RAINVISION

WP 3 REPORT

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ABSTRACT

The purpose of this study was to scientifically assess the impact of the visibility of different pavement markings in different conditions (night time driving in dry, wet and wet &rainy circumstances), also taking into account different age groups. Therefore, a field experiment was carried out on a specifically prepared test track near the city of Melk, Austria. 90 of 120 subjects have been selected based on psychological pre-testing to ensure a homogenous test sample for three age groups.

Test drives were carried out at night within three different marking conditions (non-reflective, standard reflective material, wet reflective material) on three different test nights under dry, wet and wet & rainy driving conditions with four identical test vehicles. With the help of in-vehicle data loggers, driving performance was measured by means of speed choice, cornering and acceleration behaviour. Additionally, a questionnaire used to measure drivers´ subjective comfort levels after each test run.

Results indicate that that driving comfort as well as clearness and perceptibility of track trajectory was assessed best when advanced reflective material was applied on the track. Regarding driving behaviour by means of speed choice, test subjects drove slowest in the non-reflective condition, faster under condition with applied standard reflective marking material, and even slightly faster under the condition with advanced reflective material. This result holds especially true for older persons as an age interaction could be observed within the oldest test subject group (61 years of age or older).

As the lap times can be interpreted as the time needed for solving the driving task, it can be concluded that it takes significantly longer for aged male persons to grasp the driving situation and especially the driving trajectory under adverse conditions when there is no road marking. Within the female test subjects, a statistical trend indicated a similar effect.

With regard to driving behaviour expressed in terms of mean lateral and longitudinal accelerations, no statistically significant differences occurred after controlling for speed. This result indicates that subjects did not follow the track trajectory differently in various conditions by means of different driven radius, e.g. cutting corners.

It could be clearly shown that both reflective marking materials are perceived as more comfortable and guiding compared to the non-reflective marking. Applying reflective marking material has a positive effect on the subjective comfort feeling of drivers, especially in adverse driving conditions which were simulated in this experiment. Under night-time and rainy driving conditions, the wet retro-reflective material was assessed as clearly guiding the driving path, thus providing anticipatory stimuli of road environment and taking mental workload off the driver.

From a traffic safety perspective, the main difference in terms of traffic safety lies in the question whether to apply or not to apply reflective marking material at all. If reflective material is applied, the better choice is to use wet reflective material instead of non-reflective material as the benefits (subjective driver comfort and better anticipation of road trajectory) outweigh the disadvantages (slightly higher speed choice) for drivers.

1. INTRODUCTION

1.1. PURPOSE

The present document is the report of Work Package 3 for the RAINVISION project. The purpose of the document is to provide an overview of the track experiment carried out in WP 3 in order to scientifically assess the impact of the visibility of different pavement markings in different conditions (night time driving in dry, wet and wet &rainy circumstances), also taking into account different age groups. The document contains the following sections:

- This chapter and chapter 2 include the overall scope and description of methods used in the field experiment.
- Chapter 3 informs about the study design, the recruiting and pre-selection measures of test persons.
- Chapter 4 describes the results of the study including a description of the test sample
- Chapter 5 focuses on conclusions and discussion of the study findings
- Chapter 6 lists cited literature

1.2. DEFINITIONS AND ACRONYMS

1.2.1. DEFINITIONS

Concepts and terms used in this document and needing a definition are included in the following table:

Table 1. Definitions

Concept / Term	Definition
GLM	A GLM is one of the most used mathematical models in statistics. Numerous statistical procedures can be regarded as special cases of linear models, such as comparisons of means, analyses of variances, correlation and regression procedures.
MANOVA	MANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A statistical hypothesis test is a method of making decisions using data. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis (no differences). A statistically significant result (when a probability (**p-value**) is less than a threshold (significance level)) justifies the rejection of the null hypothesis
P-VALUE	In statistical testing, a result is deemed statistically significant if it is so extreme that such a result would be expected to arise simply by chance only in rare circumstances. Hence the result provides enough evidence to reject the hypothesis of 'no effect'. The probability that the observed data would occur by chance in a given single null hypothesis. A fixed number, most often 0.05, is referred to as a significance level. In the current study, the used threshold level of the p-value was between 0.05 and above 0.01. It was assessed as significant and marked with one asterisk beneath the value. If a p-value equals 0.01 or below, the p-value was regarded as highly significant, indicated by two asterisks.

1.2.2. ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

Table 2. Acronyms

Acronym	Definition
ÖAMTC	Austrian Automobile, Motorcycle- and Touring Club

2. DESCRIPTION OF METHOD

2.1. DESCRIPTION OF TEST TRACK

The track test was carried out near the Austrian city of Melk, on the premises of the ÖAMTC, i.e. the "Wachauring". This closed circuit is situated in lower Austria and is about 12Ha in size. For the RAINVISION project, a track route was selected in a way that potential differences of marking levels could be identified by means of driving data (speed, lateral and longitudinal acceleration). Due to an economic test design, test subjects completed the track in one driving direction (clockwise).

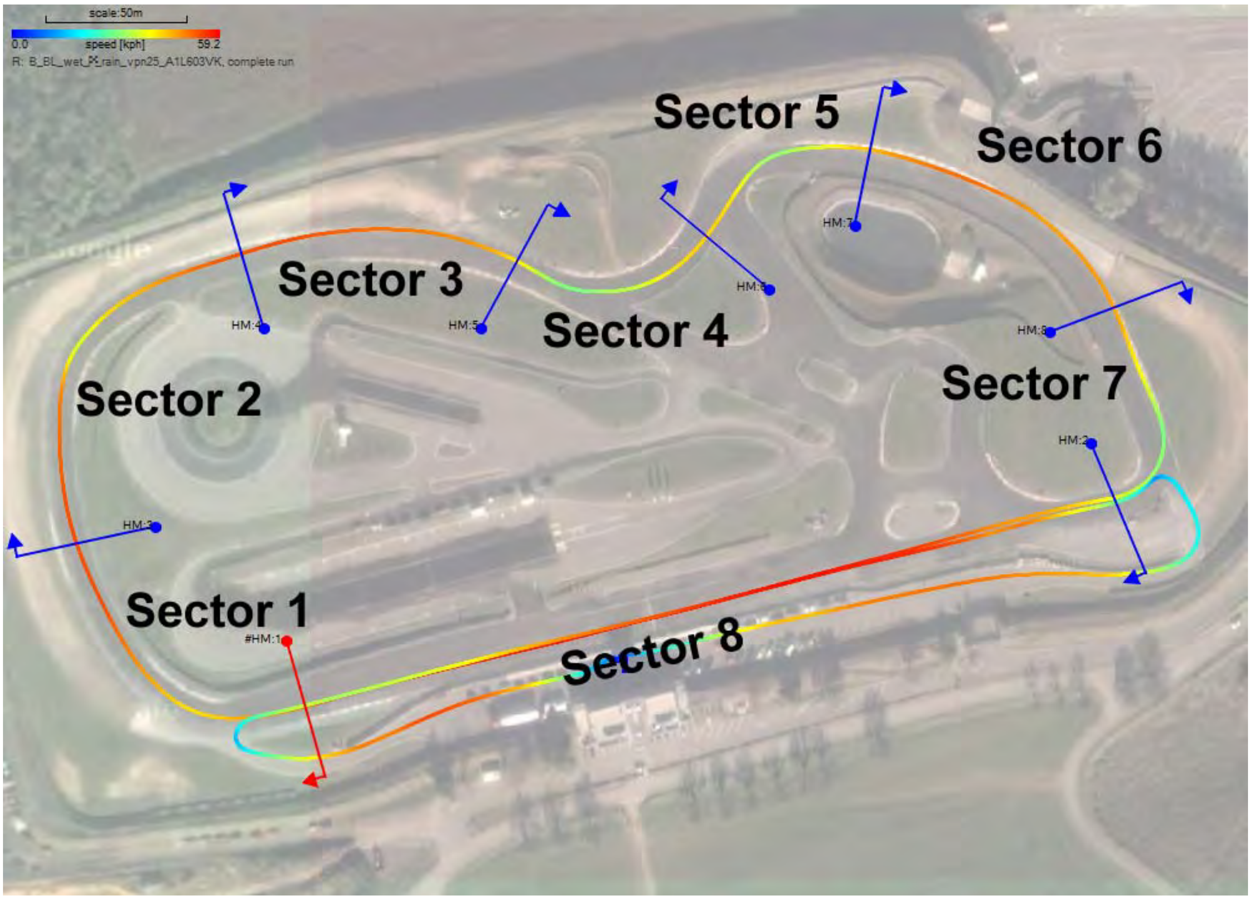


Figure 1. The test track with marked sectors

Test drives were carried out with 3 different marking conditions (non-reflective=baseline, marking material I=reflective material, marking material II=wet reflective material) under 3 different driving conditions: (dry, wet and wet & rainy).

The coloured line in Figure 1 symbolises the route that was chosen on which test subjects had to drive. Furthermore, the track was segmented into 8 sections to be able to perform an analysis in a e sector-wise manner. This approach was chosen as a sector can be understood as one semantic driving task/unit, i.e. driving through a left or right bend or a straight.

The total length of the track route where test subjects had to drive was approx. 980m.

The wet condition was realised by wetting the road surface with sprinklers. The wet & rainy condition was set up by specially prepared sprinklers which were adjusted in a way that the water moistened not only the track, but also the windshield of the test vehicles.

2.2. PRACTICAL LIMITATIONS

Due to inappropriate weather conditions the tests had to be postponed from March 2013 to April 2013. At the time of the tests, the test track was no longer exclusively available for the RAINVISION track experiment, but was in use during the day for other customers. After marking material I had been applied in the morning of the experiment, the track was in use for a private racing event. Unfortunately, during this event, some of the material was irretrievably damaged by race cars going over the applied material (Figure 2):

Figure 2. Race car damaging marking material

Only some of the damaged material could be re-applied due to the great support and effort of the local marking company. As a consequence, sector 2 and sector 6 were left unmarked and could not be considered in the analysis.

2.3. DESCRIPTION OF PAVEMENT MARKING MATERIALS

As the driveway of the test track is wider than a typical rural road, the different marking materials were applied in such way, that a narrow rural road in Austria was simulated. As such, the marked road was about 5 m wide, each lane 2.55m wide.

2.3.1. NON-REFLECTIVE MATERIAL (BASELINE)

For the baseline condition non-reflective priming material has been applied, which can be hardly perceived at night, especially in dark and/or rainy weather circumstances.

Figure 3. Baseline marking

As the track marking was hardly seen at night, 15 pairs of traffic cones were placed throughout the track to ensure that test subjects did not run off the marked road.

2.3.2. MARKING MATERIAL I (TYPE 1)

As marking material I, “3M Stamark A 650” (type 1) without additional wet reflectivity feature was used. This product is a flat white pavement marking product using standard glass bead technology for night time visibility and corundum skid particles for anti-slip on wet surfaces. This is a typical product construction used with different marking systems such as thermoplastics, paint, or plastics.

Figure 4. Marking material I, without additional reflective feature (picture shows wet track)

This product construction does not provide additional wet reflectivity performance. When the surface is wet or covered with water, the optical system is affected and the optical performance of the marking drops significantly. This effect is illustrated in Figure 4where a big difference between wet and the (triangle-shaped) dry parts of the marking material reflects the flashlight of the camera differently.

Retro-reflective parameters of "3M Stamark A 650" were measured on the track:

R_L (dry) 570 - 685mcd/m² lx (exceeding Class R5 in EN 1436)
R_L(wet) 3 -12mcd/m² lx (RW0 = no wet reflectivity performance according to EN 1436)

2.3.3. MARKING MATERIAL II (TYPE 2)

Marking material II was "3M Stamark A 380 ESD" (type 2) with an additional wet reflectivity feature. This product is a profiled white pavement marking product using ceramic glass bead technology for night time visibility and corundum skid particles for anti-slip on wet surfaces.

Figure 5. Marking material II, additional wet reflective features (picture shows wet track)

Due to the pattern profile, the material has “raised” and “drain" areas. When material becomes wet, water can rinse off the raised areas and the optical system will be exposed over the water line. Therefore, this product construction provides additional wet reflective features.

