrians stand at a crossing on each side of the road, the two younger groups (*= $p < 0,05$; t-test).

The only significant difference for the three other groups was the distance. Older participants with good vision reacted earlier, see Figure 14. Further analysis demonstrated that it was the group with eye disease that were different from the two older groups.

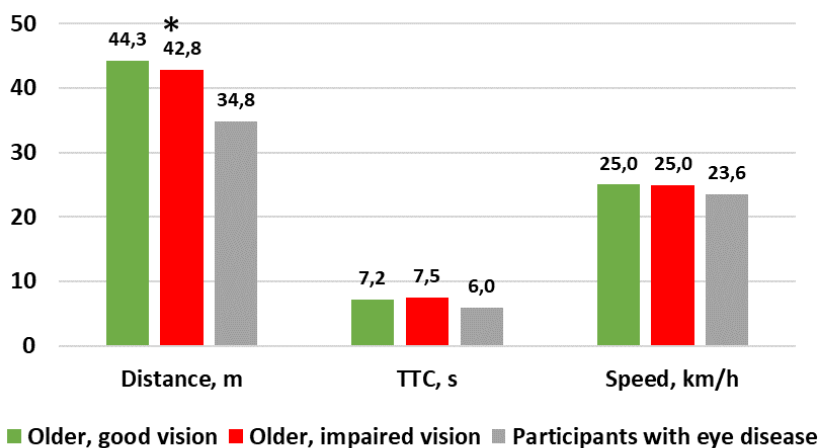


Figure 14. Driving behaviour when two pedestrians stand at a crossing on each side of the road, the two older groups and the group with eye disease (*= $p < 0,05$; ANOVA).

The participants with eye disease tended to give way more often to pedestrians (78% of drivers) compared with the two older groups (42% each), it was not a significant difference however.

3.2.8. Event 8: Pedestrian on the right hand side of a crossing



Seven participants did not give way to the pedestrian, but went past the pedestrian a little to the side (whether participants collided with the pedestrian is not ascertainable from the available data). This happened for one person in each of the younger groups, two people in the older group with good vision, and three people in the older group with impaired vision. The average speed for these seven people was over 45km/h. All participants with eye disease gave way to the pedestrian. The following figures are based on the participants who gave way see Figure 15.

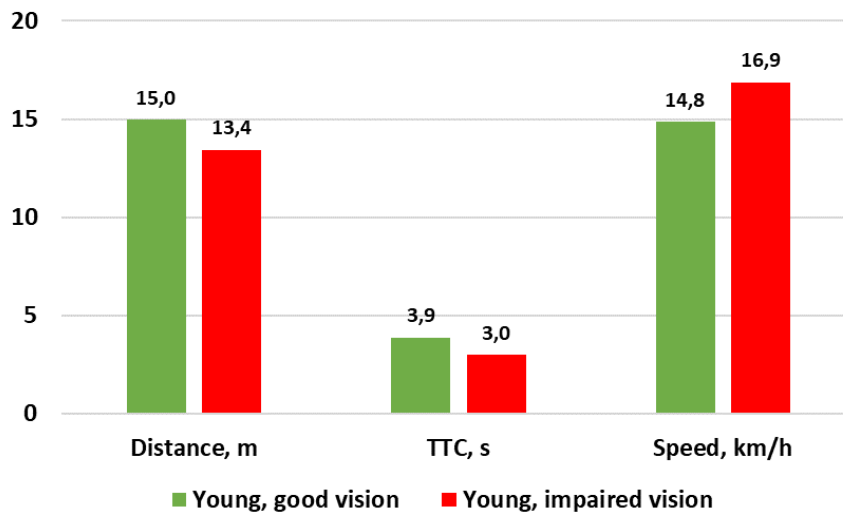


Figure 15. Driving behaviour when pedestrian stands on the right side at a crossing, the two younger groups, way was given to pedestrians.

No significant differences were detected between the two younger groups or between the three other groups, see Figure 16.

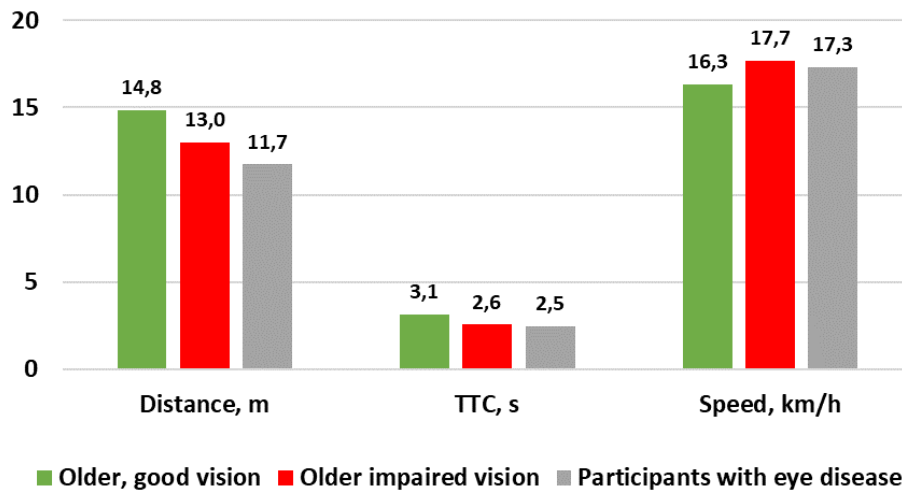


Figure 16. Driving behaviour when a pedestrian stands on the right hand side of a crossing, the two older groups and the group with eye disease, way was given to the pedestrian.

3.2.9. Event 9: A girl runs out from in front of a parked bus



Over 40%, 36 out of 87 participants, did not brake in the situation when a girl ran out from in front of a bus at a busstop. Young participants with good vision braked most often (70%) and the participants with eye disease braked almost as often (67%). Young participants with impaired vision braked about half of the time (55%) and the two older groups braked a little less often than that (53%).

The following Figure 17 show the TTC value for the participants who braked. There were no significant differences between groups.

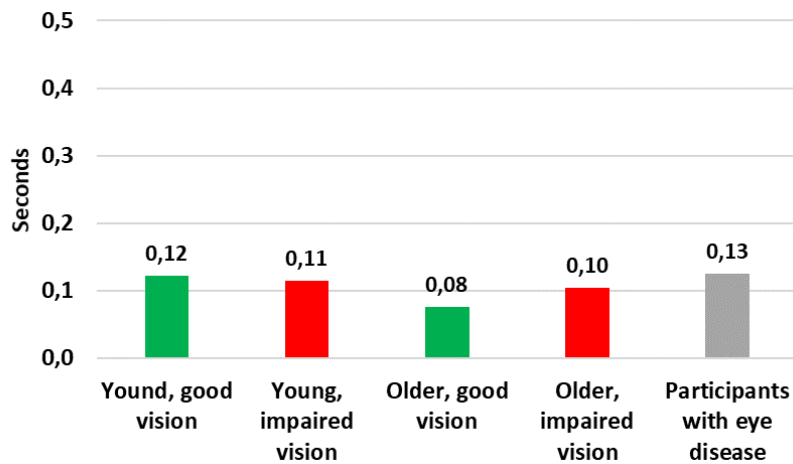


Figure 17. Average TTC when a girl stands by a bus, all groups.

3.2.10. Event 10: Car reversing in a residential area



There were no significant differences between the two younger groups with regards to the proportion that braked when the car was backing out of a driveway. TTC and reaction distance are reported in Figure 18.

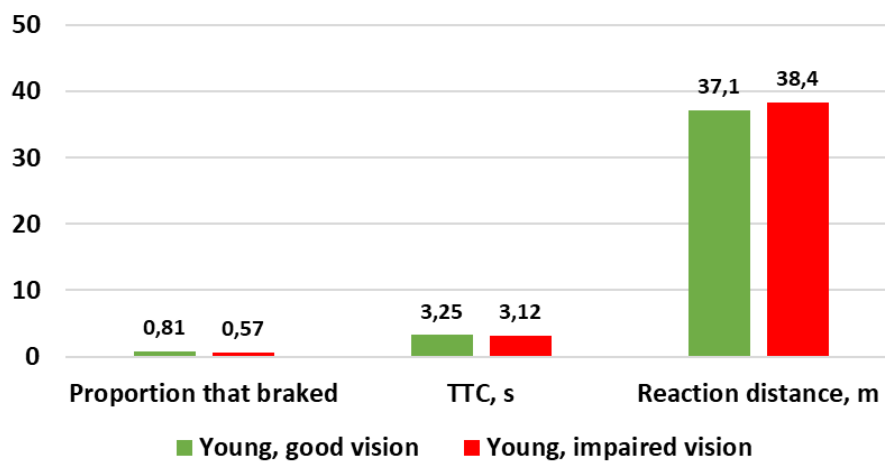


Figure 18. Driving behaviour when a car reverses in a residential area, the two younger groups.