The retro-reflective characteristics of 3M Stamark A 380 ESD were measured on the track:

R_L (dry) 407 - 572mcd/m² lx (exceeding Class R5 in EN 1436)

R_L (wet) 43 - 112mcd/m² lx (Class RW2 – RW4 in wet reflectivity performance according to EN 1436, the performance range was measured in different locations and is a result of the varying rain and drainage conditions throughout the track)

The following figure compares the drivers view for the three marking materials in wet & rainy conditions:

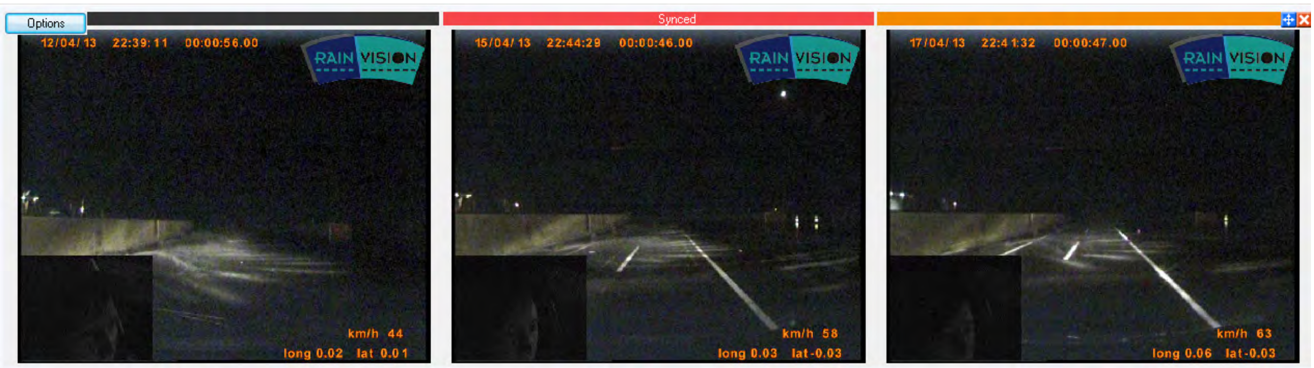


Figure 6. Comparison of marking materials from inside the test vehicle

(left: baseline, existing marking, middle: marking material type I, right: marking material type II)

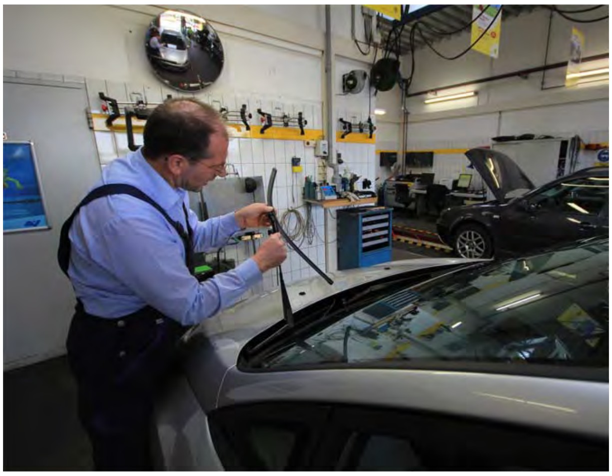
2.4. TEST VEHICLES

A total of four identical vehicles (Ford Fiesta, 1.25l, petrol-driven) were used to carry out the track tests. The vehicles were brand new, equipped with manual gearshift and provided an engine power of 44kW, equalling to 60 HP with a maximum torque of 109Nm.

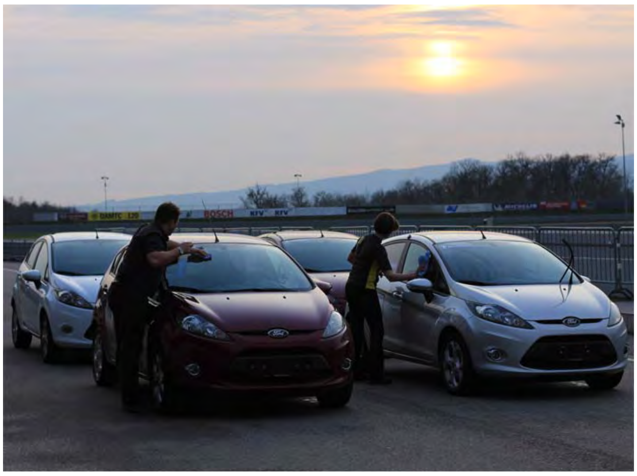
Before the test runs took place, all four cars have been checked regarding the proper adjustment of the headlamps, windscreen wipers have been renewed. Directly before and during the test runs, the windshield was cleaned.

Four identical test vehicles, Ford Fiesta

Headlamp adjustments



Renewing of windscreen wipers



Cleaning of windshield and side windows

Figure 7. Test vehicle and test run preparations

This type of vehicle was chosen due to representativeness reasons as it resembles common engine power and is widely sold. According to an Austrian Newspaper[2], the Ford Fiesta model was the second most sold model within the EU-25 countries.

[2]Kurier, Austrian daily newspaper: http://kurier.at/lebensart/motor/pkw-neuzulassungen-nur-noch-halbgas/717.239, on 18.01.2013

2.5. DATA LOGGING EQUIPMENT

The specified unit used within this study was an off-the-shelf data collection system, i.e. pDrive lite system ® (see Figure 8). This system is a small black box which allows the capturing of vehicle and video data.

The data are stored on a memory card (up to 64 GByte) and can then be subsequently downloaded and analysed using comprehensive computer software, or simply archived to a hard drive or DVD.

The box is specifically designed for Naturalistic Driving studies as it was downsized from an original device which was made for driver training and feedback purposes. This device allows for a quick but unobtrusive installation in the car as only a few lead cables have to connect to the main unit.

In this study, video data was also collected in order to identify the driver.

Additionally, videos can also be triggered based on acceleration/braking values or GPS position. Such functionalities have been already used in Naturalistic Driving research projects, such as in the EU-funded project PROLOGUE.[3]

Figure 8. pDrive lite® front view

For the RAINVISION project purposes, it had to be ensured that drivers are not irritated by visible devices, reminding them that their driving behaviour is recorded. In order to avoid such effects, it is necessary to conceal the used technology as much as possible, i.e. installing recording technology in an unobtrusive way.

As the box is only 3,5 cm high, 14 cm wide and 15 cm deep, it was installed under the passengers´ seat. The usage of hook and loop fasteners allowed for a stable installation on the vehicles´ floor carpet. At the same time the mounting material used ensured sufficient air circulation for equipment cooling.

On the rear of the unit there are a number of inputs (listed below):

1. 4 external camera inputs
2. GPS antenna
3. External sensor input (ECU/OBD)
4. Data port (RS 232)
5. Audio input (stereo)
6. Audio output (stereo)
7. Video output
8. Power connector

Beside the collection of GPS data, accelerometer data was also collected. The main pDrive lite ® system unit contains a 3-axis accelerometer that is used to measure the lateral, longitudinal and vertical

[3] Videos are not part of task 6.3.

acceleration of the vehicle. Accelerations measured are used for a number of different purposes in the pDrive lite ® system, namely:

- to measure directly how quickly the vehicle is being accelerated or how much braking is being used
- to measure how hard the vehicle is cornering
- to combine with the speed measurements from the GPS system to improve accuracy
- to combine with the positional measurements from the GPS system to improve accuracy

The following data was collected with the pDrive lite ® system:

- GPS position
- Lateral acceleration
- Longitudinal acceleration
- Speed
- Date/Time

With pDrive lite ®, raw data is gathered with a rate of 100 values per second which represents 100 Hz.

Two cameras were mounted behind the rear mirror in the most unobtrusive way (Figure 9).

Figure 9. Cameras behind rear mirror

Within this project, the data was analysed subsequently with specific analysis software, i.e. comparing the parameters of driving behaviour (steering, braking, acceleration, and speed) between test conditions and age/sex groups. The following picture shows an example of the analysis software (Screenshot):

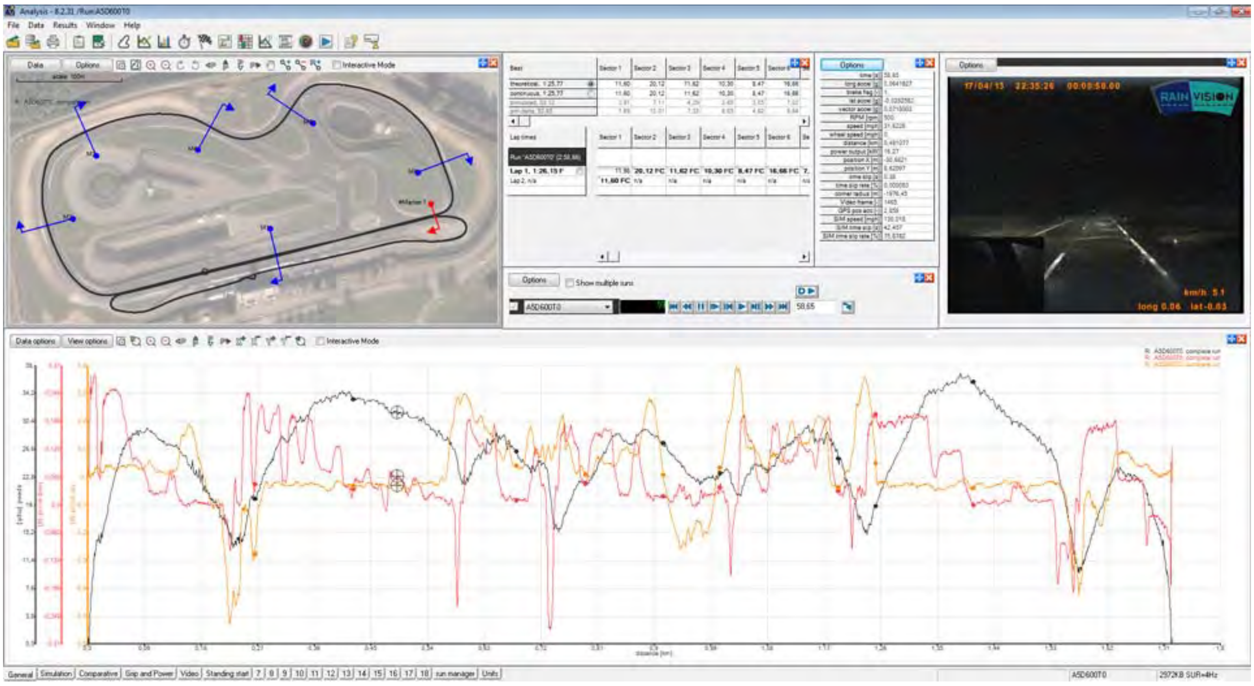


Figure 10. Screenshot of analysis software

The analysis software allows for documentation and illustration of the test drives. Furthermore, it is possible to create summary statistics for subsequent statistical comparisons. Thus, statistical tests are carried out to calculate possible differences in driving behaviour (speed choice, acceleration and braking forces).

It was especially necessary to compare the subjects´ driving performance different within different sectors of the test track. This was realized as the software offers the possibility to mark sectors, create and export summary statistics sector-wise for, e.g. analyses within IBM® SPSS® Statistics 19.

3. STUDY DESIGN

In order to study the impact of the visibility of different pavement markings in different conditions (night time driving in wet and rainy circumstances), also taking into account different age groups, a number of onsite tests was carried out. The test investigates a number of parameters, such as road characteristics (straight road, left and right turns), different simulated weather conditions and sex/age groups.

Participants drove on a test track, containing several typical road characteristics, like left and right bends or a straight road. Drivers´ performance was investigated in three test conditions:

1. Condition I: Baseline, no or existing (non-reflective) lane marking
2. Condition II: Site equipped with marking material I (dry reflective)
3. Condition III: Site equipped with marking material II (wet reflective for enhanced wet night visibility performance)

Drivers took nine runs in total through specifically chosen road sections, completing the track in 3 different night time driving situations: dry, (1), wet (2) and wet & rainy (3).To ensure comparability with the design of WP 2, the design was set up for analysing three age groups: 20-40 year, 41-60 year and 61+ year old drivers, both male and female.

The sample (n=88) was randomly split into two groups A and B, where group A consisted of 46 subjects and group B of 42test subjects. This approach allowed testing for possible positional effects. Hence, the following test design was realised:

Table 3. Order of test runs for group A and B

	Condition		
	baseline	**marking material I**	**marking material II**
Group A	test day 1	test day 2	test day 3
Group B	test day 3	test day 1	test day 2

The advantage of such a counter balanced design is that it makes an experiment more efficient and helps keep the variability low. This helps to keep the validity of the results higher, while still allowing for smaller than usual subject groups (Minke, 1997)[4]. However, a possible disadvantage is that it may not be possible for each participant to be in all conditions of the experiment (e.g. time constraints, etc.).

In the current study, it was not possible to carry out the Baseline condition for both groups A and B, as it rained on the test track location before group B was ready to carry out the “dry” condition.

Hence, the track was wet for group B and therefore all subsequent analyses for dry conditions were carried out with only one half (group A) of the total sample. Table 4 shows the sample sizes per group and test condition:

[4] Minke, A. (1997). Conducting Repeated Measures Analyses: Experimental Design Considerations. Retrieved February 18, 2008, from Ericae.net: http://ericae.net/ft/tamu/Rm.htm

Table 4. Group sample sizes per track and marking condition

	track condition	Marking condition		
		baseline	**marking material I**	**marking material II**
Group A	dry	n=44	n=45	n=46
	wet	n=45	n=46	n=46
	wet & rainy	n=46	n=46	n=46
Group B	dry	**n.a.**	n=42	n=40
	wet	n=39	n=42	n=41
	wet & rainy	n=40	n=40	n=40

Test subjects were told to drive the same way they do in real traffic circumstances, especially regarding speed choice. Furthermore, they were instructed to only use the low-beam headlights to ensure comparable visibility of markings. Otherwise it would have been difficult to compare e.g. specific sectors if some test subjects used high-beam headlights where other subjects used low-beam light.

3.1. RECRUITING OF SUBJECTS

The test persons for the track test have been recruited by several means: flyers were posted on the blackboard of the RSTC in Melk, a sub-website was set up within the main page of Test & Training International, a short paragraph regarding the project was advertised in local newspapers. Finally, most participants were recruited by word-of-mouth advertising.

In a first step, interested subjects were informed about participating in test drives on a closed circuit. In order to take part, they were informed to pass a psychological test battery at first. If they passed the test, they could apply for taking part in the track test. The potential subjects were informed that they would receive small allowances (15€ for completing the psychological test battery and 100 € for completing the track tests).

3.2. PRE-SELECTION OF TEST SUBJECTS

In order to ensure that possible (bad) performance differences in the later carried out track are not due to test subjects´ level of driving fitness, a psychological test battery from a well-known psychological test provider company[5] was applied. The test battery consisted of 3 different tests; the time taken to complete the test battery was about 30 to 45 minutes.