Nor could any significant differences be noted with regards to reaction times, see Figure 19.

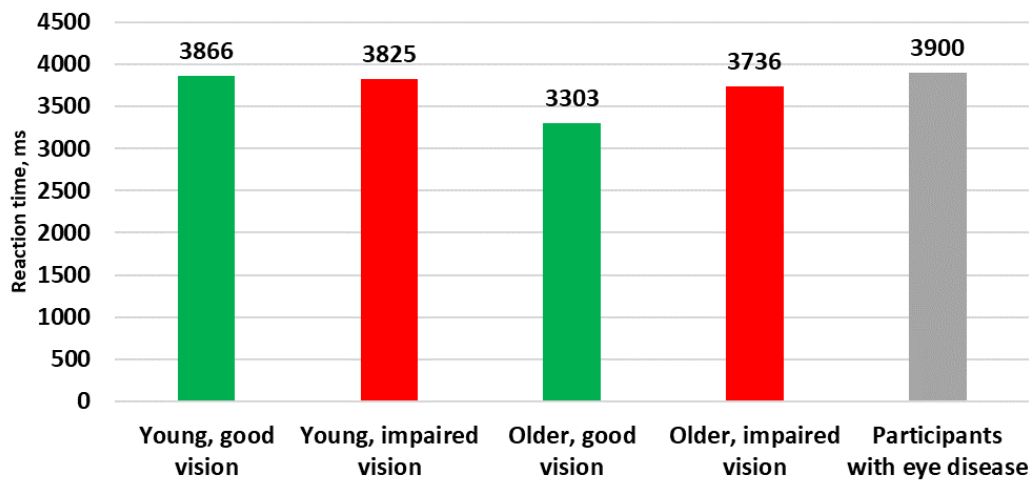


Figure 19. Reaction time when a car reverses in a residential area, all groups.

No significant differences could be seen between the two older groups and the group with eye disease either with regards to the proportion that braked in the situation, TTC and reaction distance, see Figure 20.

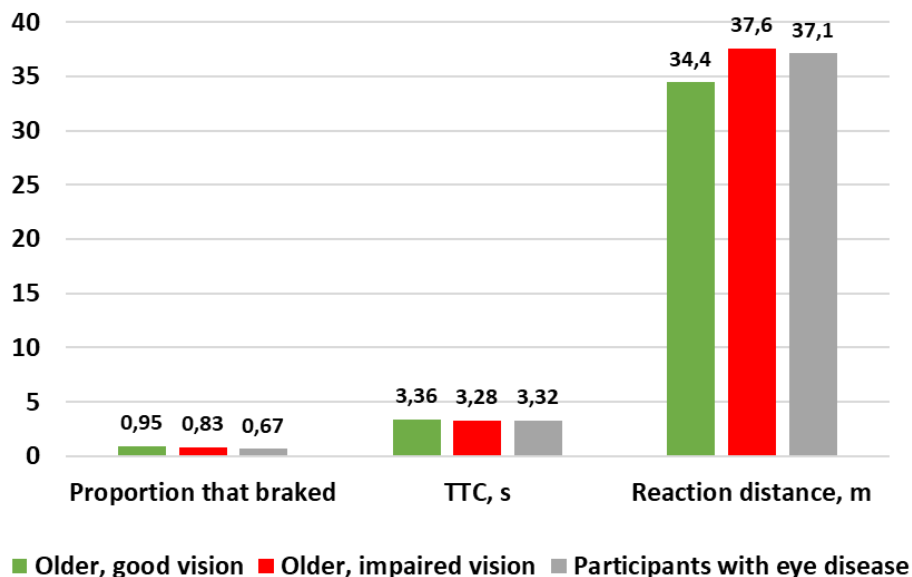


Figure 20. Driving behaviour when a car reverses in a residential area, the two older groups plus the group with eye disease.

3.2.11. Event 11: Car approaching from the right at an intersection in a residential area



Younger participants with impaired vision drove at a significantly higher speed than those with good vision which resulted in a shorter distance and TTC, see Figure 21. The younger participants with impaired vision reacted when they were much closer to the vehicle.