From 120 potential candidates 90 have been chosen to take part in the track test study. The decision was based on test performances, i.e. if a test subject reached an extremely high or low score in any of the tests, then the person was left out for the track test. This approach ensures that the test performance on the track is not due to extremely bad (or good) driving skills which were measured with the following psychological tests or parameters of driving ability:

Visual Pursuit Test ("LVT")

This test measures the visual orientation performance for simple structures in a complex environment.

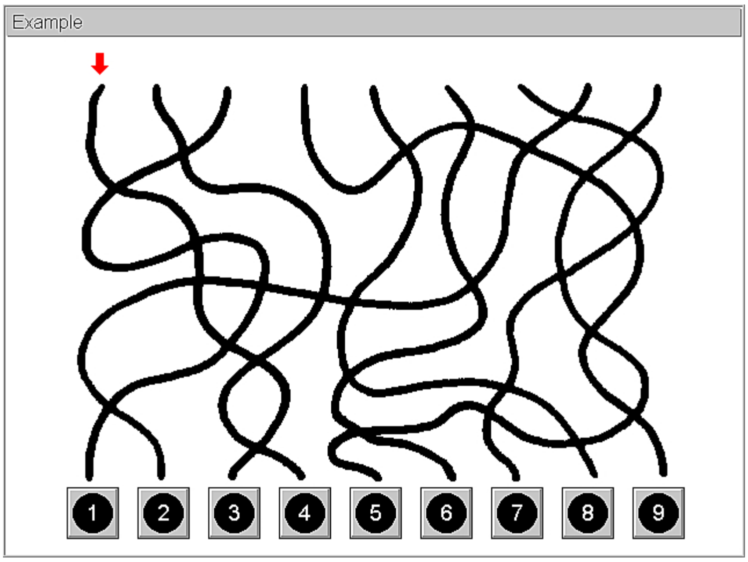


Figure 11. Screenshot of Visual Pursuit Test

The test commences with a combined instruction and practice phase. If the eight practice items are worked with fewer than three errors, the respondent moves on to the test phase items. The respondent is presented with an array of lines and must as quickly as possible find the end of a specified line. The respondent can work at his own speed.

Adaptive Tachistoscopic Traffic Perception Test ("ATAVT")

The ATAVT tests observational ability by briefly presenting pictures of traffic situations. The items are constructed using an explicit, theory-led rationale which is based on detailed analysis of the cognitive processes involved in working the test.

[5] Schuhfried GmbH, Website: www.schuchfried.com

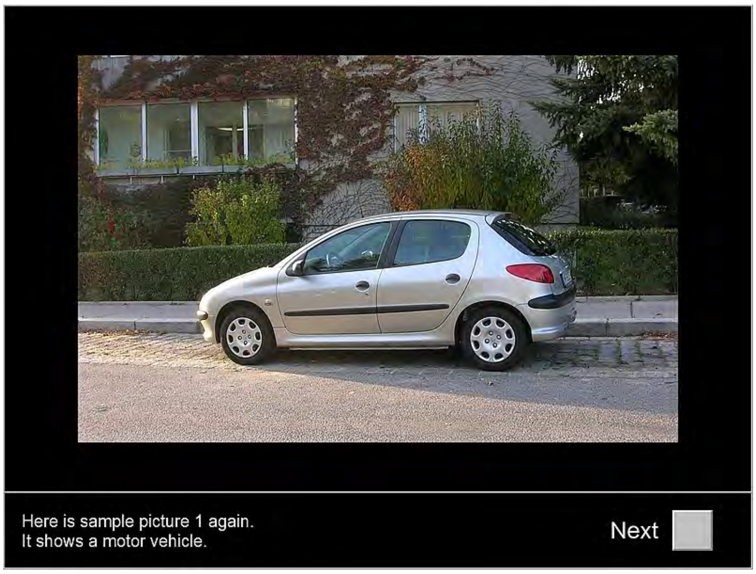


Figure 12. Screenshot of Adaptive Tachistoscopic Traffic Perception Test

The respondent is briefly shown pictures of traffic situations. After seeing each picture, the subject is asked to state what was in it, choosing from five answer options that he is given. Items are presented adaptively – that is, after an initial phase the respondent is presented with items whose difficulty is increasingly tailored to match the test subjects´ ability.

Reaction Test ("RT")

RT is used to measure reaction time or reaction time and motor time. Reaction time and motor time in response to simple and complex visual or acoustic signals is assessed.

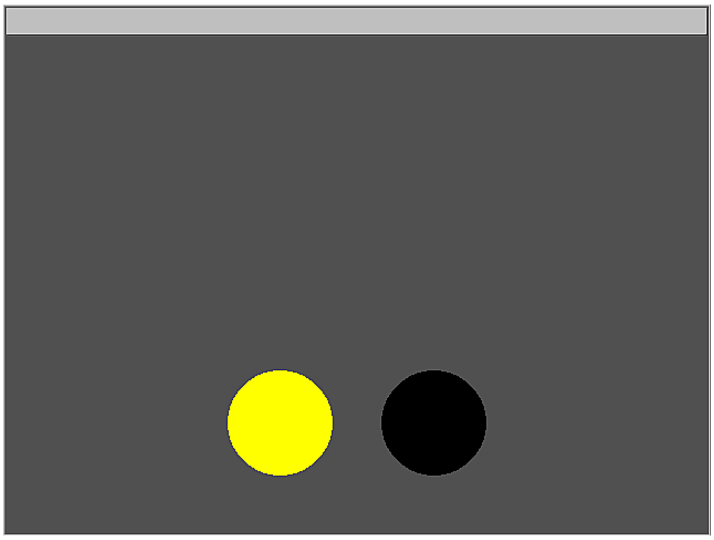


Figure 13. Screenshot of Reaction Test

A specific response panel is used as input device. An animated instruction phase and an error-sensitive practice phase lead on to the task itself. The test involves the presentation of coloured stimuli and/or acoustic signals. The respondent is instructed to press the reaction key only when specific stimuli are presented and, having pressed the key, to return his finger immediately to the rest key.

4. RESULTS

The statistical procedures have been carried out with IBM® SPSS® Statistics 19. Due to the design of the study, either general linear models (GLM) for repeated measures or multivariate analysis of variance (MANOVA) for repeated measures were chosen. In principal, the repeated measures design (also known as a “within-subjects” design) uses the same subjects with every condition of the research. In the current research project, the repeated measures represent individual measures for different track and marking conditions.

4.1. SAMPLE DESCRIPTION

4.1.1. SEX, AGE GROUPS AND VISUAL PERFORMANCE

The sample consisted of a total of 88 test subjects who completed all three test conditions, equalling to 41 female and 47 male subjects, which represents a rounded 47:53percentage distribution. The youngest test person was aged 20 years whereas the oldest test subject was aged 74. Three age groups have been classified:

Table 5. Age groups by sex

		Age group			
		20-40 years	41-60 years	61+ years	total
Sex	**Female**	15	16	10	41
	Male	17	15	15	47
	total	**32**	**31**	**25**	**88**

A total of 42 subjects (22 female and 20 male) indicated that they need an optical aid (glasses or lenses) for car driving. On the test night, 37 (16 female and 21 male) persons used glasses, whereas 8 (6 female and 2male) wore contact lenses. Asked about the type of vision impairment, 31 persons (12 female and 19 male) indicated short-sightedness and 5 (2 female and 3 male) subjects said that they are far-sighted. Nine persons (8 female and 1 male) stated that they have both types of vision impairment. Interestingly, eight of these nine persons who suffer from both types of vision impairments, were aged 55 years or older. Table 6provides an overview regarding the samples´ visual performance levels:

Table 6. Age groups, sex and visual performance

			Do you use an optical aid for car driving?		If yes, do you use glasses or contact lenses today?		If you use glasses or contact lenses, please indicate the type of the defective vision		
Age group			yes	no	glasses	contact lenses	short-sightedness	far-sightedness	both short and far-sighted
20-40 years	Sex	female	10	5	5	5	8	2	
		male	9	8	7	2	8	1	
		total	19	13	12	7	16	3	
41-60 years	Sex	female	4	12	3	1	2	0	2
		male	4	11	5		4	1	
		total	8	23	8	1	6	1	2
61+ years	Sex	female	8	2	8		2	0	6
		male	7	8	9		7	1	1
		total	15	10	17	0	9	1	7

If subjects mentioned that they are using glasses or contact lenses for driving, they were further asked to indicate the dioptre value of the left and right eye. For female subjects, the mean dioptre value for the right eye was 2.9 and for the left eye 3.25. Interestingly, the highest mean values for both the left and right eye was found within the youngest age group, i.e. 20-40 years. Mean values for the other two age groups were lower. Within male test subjects, highest mean values were found in the age group of 41-60 years, as the following table indicates:

Table 7. Age groups, sex and mean dioptre values for left and right eye

Age group	sex	n	mean dioptre left eye	mean dioptre right eye
20-40 years	female	9	3.36	3.78
	male	9	1.41	1.42
41-60 years	female	4	2.81	3.31
	male	5	4.10	4.20
61+ years	female	5	2.29	2.35
	male	5	2.13	2.21

4.1.2. DRIVING EXPERIENCE

The subjects have been asked about their yearly driving routine (vehicle class B only) as well as daily, weekly or monthly driving experience. The following tables provide an overview about the respective distribution:

Table 8. Distribution of annual driving exposure by age group and sex

Age group			Driving exposure: km per year			total
			0-10.000 km/year	10-20.000 km/year	more than 20.000 km/year	
20-40 years	Sex	female	4	9	2	15
		male	5	5	7	17
		total	**9**	**14**	**9**	**32**
41-60 years	Sex	female	2	11	3	16
		male	1	6	8	15
		total	**3**	**17**	**11**	**31**
61+ years	Sex	female	2	5	3	10
		male	1	10	4	15
		total	**3**	**15**	**7**	**25**
Total	Sex	female	8	25	8	41
		male	7	21	19	47
		total	**15**	**46**	**27**	**88**

Table 9. Daily, weekly or monthly driving routine

Age group			How often do you drive a car?			total
			daily	sometimes a week	sometimes a month	
20-40 years	Sex	female	12	3		15
		male	10	7		17
		total	**22**	**10**		**32**
41-60 years	Sex	female	12	3	1	16
		male	14	1		15
		total	**26**	**4**	**1**	**31**
61+ years	Sex	female	6	4		10
		male	9	6		15
	total		15	10		25
Total	Sex	female	30	10	1	41
		male	33	14		47
		total	**63**	**24**	**1**	**88**

As both previous tables show, the participants stated that they were quite experienced drivers as they regularly use their vehicle, mostly on a daily basis. Therefore it can be concluded that the measured driving performance of the test sample leads to representative results.

4.1.3. EDUCATION AND PROFESSION

Subjects were asked regarding their highest level of completed formal education. Exactly a third completed some form of apprenticeship, whereas all other mentioned categories are distributed between 19% and 4%. The following figure illustrates the distribution of highest education among test subjects:

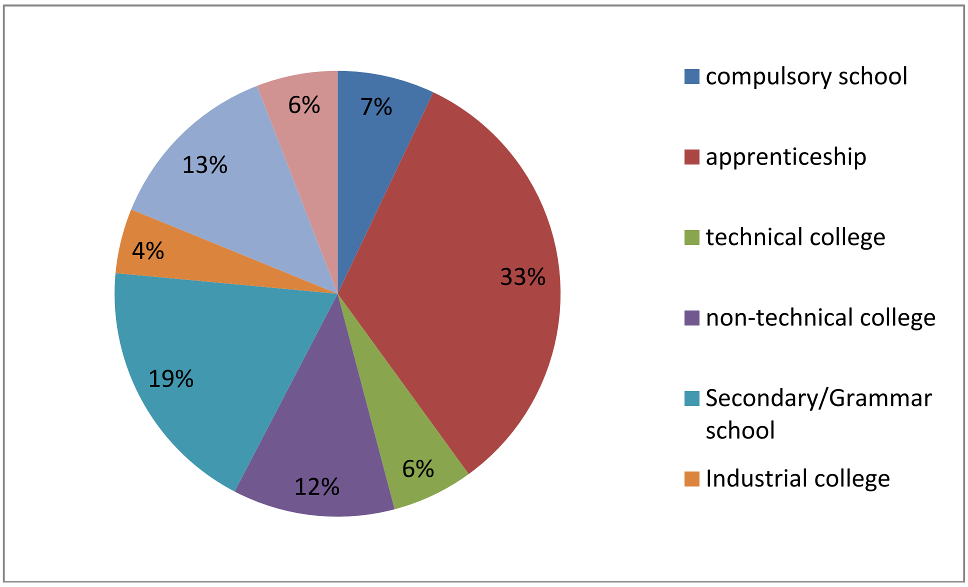


Figure 14. Distribution of highest level of completed education

The type of their current profession was also a topic that was asked. 39% of the sample was currently employed or working as a civil servant. Another big share (28%) was found among retired persons, which was not surprising as the target was to recruit also among older people. The next figure shows the whole distribution of profession type:

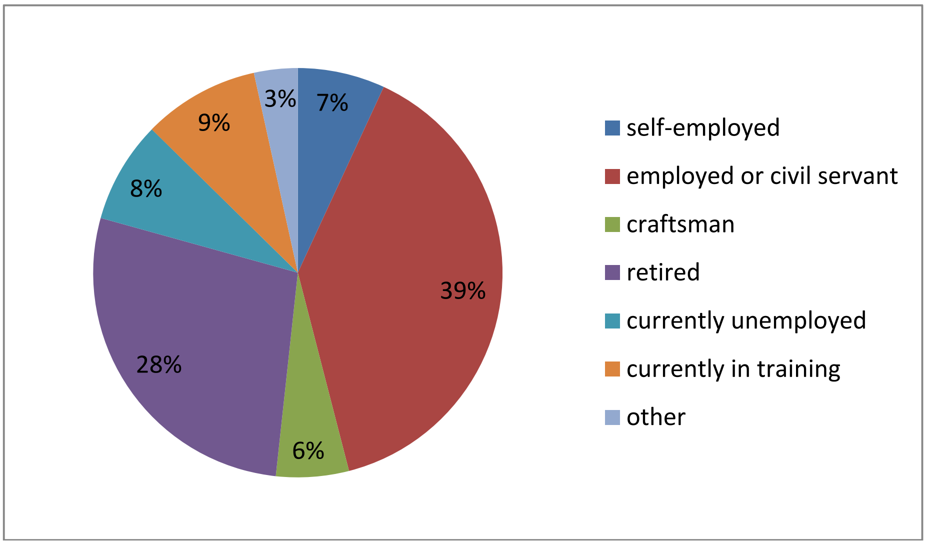


Figure 15. Distribution of profession among test subjects

4.1.4. PARTICIPANTS´ VEHICLE CHARACTERISTICS

Asked regarding the engine power of their own vehicle, the mean engine power of the females vehicles was 98hp (72 kW), whereas the mean vehicle engine power the male sample vehicles was 115hp (85 kW). As regards comparability with the test vehicles (60hp or 44kW), it must be stated that the subjects own vehicles provide somewhat higher engine power. This has to be kept in mind when interpreting results regarding driving behaviour.

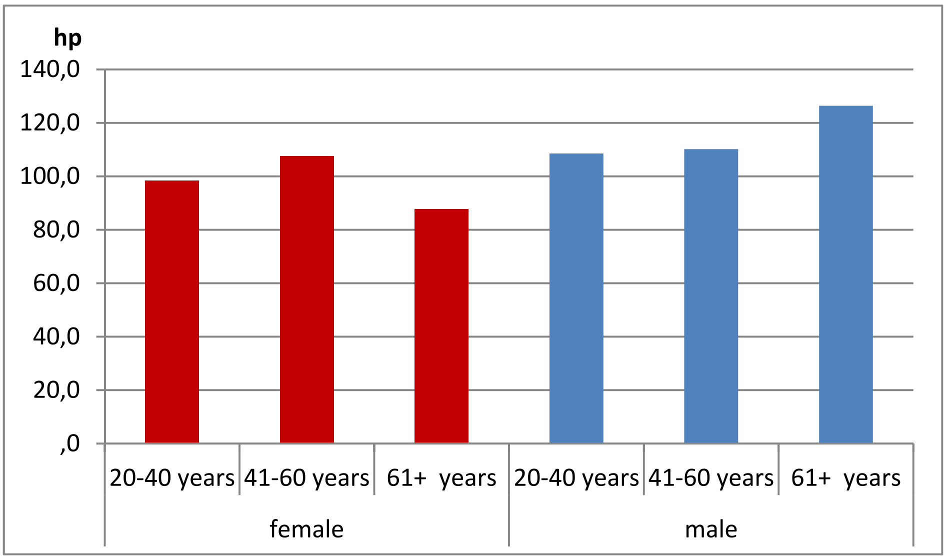


Figure 16. Distribution of engine power of subjects vehicles by age group and sex

Test persons were asked about the type of gear shift they have in their own vehicle. 87% (43% female, 44% male) of the total sample stated that they have manual gearshift, just like the test vehicle, only 13% (5% female and 8% male) have automatic gearshift in their vehicle.

Asked about the fuel type of their own vehicle, 57% drive a diesel powered car, whereas 43% of subjects´ use petrol.

4.2. QUESTIONNAIRE

In order to get an impression of how the test participants perceived the different track and marking conditions, a questionnaire was filled out directly after test persons completed all three runs (dry, wet, wet & rainy) for every marking condition (baseline marking, marking material I and II).

Beneath socio-demographic variables which have been described earlier, the questionnaire was used to collect subjective data for every specific track and marking condition in terms of comfort and stress level for every undertaken trip as well as clearness and irritation tendency of the road course. Additionally, the participants were asked to assess the track trajectory in terms of perceptibility and demand on attention level. The questionnaire was presented by means of the following opposite pairs of characteristics:

- comfort (comfortable vs. uncomfortable)
- stress (unstressed vs. stressed)

The first two pairs of opposites were asked how test persons perceived the trip as a whole, whereas the next four pairs were used to assess the track trajectory:

- clearness (well-arranged vs. unclear)
- confusion (non-irritating vs. irritating)
- perceptibility (apparent vs. non-apparent)
- attention (attention-grabbing vs. unobtrusive)

4.2.1. INTER-INDIVDUAL (GROUP) COMPARISONS

The following figures present mean assessments of the whole female and male test sample, i.e. between subjects. Results and differences within test subjects are presented in the subsequent (sub)chapters.

In the dry condition, both the female (Figure 17) and male (Figure 18) subjects assess both marking materials I and II quite similar, with slight better preference values for marking material II.

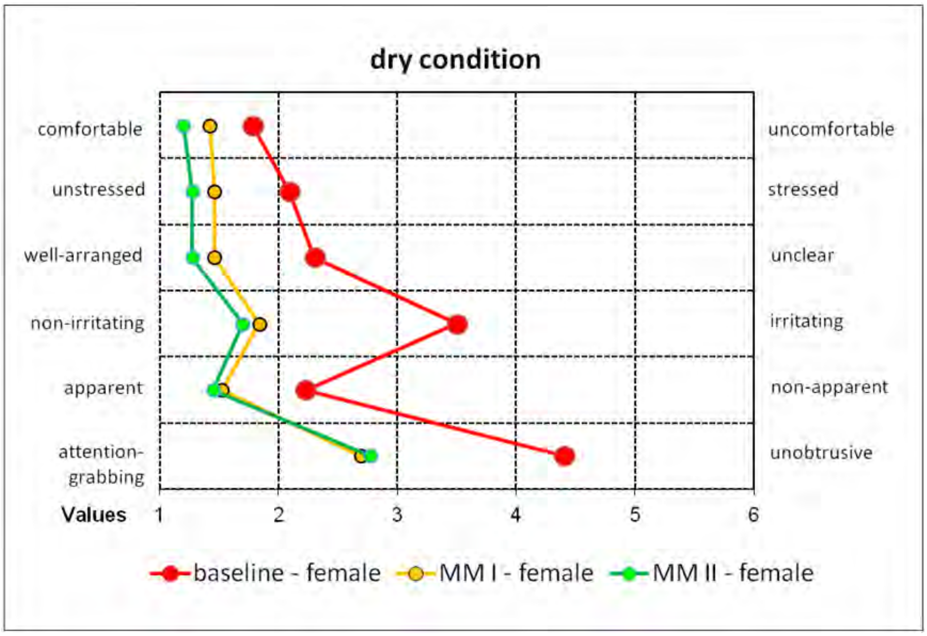


Figure 17. Mean questionnaire values of female subjects for different marking conditions, dry condition

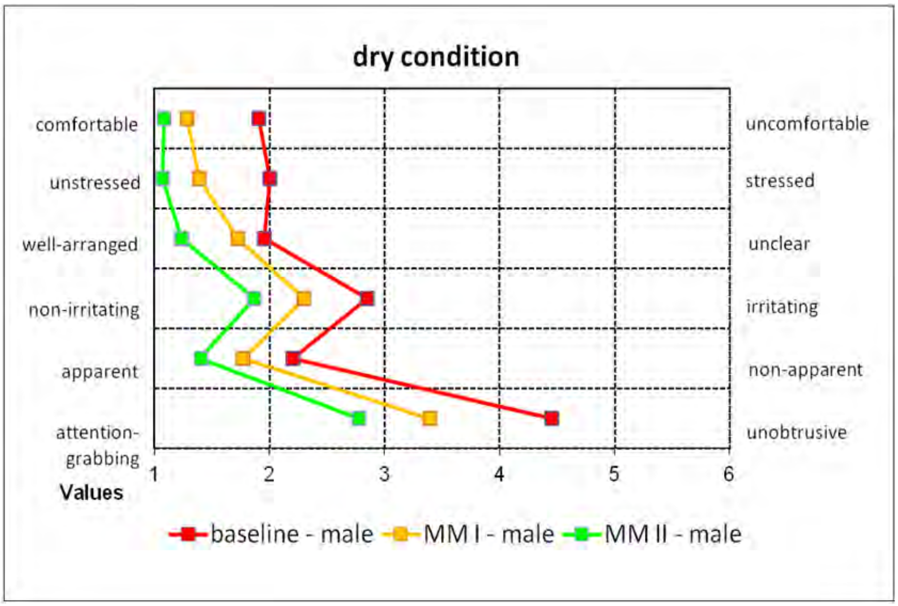


Figure 18. Mean questionnaire values of male subjects for different marking conditions, dry condition

For male subjects, the difference between the marking conditions is bigger compared to their female counterparts.

For the wet condition, the picture is quite similar to the dry condition, but the pattern is shifted to the right end of the grid. This holds true for both sexes (Figure 19, Figure 20).

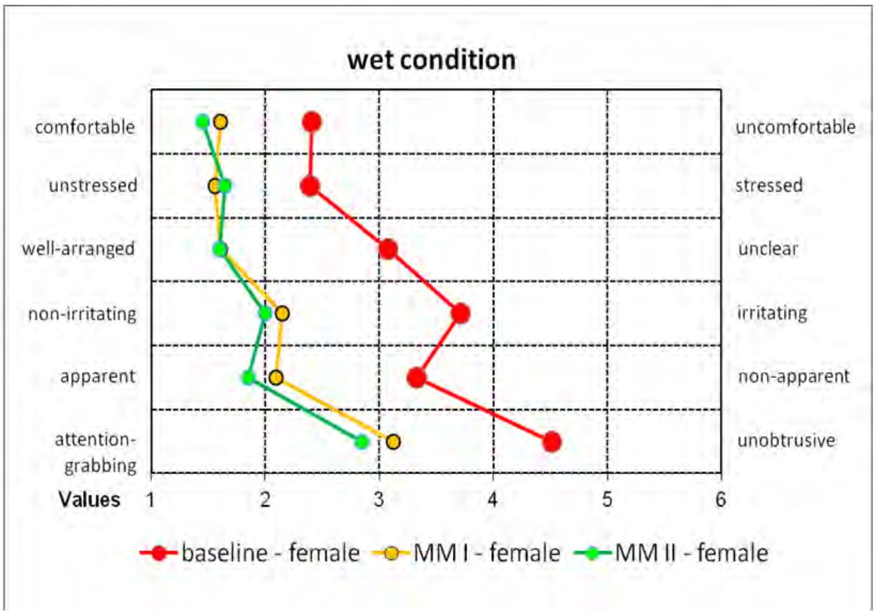


Figure 19. Mean questionnaire values of female subjects for different marking conditions, wet condition

Interestingly, female test persons assessed the test run in marking condition I less stressed than the test run where marking material II was applied.

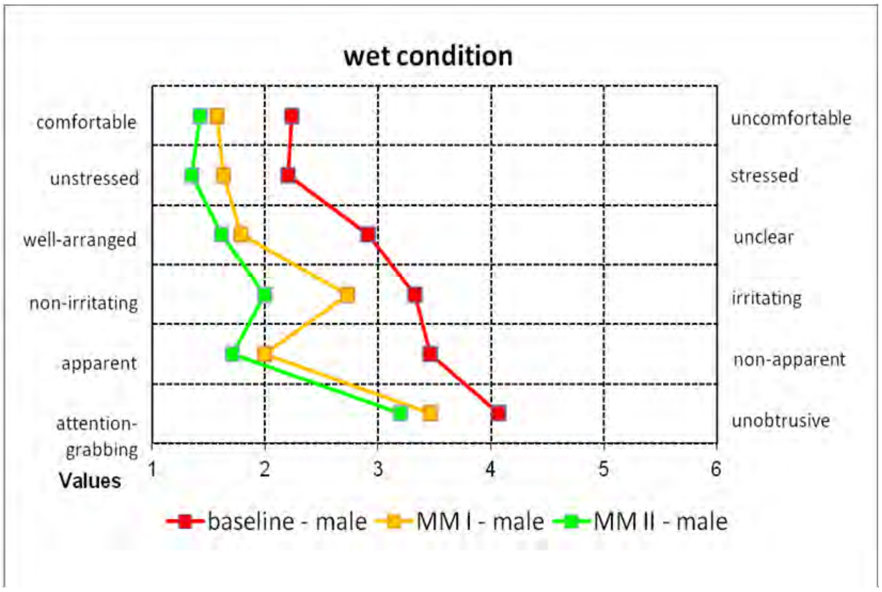


Figure 20. Mean questionnaire values of male subjects for different marking conditions, wet condition

In the wet condition, it could be observed that male test person group assessed the runs under condition marking material II best. It could be observed that the test run within condition marking material I was clearly assessed more irritating than under condition marking material II.

The last track condition was driving in wet & rainy conditions. Here one can see a clear shift towards the right side of the grid in terms of all assessed characteristics for both sex groups. Under this condition, the difference between baseline compared to both marking conditions are biggest, independent of sex group.