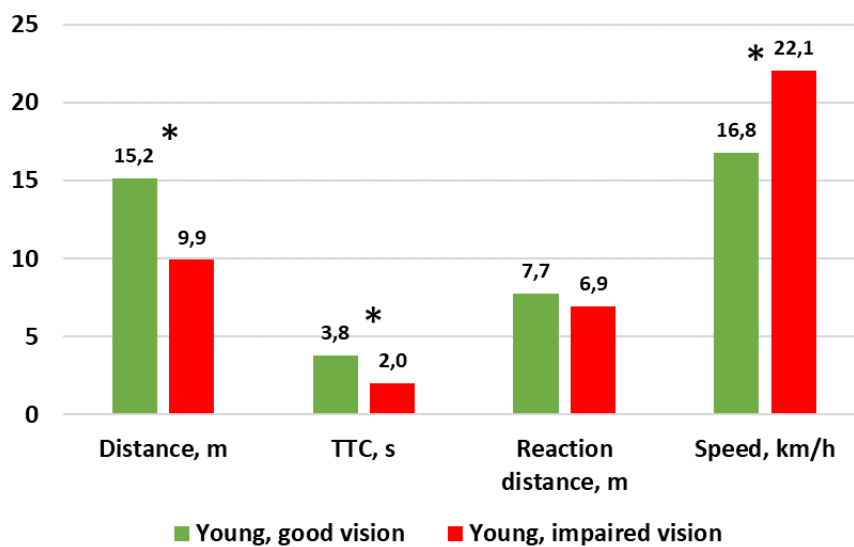


Figure 21. Driving behaviour when a car approaches from the right in a residential area, the two younger groups (*= $p < 0,05$; t-test).

No significant differences were found between the three other groups in this situation, see Figure 22.

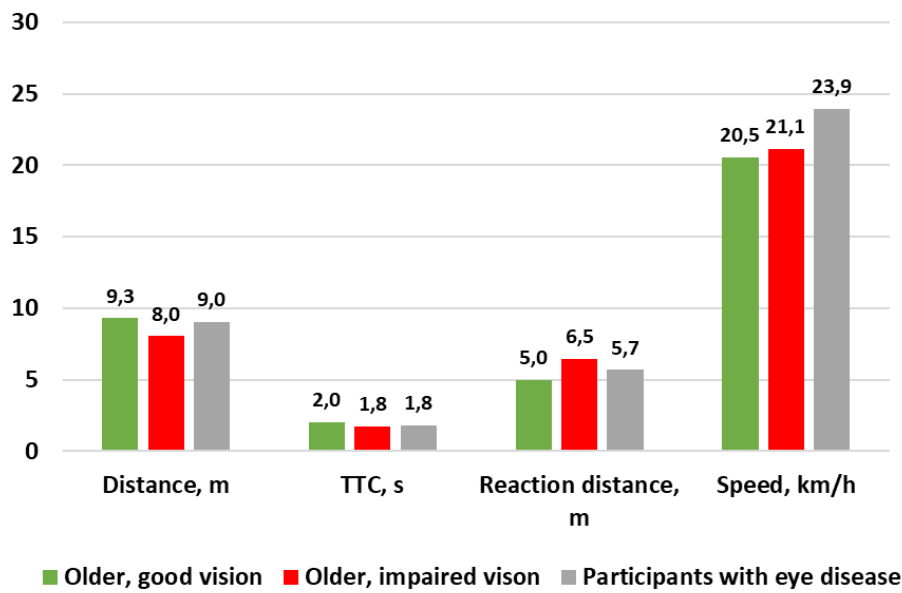


Figure 22. Driving behaviour when a car approaches from the right in a residential area, the two older groups plus the group with eye disease.

3.2.12. Event 12: Parked bus



The speed at which participants passed the bus was investigated in this situation, see Figure 23. Young participants with impaired vision drove significantly faster than young participants with good vision. The differences between the three other groups were not significant.