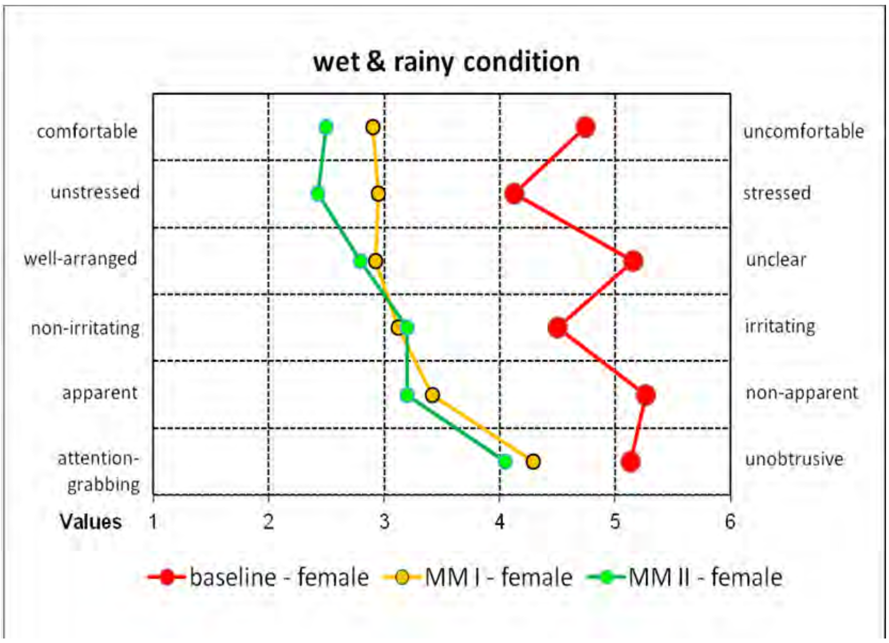


Figure 21. Mean questionnaire values of female subjects for different marking conditions, wet & rainy condition

Female subjects clearly experienced the wet & rainy conditions as most uncomfortable and stressful, especially under the baseline condition. The same is true for male test subjects, although the stated stress level was lower within this group. Again, both marking materials are assessed much more convenient than the baseline marking. However, there are significant differences also between the assessed marking material I condition and marking material II condition.

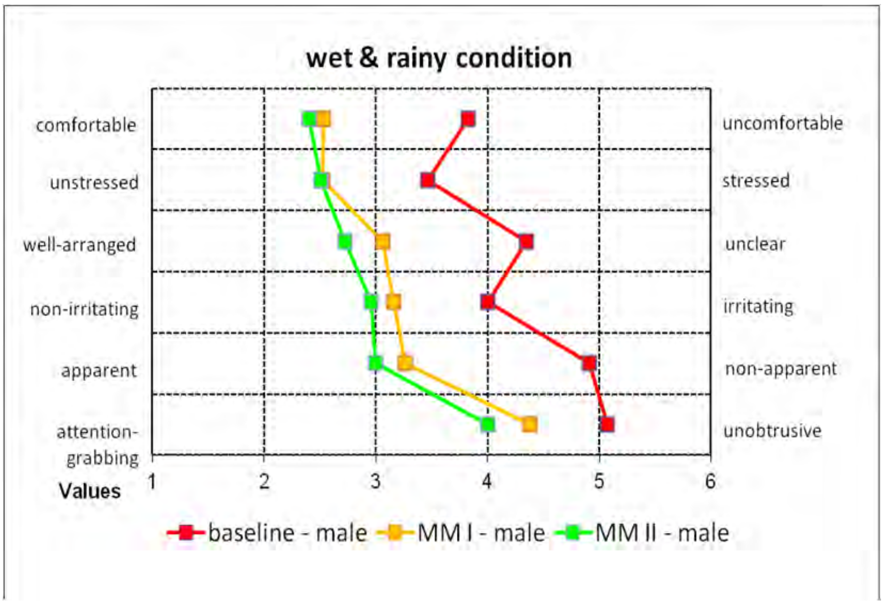


Figure 22. Mean questionnaire values of male subjects, for different marking conditions, wet & rainy condition

A deeper view between the intra-individual comparisons is provided in the next section.

4.2.2. INTRA-INIVIDUAL COMPARISONS

The used statistical model compares the data of a single person between the different conditions with him/herself. General linear models (GLM) for repeated measures have been used to show statistical differences depending on different track and marking conditions. This kind of GLM are commonly used if dependent variables represent measurements of the same variable (or variables) taken repeatedly.

In the tables, mean and p-values for marking effects are presented, as well as the effect size, noted as Eta²[6]. Furthermore, p and Eta²-values of possible age interactions are also mentioned as well as p- and Eta²-values for the contrast between marking condition for material I and II.

As stated earlier, due to current weather conditions, the second sample group (group B) did not carry out the test run under the baseline dry condition. Hence, the subsequent analyses for this specific condition were carried out with only half of the total sample. This fact is marked by grey cell rows in the subsequent result tables. Results including this very sample should be interpreted with care due to relatively small sample sizes.

[6]. The effect size estimates facilitate the comparison of findings in studies and across disciplines. Aron, Aron & Coups (2009) suggest low effect sizes of.01 as small effect, .06 as medium effect and .14 as large effect.

4.2.2.1. Comfort (comfortable vs. uncomfortable)

Asked about driving comfort, female test subjects state significantly different comfort levels: baseline run was perceived most uncomfortable, followed by condition marking material I and then marking material II.

Table 10. Assessment of driving comfort for different track and marking conditions for different age and sex groups

	Marking condition>>		Baseline		MM I	MM II	Sign.	Effect size	Sign.	Effect size	Contrast MM I vs. MM II	
sex	track condition	age group	n	mean (s)	mean (s)	mean (s)	p (within, marking)	Eta^2	p (within, age)	Eta^2	p (within, marking)	Eta^2
female	dry	20-40 y	11	1.55	1.18	1.00	.019	.181	.111	.167	.149	.101
		41-60 y	10	2.20	1.20	1.40						
		61+ y	2	1.00	1.00	1.00						
	wet	20-40 y	15	2.40	1.60	1.40	**.000****	**.250**	.993	.003	**.000****	**.317**
		41-60 y	14	2.29	1.57	1.36						
		61+ y	10	2.60	1.70	1.70						
	wet & rainy	20-40 y	15	5.20	2.67	2.13	**.000****	**.548**	.090	.104	**.000****	**.519**
		41-60 y	14	4.71	3.14	3.00						
		61+ y	10	4.10	2.80	2.40						
male	dry	20-40 y	7	1.86	1.00	1.00	**.000****	**.35**	.682	.057	**.000****	**.516**
		41-60 y	9	2.22	1.33	1.11						
		61+ y	6	1.50	1.17	1.00						
	wet	20-40 y	17	2.41	1.71	1.53	**.000****	**.317**	.451	.040	**.000****	**.452**
		41-60 y	15	2.47	1.60	1.40						
		61+ y	15	1.80	1.40	1.33						
	wet & rainy	20-40 y	17	4.06	2.88	2.59	**.000****	**.382**	.961	.007	**.000****	**.410**
		41-60 y	15	4.07	2.73	2.60						
		61+ y	14	3.29	2.00	2.07						

Differences between the marking conditions are all statistically significant, the biggest difference however was found when comparing the baseline condition against the other conditions. No age interaction was found.

4.2.2.2. Stress (unstressed vs. stressed)

Stress levels were investigated for every test run and condition. Table 11 clearly indicates, that stress levels generally are highly significantly lower in marking conditions I and II, compared to the baseline condition

Table 11. Assessment of driving stress for different track and marking conditions for different age and sex groups

	Marking condition>>		Baseline		MM I	MM II	Sign.	Effect size	Sign.	Effect size	Contrast MM I vs. MM II	
sex	**track condition**	age group	n	mean (s)	mean (s)	mean (s)	p (within, marking)	Eta²	p (within, age)	Eta²	p (within, marking)	Eta²
female	**dry**	20-40 y	10	1.90	1.20	1.00	.011	.223	.264	.132	.072	.169
		41-60 y	9	2.44	1.22	1.44						
		61+ y	2	1.00	1.00	1.00						
	wet	20-40 y	15	2.40	1.60	1.53	**.000****	**.359**	.468	.049	.009	.182
		41-60 y	13	2.23	1.62	1.54						
		61+ y	10	2.60	1.50	2.00						
	wet & rainy	20-40 y	15	4.33	2.87	2.07	**.000****	**.482**	.105	.097	**.000****	**.446**
		41-60 y	15	4.40	3.07	2.73						
		61+ y	10	3.40	2.80	2.50						
male	**dry**	20-40 y	7	2.00	1.00	1.00	**.001****	**0.392**	0.739	0.062	**.002***	**.485**
		41-60 y	7	2.43	1.43	1.14						
		61+ y	4	1.50	1.00	1.00						
	wet	20-40 y	17	2.29	1.71	1.41	**.000****	**.280**	.897	.014	**.000****	**.411**
		41-60 y	14	2.21	1.71	1.36						
		61+ y	11	2.00	1.36	1.36						
	wet & rainy	20-40 y	17	3.71	2.65	2.71	**.000****	**.314**	.161	.078	.008	.164
		41-60 y	15	3.93	2.87	2.53						
		61+ y	11	2.73	1.91	2.45						

Taking a look at the difference between condition marking material I and II, significant differences occurred in the wet & rainy condition within female subjects as well as in the wet condition within male subjects showing less stressful assessments within marking condition II. In condition "wet", mean values are lower (less stressful) within marking condition I for female age group 61+ years as well as in the "wet & rainy" condition in the youngest and the oldest male age group, although not statistically significant.

4.2.2.3. Clearness (well-arranged vs. unclear)

Clearness was the first trait that was asked about how the track trajectory was experienced. Not surprisingly, the baseline condition was assessed to have an unclear track trajectory, highly significant.

Table 12. Assessment of clearness for different track and marking conditions for different age and sex groups

	Marking condition>>		Baseline		MM I	MM II	Sign.	Effect size	Sign.	Effect size	Contrast MM I vs. MM II	
sex	track condition	age group	n	mean (s)	mean (s)	mean (s)	p (within, marking)	Eta²	p (within, age)	Eta²	p (within, marking)	Eta²
female	dry	20-40 y	11	2.45	1.18	1.27	**.004***	**.246**	.885	.028	.023	.233
		41-60 y	10	2.20	1.10	1.30						
		61+ y	2	2.00	1.50	1.00						
	wet	20-40 y	15	3.27	1.47	1.40	**.000****	**.368**	.311	.063	**.001**	.256
		41-60 y	14	2.50	1.50	1.79						
		61+ y	10	3.60	2.00	1.70						
	wet & rainy	20-40 y	14	5.29	3.00	2.29	**.000****	**.549**	.201	.083	**.000****	.464
		41-60 y	14	5.57	2.93	3.43						
		61+ y	9	4.67	3.22	2.67						
male	dry	20-40 y	7	1.86	1.29	1.29	**.001****	**.307**	.840	.038	**.003***	**.396**
		41-60 y	9	2.11	1.56	1.11						
		61+ y	5	1.80	1.40	1.00						
	wet	20-40 y	17	3.18	1.82	1.82	**.000****	**.294**	.749	.021	**.001**	**.219**
		41-60 y	15	2.93	2.13	1.53						
		61+ y	15	2.60	1.40	1.47						
	wet & rainy	20-40 y	17	4.65	3.35	3.00	**.000****	**.315**	.943	.009	**.000****	**.306**
		41-60 y	15	4.60	3.13	2.80						
		61+ y	14	3.71	2.71	2.43						

Both male and female subjects perceive the track trajectory in marked driving conditions to be significantly clearer, independent of track condition or age group. As regards the differences between condition marking material I and II, female subjects within the middle age group rate the clearness of marking material I better in the “wet” condition slightly better, just like their male counterparts in the oldest age group. However, no age interaction was found.

4.2.2.4. Confusion (non-irritating vs. irritating)

Significant differences regarding the level of confusion of the track trajectory reveal that the baseline condition was most confusing for all test subjects, regardless of age, sex group and track condition.

Table 13. Assessment of confusion for different track and marking conditions for different age and sex groups

	Marking condition>>			Baseline	MM I	MM II	Sign.	Effect size	Sign.	Effect size	Contrast MM I vs. MM II	
sex	track condition	age group	n	mean (s)	mean (s)	mean (s)	p (within, marking)	Eta²	p (within, age)	Eta²	p (within, marking)	Eta²
female	dry	20-40 y	11	3.64	1.18	1.64	.007	.228	.521	.079	.041	.202
		41-60 y	9	3.33	1.78	2.22						
		61+ y	2	3.50	3.00	1.50						
	wet	20-40 y	15	4.33	1.73	1.80	**.000****	**.254**	.107	.102	**.000****	**.329**
		41-60 y	13	3.08	1.92	1.92						
		61+ y	10	3.60	3.20	2.60						
	wet & rainy	20-40 y	17	4.64	3.00	2.79	**.002****	**.169**	.733	.028	.049	.160
		41-60 y	15	4.93	3.20	3.53						
		61+ y	12	3.56	3.00	2.78						
male	dry	20-40 y	7	2.57	1.14	1.14	**.001****	**.348**	.044	.258	.017	.307
		41-60 y	8	2.25	2.50	2.00						
		61+ y	4	5.00	2.25	2.25						
	wet	20-40 y	17	3.18	2.76	2.12	**.000****	**0.215**	0.134	0.083	**.000****	**.323**
		41-60 y	14	2.79	2.64	2.21						
		61+ y	12	4.17	2.67	1.75						
	wet & rainy	20-40 y	14	3.88	3.18	3.41	**.004***	**.124**	.619	.031	.008	.160
		41-60 y	15	3.80	3.13	2.87						
		61+ y	9	4.17	3.33	2.58						

Comparing the conditions marking material I and II, significant differences could be observed which indicate that in the “wet” condition, marking material II is preferred over marking material I. No significant differences were found in the “wet & rainy” condition between the two marking materials, although mean values suggest that material II was rated less irritating. However, this was not the case for female test persons in the middle age group as well as for male subjects aged between 20-40 years.

4.2.2.5. Perceptibility (apparent vs. non-apparent)

Test persons asked about how apparent the track trajectory in different track and marking conditions was experienced, significant differences occur between all conditions – independent of age and sex.

Table 14. Assessment of perceptibility for different track and marking conditions for different age and sex groups

	Marking condition>>			Baseline	MM I	MM II	Sign.	Effect size	Sign.	Effect size	Contrast MM I vs. MM II	
sex	track condition	age group	n	mean (s)	mean (s)	mean (s)	p (within, marking)	Eta²	p (within, age)	Eta²	p (within, marking)	Eta²
female	dry	20-40 y	7	2.27	1.27	1.36	**.001****	**.312**	.503	.082	.542	.020
		41-60 y	8	2.11	1.33	1.89						
		61+ y	4	2.50	1.00	1.50						
	wet	20-40 y	15	3.47	2.47	1.80	**.000****	**.329**	.550	.043	**.000****	**.376**
		41-60 y	13	2.69	1.62	1.77						
		61+ y	9	4.00	2.44	2.33						
	wet & rainy	20-40 y	14	5.36	3.29	2.64	**.000****	**.526**	.317	.064	**.000****	**.421**
		41-60 y	14	5.71	3.71	4.00						
		61+ y	10	4.50	3.10	2.70						
male	dry	20-40 y	11	2.43	1.57	1.14	**.001****	**.342**	.946	.022	**.001****	**.509**
		41-60 y	9	2.25	1.50	1.25						
		61+ y	2	2.00	1.25	1.25						
	wet	20-40 y	17	3.71	2.00	1.65	**.000****	**.417**	.283	.062	**.000****	**.417**
		41-60 y	14	3.07	2.36	1.71						
		61+ y	11	3.45	1.73	1.91						
	wet & rainy	20-40 y	17	5.12	3.41	3.47	**.000****	**.563**	.417	.046	**.000****	**.573**
		41-60 y	15	5.20	3.40	2.87						
		61+ y	12	4.25	3.00	2.58						

Results suggest that generally track trajectory in condition marking material II was rated significantly more apparent than in condition marking material I, although not for all subjects. In the “wet” condition, female subjects aged between 41-60 show a better value within condition marking material I, just like male subjects age 61+ years and male subjects in the youngest age group in the “wet & rainy” condition.

4.2.2.6. Attention (attention-grabbing vs. unobtrusive)

The last characteristic to be assessed was how attention-grabbing the track trajectory is. As with the previous assessments, the track trajectory within the baseline condition was rated as to be easily unobtrusive. Surprisingly, in the “wet & rainy” condition, female test subjects 61+ year old rated the track trajectory to be more attention-grabbing within the baseline condition, however not statistically significant. The same is true for male participants of the young and middle age group in the “wet” condition as they assess the track trajectory to be more attention-grabbing.

Table 15. Assessment of attention for different track and marking conditions for different age and sex groups

	Marking condition>>		Baseline		MM I	MM II	Sign.	Effect size	Sign.	Effect size	Contrast MM I vs. MM II	
sex	track condition	age group	n	mean (s)	mean (s)	mean (s)	p (within, marking)	Eta²	p (within, age)	Eta²	p (within, marking)	Eta²
female	dry	20-40 y	11	4.45	2.00	2.45	.116	.107	.453	.090	.691	.009
		41-60 y	9	4.22	2.22	3.11						
		61+ y	2	5.00	5.50	5.50						
	wet	20-40 y	15	5.00	2.60	2.40	**.000****	**.224**	.057	.124	**.001****	**.285**
		41-60 y	12	3.58	2.92	2.25						
		61+ y	10	4.90	4.40	4.50						
	wet & rainy	20-40 y	14	5.57	3.93	3.00	.026	.101	.015	.164	.026	.137
		41-60 y	14	5.14	4.36	4.71						
		61+ y	9	4.44	5.00	4.56						
male	dry	20-40 y	7	4.29	2.71	2.14	**.000****	**.443**	.751	.056	**.000****	**.545**
		41-60 y	8	4.13	3.00	2.25						
		61+ y	4	6.25	3.75	2.75						
	wet	20-40 y	17	2.40	3.59	3.06	**.003***	**.144**	.524	.041	**.002***	**.217**
		41-60 y	14	2.25	3.50	2.79						
		61+ y	10	4.50	3.70	3.40						
	wet & rainy	20-40 y	17	4.76	4.59	4.35	.006	.119	.494	.041	**.005***	**.179**
		41-60 y	14	5.07	4.36	3.43						
		61+ y	12	5.50	4.42	4.33						

Generally, the track trajectory within marked conditions seemed to be less attention-grabbing, both for male and female subjects where the condition marking material II was rated to be less attention demanding. Mean values for female subjects in the “wet & rainy” condition suggest that condition marking material I was rated to be most unobtrusive, although not statistically significant.

4.3. DRIVING DATA

From the test runs, not only questionnaire data but also data from actual driving behaviour was obtained. The collected data was retrieved from the data logger which is described under section 2.5.

In order to compare driving behaviour under different track and marking conditions, driving parameters such as speed, longitudinal and lateral accelerations were collected.

The following sections present these driving parameters for either the whole lap, i.e. lap times and separate sectors within the lap. As stated earlier (see section 2.1), sectors 2 and 6 had to be omitted for further analyses.

4.3.1. LAP TIMES

GLM models were used to compare lap times and identify possible age interaction effects within subjects and age effects between subjects. The following table shows realised lap times for different driving and marking conditions.

The following figure (Figure 23) presents an overview of completed mean lap times for all track and marking conditions:

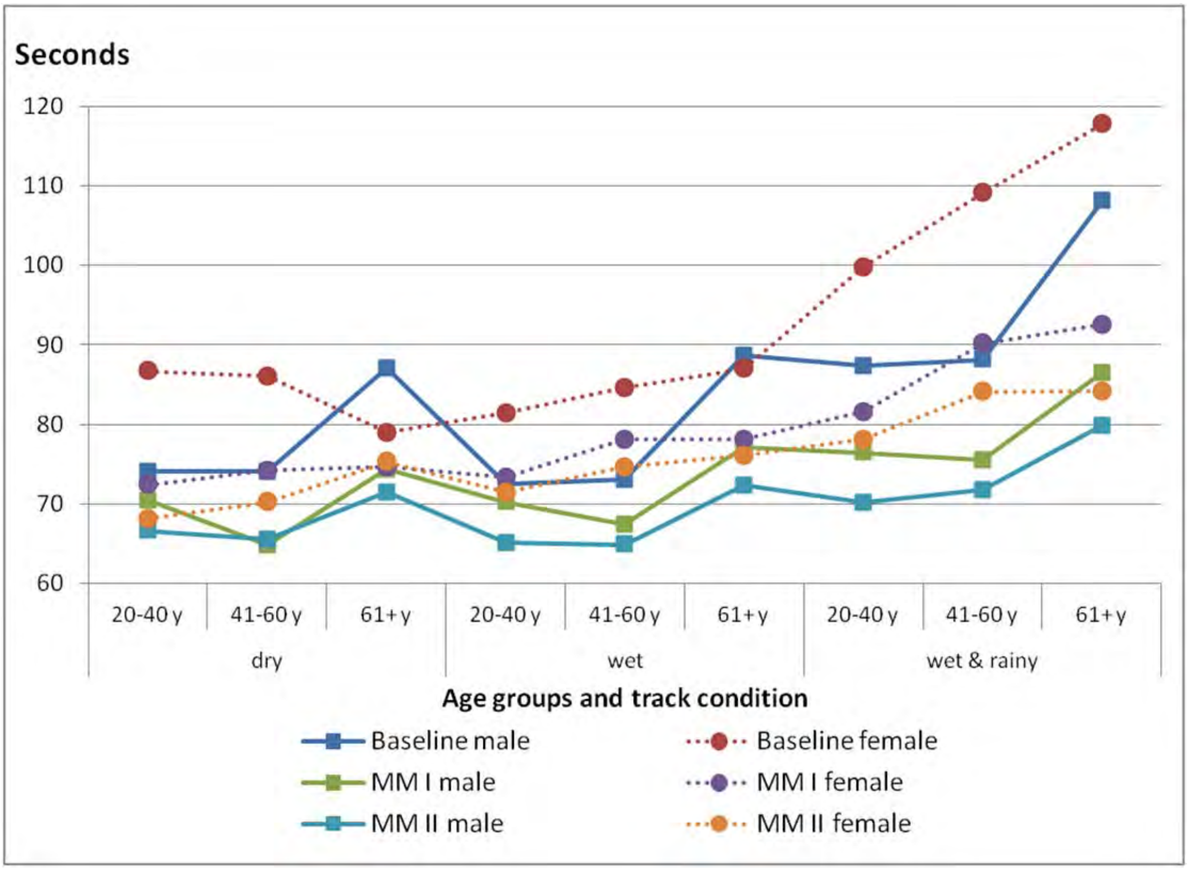


Figure 23. Mean lap times for different age groups and marking conditions by sex

A clear tendency can be observed as lap times are generally lower in dry and wet conditions compared to the wet & rainy condition. This effect could be most clearly isolated within subjects of the oldest age groups of both sexes.

Taking a closer look to the lap time distribution, one can see that there are significant differences between the marking conditions, for both female and male subjects (Table 16):

Table 16. Lap times of test subjects in different marking and track conditions

	Marking condition>>		Baseline		MM I	MM II	Sign.	Effect size	Sign.	Effect size	Sign.
sex	track condition vv	age group	n	mean (s)	mean (s)	mean (s)	p (within, marking)	Eta²	p (within, age group)	Eta²	p (between, age group)
female	dry	20-40 y	10	86.71	72.42	68.13	**.000****	.436	.321	.113	.939
		41-60 y	10	86.04	74.20	70.25					
		61+ y	2	79.03	74.68	75.29					
	wet	20-40 y	15	81.42	73.40	71.49	**.000****	.659	.848	.019	.109
		41-60 y	15	84.64	78.14	74.66					
		61+ y	8	87.01	78.15	76.11					
	wet & rainy	20-40 y	15	99.81	81.58	78.15	**.000****	.804	.100	.104	.165
		41-60 y	15	109.09	90.16	84.10					
		61+ y	8	117.78	92.55	84.18					
male	dry	20-40 y	7	74.10	70.48	66.64	**.000****	.553	**0.006**	.32	**.006**
		41-60 y	9	74.08	64.80	65.59					
		61+ y	4	87.08	74.41	71.51					
	wet	20-40 y	17	72.50	70.26	65.17	**.000****	.620	**.000****	.232	.229
		41-60 y	15	73.03	67.41	64.90					
		61+ y	14	88.64	77.17	72.35					
	wet & rainy	20-40 y	17	87.39	76.48	70.14	**.000****	.622	**.040***	.109	.165
		41-60 y	15	88.15	75.54	71.79					
		61+ y	14	108.07	86.45	79.86					

In general, test subjects drove slowest in the baseline condition, faster under condition with applied marking material I (type I), but fastest under condition with applied marking material II (type II). A significant age interaction[7] effect within male subjects could also be observed for the "wet" and "wet & rainy condition". The age interaction suggests that especially older (male) subjects took significantly more time condition to complete the test track in the baseline and were faster under condition MM I and slightly faster under the MM II condition. The same holds true for female subjects in the oldest age group although not statistically significant.

[7] A statistical interaction occurs when the effect of one independent variable (here marking condition) on the dependent variable (here lap time) changes depending on the level of another independent variable (here age group). Furthermore, this simultaneous influence of two variables on a third is not additive.

4.3.1.1. Analysis of positional effects

If multiple runs on a test track are completed it can be expected that there are positional effects: it could be assumed that test subjects adapt their driving behaviour despite of the dependent variables. In the current design, authors suspected a positional effect in terms of adaption of driving speed, i.e. test persons show a tendency to complete the track faster with every run they do. If a positional effect occurred, the lap times would have been faster independently of track or marking condition.

The current design was set up in a way that allowed for testing positional effects. As described earlier, the test sample was randomly split into two groups. One group (Group A) completed first a baseline run (preparation marking only), then marking material I and at last the track condition with marking material II. Group B started with condition marking material I, subsequently test condition with marking material and lastly completed the baseline condition.

Authors' expectation was that the test subjects would be slowest in the baseline condition, faster in the marking material I condition and fastest in condition with marking material II. This was exactly the order which was observed for group A. If a positional effect occurred, Group B would be slowest within condition marking material I (their first test condition) then faster within condition marking material II but fastest within their last test condition, i.e. baseline condition, but that was not the case. Hence, signs of a positional effect did not occur.