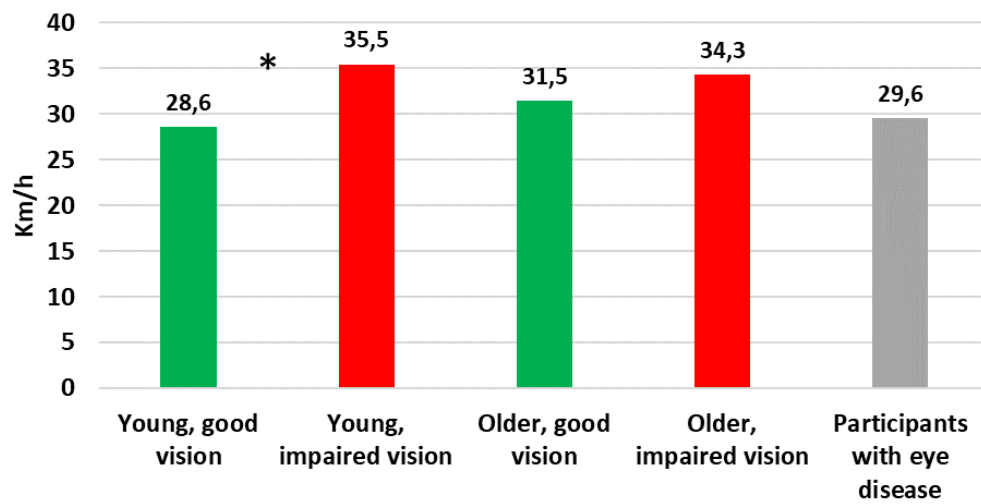


Figure 23. Average speed when passing a parked bus, all groups.

4. Discussion

Because it is common that vision deteriorates as we age (and as a result of eye disease/s), many studies around vision and driving suitability has focused on adults ≥ 50 years old (13). This study was performed with the aim of investigating the impact of visual acuity on driving ability, regardless of age. The results showed that there were no differences in the number of collisions between the groups, but that there were significant differences between them during other events that occurred during simulated driving. There were significant differences in 5 of 12 events for the two younger groups. Those who had impaired vision saw pedestrians or vehicles later than those with better vision. This resulted in risky driving behaviour because they reacted to the object (braking or stopping) later or were driving faster than was appropriate. There were significant differences in 3 of 12 events for the older participant groups. The older drivers with good vision were able to see vehicles and pedestrians sooner, which means that they had a greater reaction ability and consequently had safer driving behaviour.

Because it has been said that there isn't sufficient scientific evidence that visual acuity has an impact on safe driving ability, the results were quite surprising. A criticism that could be made against the study is that the participants who had impaired vision were given that impairment right before the testing began, and were therefore unused to this sudden impairment in their vision. An other alternative that was discussed before the study began was to find people with a driver's licence that already were visually impaired (that can't be corrected), but this is more or less impossible. The group with people with eye disease had fewer participants than the other two groups. This was because it was difficult to recruit people with eye disease who also had a driver's licence. Despite the fact that participating in the study would not affect their ability to retain their licence, there were several people who were not brave enough to participate.

A Swedish winter means a long and dark period of time that can be demanding to drive in, with variations in road condition, precipitation and light conditions. The frequency of accidents is higher when driving in the dark, a situation that requires contrast sensitivity, adaptation, glare resistance and recovery after glare. All people see worse in twilight and darkness, but older drivers see even worse and therefore often avoid driving in the dark (18). We were unfortunately not able to test driving in the dark in this project. The light conditions in the driving simulator were good and the driving scenarios were not adapted to be able to test drivers in twilight and the dark. Despite this there were still several negative driving behaviours or risk behaviours that are not compatible with safe driving. It might be considered obvious that people with better visual acuity are more easily able to see details in a simulator program. But driving with impaired vision should also result in difficulties in real traffic situations. Impaired vision is even worse during the dark part of the day, despite street lighting or headlights. All in all, impaired vision should probably affect driving even in real traffic, through, among other things, impaired supervision of fellow road users and delayed ability to react, which increases the risk of traffic accidents.

This study showed that a driving simulator is a useful tool to be able to assess driving ability and that visual ability plays an important role in safe driving. However, this needs to be studied further to increase our understanding of exactly the degree of impairment associated with each type of visual impairment that impairs driving behaviour and leads to reduced road safety.

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Our operations cover all modes of transport, and the subjects of pavement technology, infrastructure maintenance, vehicle technology, traffic safety, traffic analysis, users of the transport system, the environment, the planning and decision making processes, transport economics and transport systems. Knowledge that the institute develops provides a basis for decisions made by stakeholders in the transport sector. In many cases our findings lead to direct applications in both national and international transport policies.

VTI conducts commissioned research in an interdisciplinary organisation. Employees also conduct investigations, provide counseling and perform various services in measurement and testing. The institute has a wide range of advanced research equipment and world-class driving simulators. There are also laboratories for road material testing and crash safety testing.

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