The following table reveals that a positional effect was not observed as group B was slowest in the baseline condition, just as group A:

Table 17. Mean lap times of subjects of two groups (A,B) in different marking and track conditions by sex

	female				male			
track condition	Group A (n)	mean	Group B (n)	mean	Group A (n)	mean	Group B (n)	mean
BL wet	23	81.51	15	87.49	22	76.56	24	78.53
MM I wet	23	73.10	18	81.85	23	70.75	24	72.54
MM II wet	23	72.01	17	76.95	23	66.27	24	68.33
BL wet rain	23	103.32	16	115.02	23	94.80	24	94.91
MM I wet rain	23	81.68	17	94.35	23	78.23	23	80.18
MM II wet rain	23	79.31	16	84.81	23	74.69	24	74.07

4.3.2. MEAN LAP SPEEDS

Lap times have been translated in mean lap speeds to illustrate possible speed differences for the different testing conditions. The following table shows the distribution of mean lap speeds of test subjects in different test and track conditions:

Table 18. Mean lap speeds of test subjects in different marking and track conditions

track condition	age group	Baseline female (km/h)	MM I female (km/h)	MM II female (km/h)	Baseline male (km/h)	MM I male (km/h)	MM II male (km/h)
dry	20-40 y	40.86	48.92	52.00	47.80	50.26	53.15
	41-60 y	41.17	47.74	50.43	47.82	54.67	54.00
	61+ y	44.83	47.44	47.05	40.68	47.61	49.54
wet	20-40 y	43.51	48.26	49.55	48.86	50.42	54.36
	41-60 y	41.85	45.33	47.45	48.50	52.55	54.58
	61+ y	40.71	45.33	46.55	39.96	45.90	48.96
wet & rainy	20-40 y	35.49	43.42	45.33	40.53	46.32	50.50
	41-60 y	32.47	39.29	42.12	40.18	46.89	49.35
	61+ y	30.08	38.28	42.08	32.78	40.98	44.36

The subsequent table presents the speed differences between the different test conditions where marking conditions are calculated against the baseline condition and between each other:

Table 19. Mean lap speed differences of test subjects for different marking and track conditions

track condition	age group	female MM I - BL (km/h)	female MM II - BL (km/h)	female MM II vs. MM I (km/h)	male MM I - BL (km/h)	male MM II - BL (km/h)	male MM II vs. MM I (km/h)
dry	20-40 y	8.06	11.14	3.08	2.46	5.35	2.89
	41-60 y	6.57	9.26	2.69	6.85	6.19	-0.66
	61+ y	2.61	2.23	-0.38	6.93	8.86	1.93
wet	20-40 y	4.76	6.04	1.29	1.56	5.50	3.94
	41-60 y	3.48	5.59	2.11	4.04	6.08	2.04
	61+ y	4.62	5.84	1.22	5.94	8.99	3.06
wet & rainy	20-40 y	7.93	9.84	1.91	5.79	9.97	4.18
	41-60 y	6.82	9.65	2.83	6.71	9.16	2.46
	61+ y	8.20	12.01	3.81	8.20	11.58	3.38
	mean diff.	**5.89**	**7.95**	**2.06**	**5.39**	**7.96**	**2.58**

The mean lap speed differences for both marking conditions calculated against the baseline condition range from between 5-8 km/h for both male and female subjects for the overall sample. The mean lap speed between conditions marking material I and II generally differs about 2-3 km/h within the whole track (~ 1 km of length) for both sexes.

Taking a closer look to age group results, biggest lap speed differences occurred within in the oldest age group (both male and female), equaling to approx. 12 km/h lower speed in the “wet & rainy” baseline condition compared to the marking material II condition.

4.3.3. SECTOR ANALYSIS

Single sectors have been analysed with regards to marking effects and age interactions. The following table illustrates the results of MANOVA procedures where lap times for each respective sector and condition have been controlled as covariates. P-values for comparisons of average lateral and longitudinal accelerations are shown:

Table 20. P-values from MANOVA procedures for single sectors comparing lateral and longitudinal accelerations in two different marking and track conditions by sex

MM I vs. MM II		dry				wet				wetrain			
		marking effect (within subjects)		age interaction (within subjects)		marking effect (within subjects)		age interaction (within subjects)		marking effect (within subjects)		age interaction (within subjects)	
sector	sex	mean lat acc	mean long acc	mean lat acc	mean long acc	mean lat acc	mean long acc	mean lat acc	mean long acc	mean lat acc	mean long acc	mean lat acc	mean long acc
1	female	.254	.324	.406	.459	.823	.752	.191	.501	.668	.118	.962	.419
	male	.602	.720	.723	.346	.344	.128	.093	.805	.947	.152	.304	.069
2	female	.694	.689	.451	.799	.830	.045	.418	.517	.947	.987	.737	.802
	male	.690	.586	.364	.230	.810	.097	.463	.826	.920	.994	.076	.383
3	female	.776	.960	.545	.644	.886	.251	.351	.723	.575	.199	.641	.750
	male	.540	.479	.234	.607	.773	.211	.420	.718	.990	.012	.263	.461
4	female	.476	.157	.084	.944	.488	.116	.873	.723	.512	.675	.372	.495
	male	.825	.527	.212	.521	.154	.722	.102	.891	.166	.070	.250	.306
5	female	.452	.526	.579	.967	.931	**.001****	.078	.290	.457	.015	.825	.790
	male	.140	.545	.661	.176	.654	.102	.702	.792	.382	.360	.140	.750
6	female	.566	.340	.666	.950	.984	.654	.060	.603	.430	.691	.880	.770
	male	.320	.497	.346	.421	.468	.430	.464	.766	.353	.290	.268	.545
7	female	.366	.045	.782	.388	.298	.488	.097	.874	.996	.832	.720	.514
	male	.098	.631	.334	.186	.682	.419	.167	.524	.234	.451	.332	.350
8	female	.416	.502	.362	.794	.642	.583	.623	.591	.812	.283	.543	.621
	male	.351	.749	.913	.500	.632	.389	.451	.936	.744	.940	.404	.610

No statistical significances could be observed, except one which is interpreted to be caused by chance ("false positive") as e.g. a Bonferroni correction[8] was not carried out. These results indicate that mean lateral and longitudinal accelerations do not differ significantly, regardless of sex, age group or marking condition when controlled for lap time. In other words, different marking materials and/or track conditions did not provoke a different driving style within test subjects in terms of cornering and/or acceleration and braking behaviour.

[8] In statistics, the Bonferroni correction is a method used to counteract the problem of multiple comparisons.

4.3.3.1. Sector analysis: sector 1

Sector 1 is a right-hand bend as shown in the figure below:

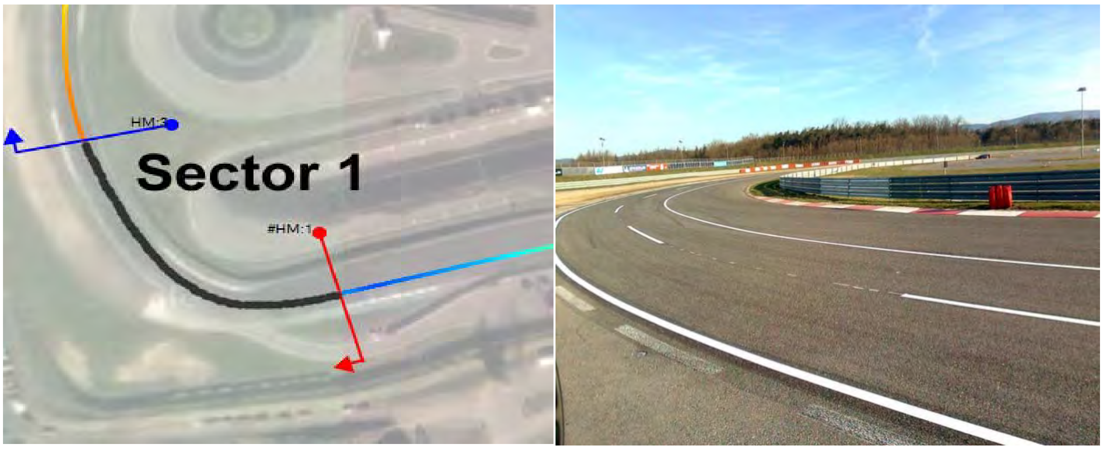


Figure 24. Sector 1, 113m

The sector has a length of about 113m. The next illustration shows the distribution of passage times for the different track and marking conditions:

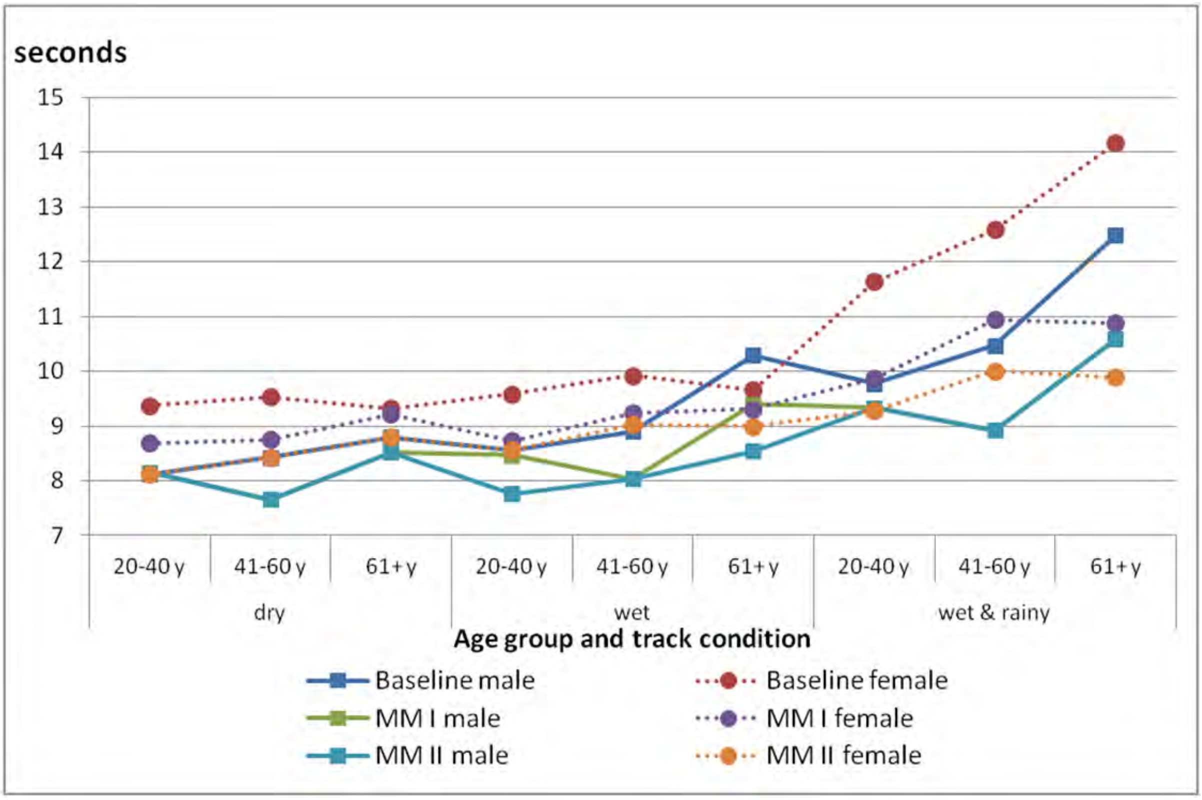


Figure 25. Sector 1 mean times for different track and marking conditions for different age groups by sex

Female as well as male test subjects completed the section in between 7.5 and 10.5 seconds in dry and wet track conditions. The passage times substantially increases under the “wet & rainy” condition.

As regards lateral acceleration, mean g-values show a tendency to decrease (upper 6 lines of the graph) from the “dry” over “wet” to the “wet & rainy” condition as shown in Figure 26. Longitudinal accelerations patterns seem stable between different test conditions (lower 6 lines of the graph):

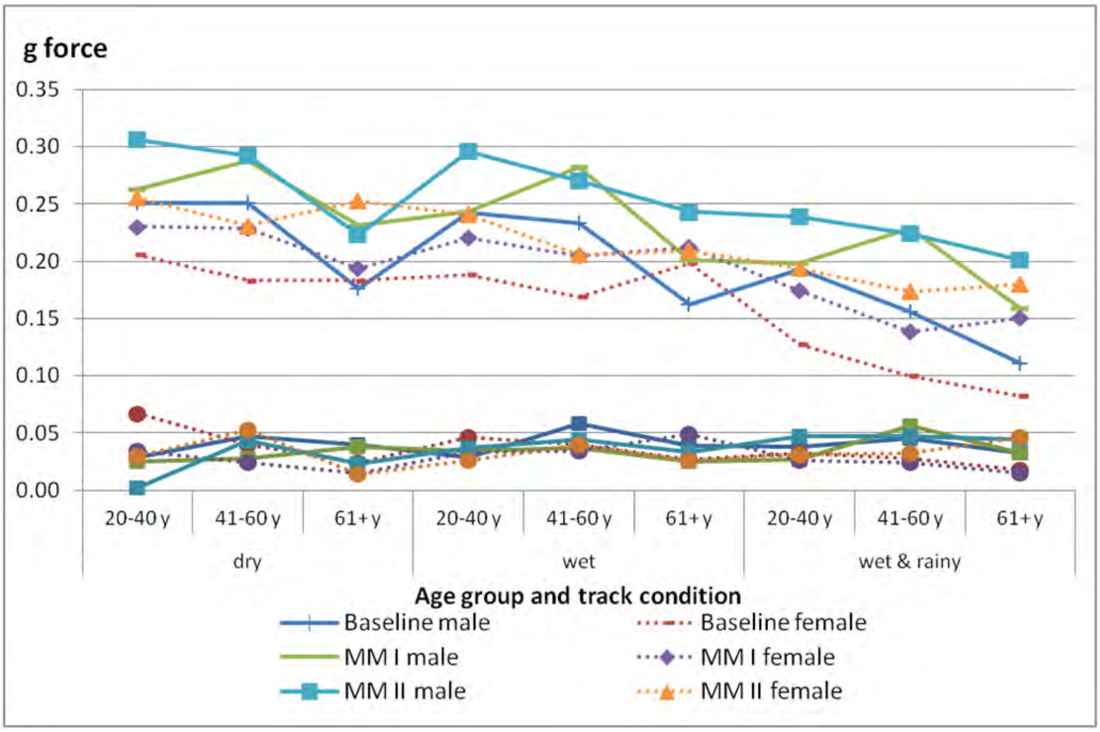


Figure 26. Sector 1 mean lateral and mean longitudinal accelerations (g) for different marking and track conditions by age group and sex

However, when controlled for speed/time, values do not differ significantly.

4.3.3.2. Sector analysis: sector 3

The right picture of sector 3 has been taken against the driving direction. From the drivers´ view, sector 3 was a right-hand bend with a length of 101m.

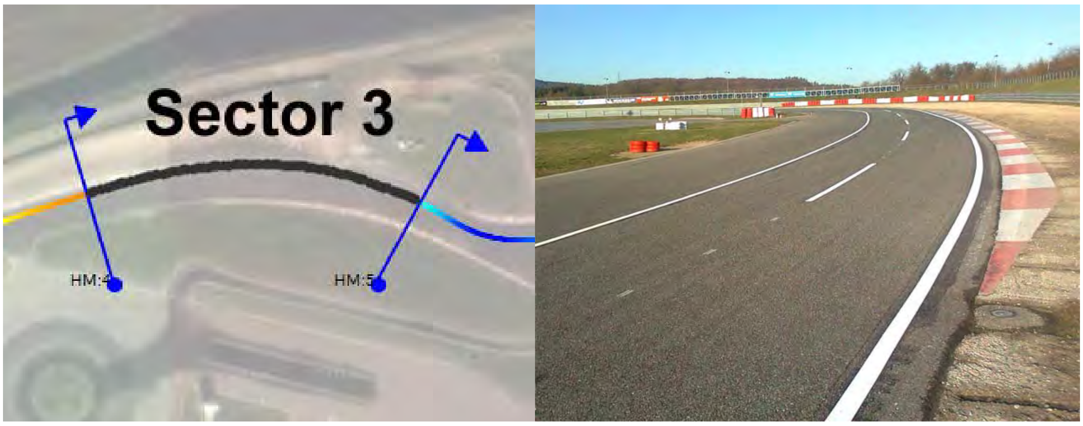


Figure 27. Sector 3, 101m

Figure 28 indicates that female subjects aged between 41-60 years spent the longest time under the baseline condition in this sector.

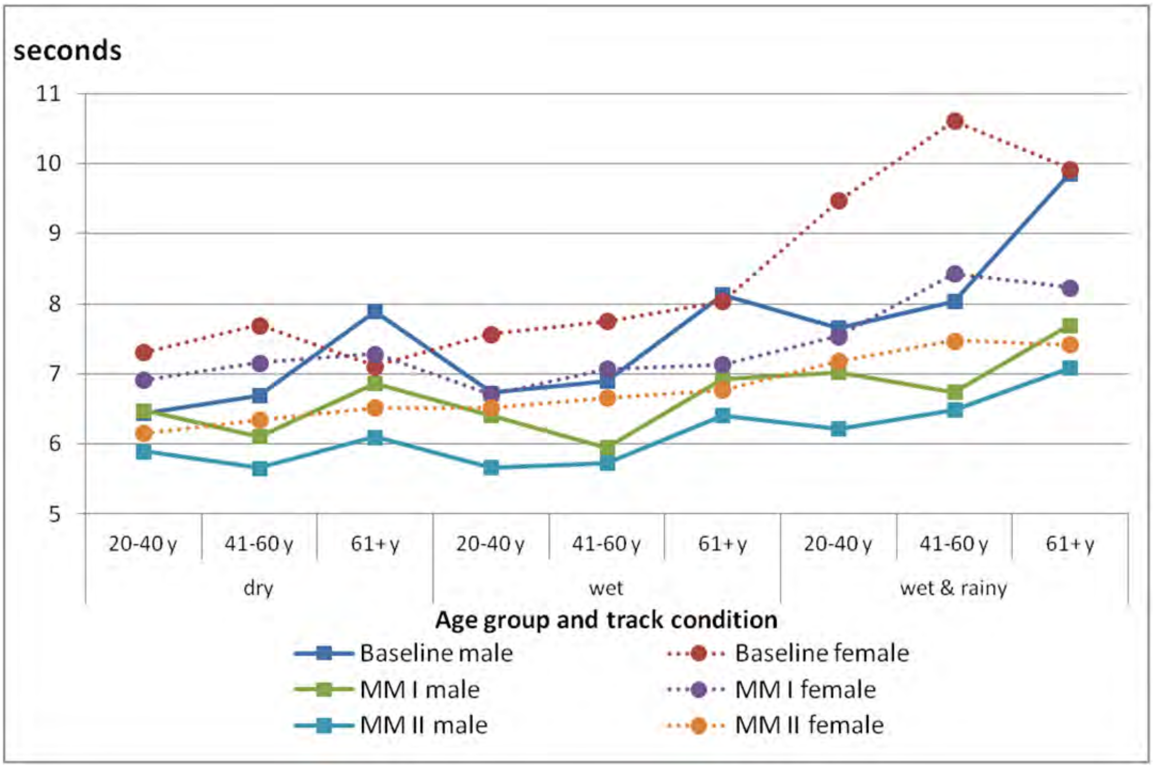


Figure 28. Sector 3 mean times for different track and marking conditions for different age groups by sex

Again, the sector time ranking reveals that driving under condition marking material II was quickest, followed by condition marking material I and driving within the baseline condition was slowest

Lateral and longitudinal g-force distributions are presented below:

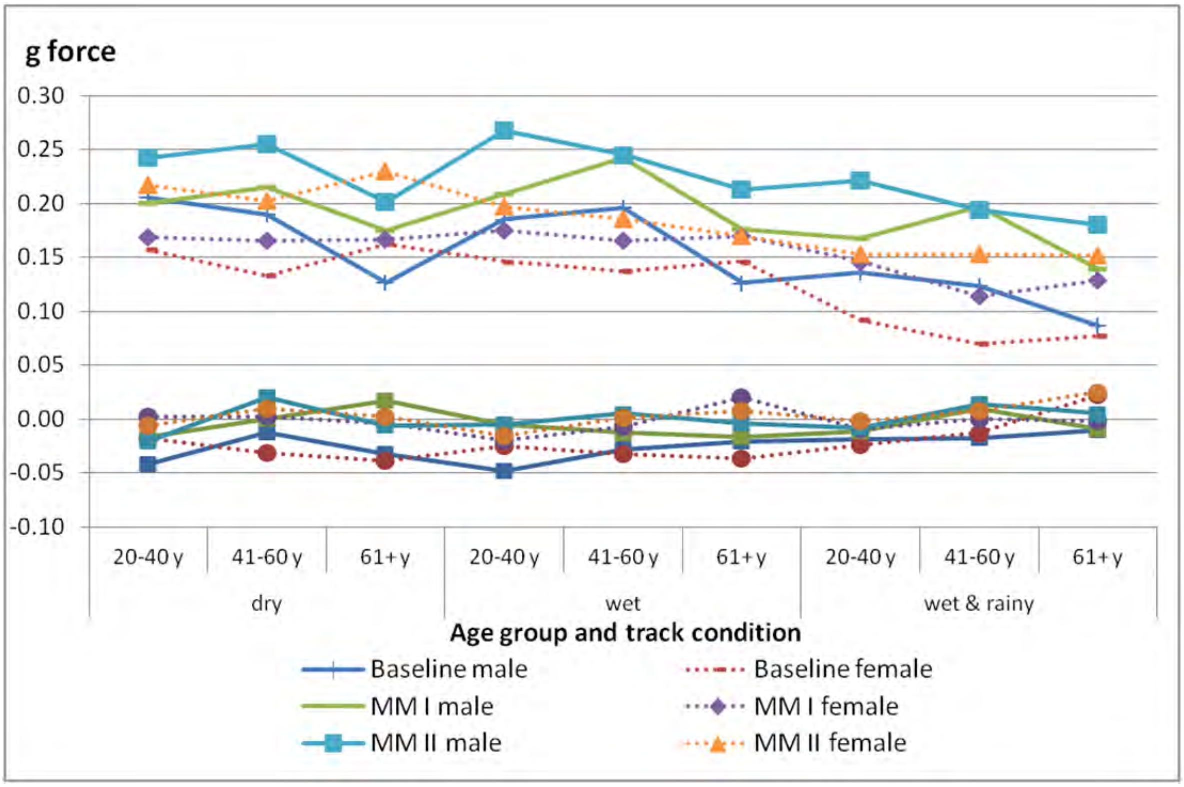


Figure 29. Sector 3 mean lateral and mean longitudinal accelerations (g) for different marking and track conditions by age group and sex

Mean lateral g-values (6 upper lines) were somewhat lower compared to section 1, comparably declining from the “dry” condition to the “wet & rainy” condition as a function of speed. Longitudinal forces stayed in a narrow range around zero.

4.3.3.3. Sector analysis: sector 4:

The right figure below shows both sector 4 and 5. Sector 4 is a (the only) left-hand bend whereas sector 5 is a right-hand bend. In sector 4 (76m of length), the track begins to slope downwards, ending in sector 5. In sector 6, the track shows an ascending slope until the middle of sector 7.

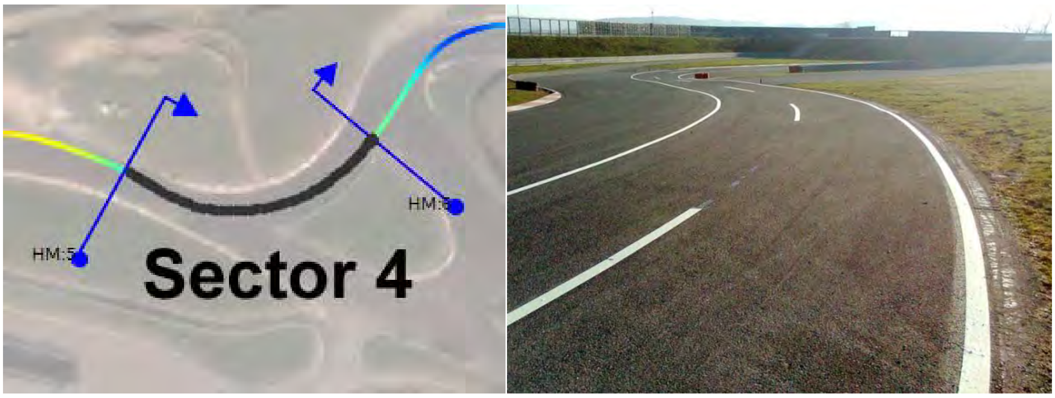


Figure 30. Sector 4 (left, 76m) and sector 4 and 5 (right)

Sector times within sector 4 are illustrated in the figure below:

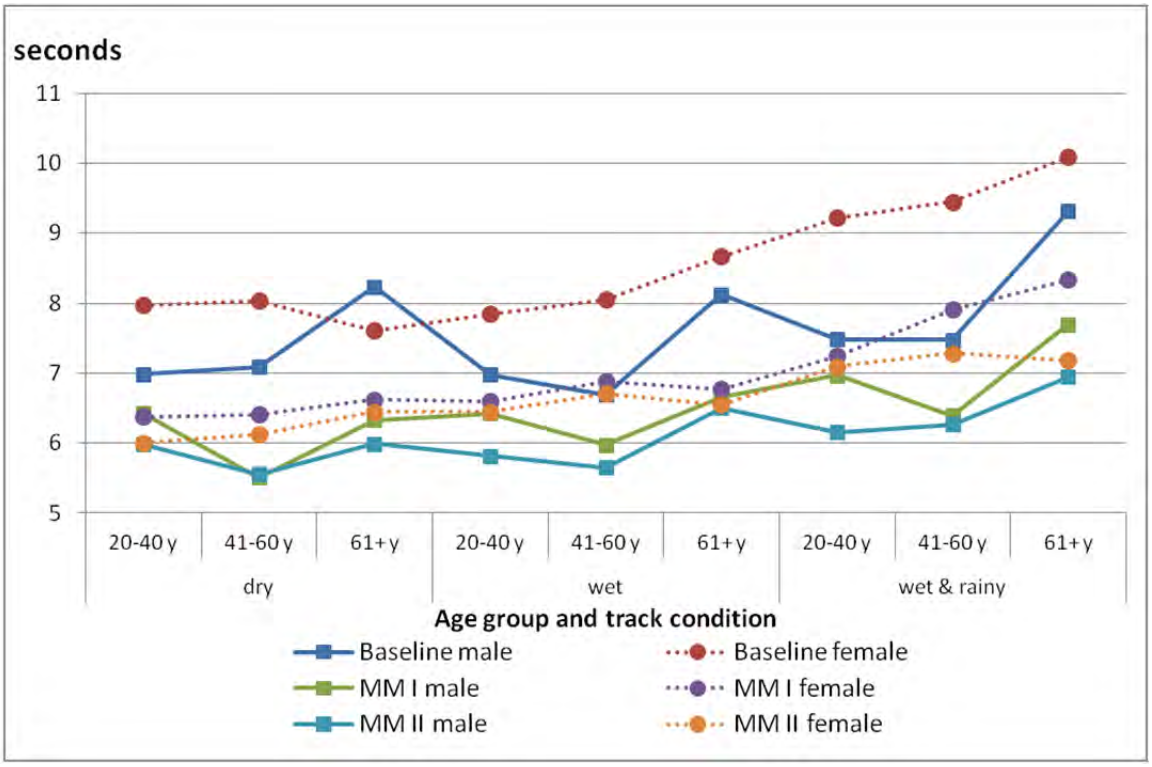


Figure 31. Sector 4mean times for different track and marking conditions for different age groups by sex

Here, sector time differences are not that big compared to the previously mentioned sectors. However, also in this sector, female and male test subjects were clearly slowest in the baseline condition; especially male subject within the oldest age group 61+ years took significantly more time to complete the sector.

Condition marking material II was completed slightly faster than condition marking material I, independent of sex and age.

Figure 32 shows both longitudinal (6 upper lines) and lateral (6 lower lines) g-values for different conditions:

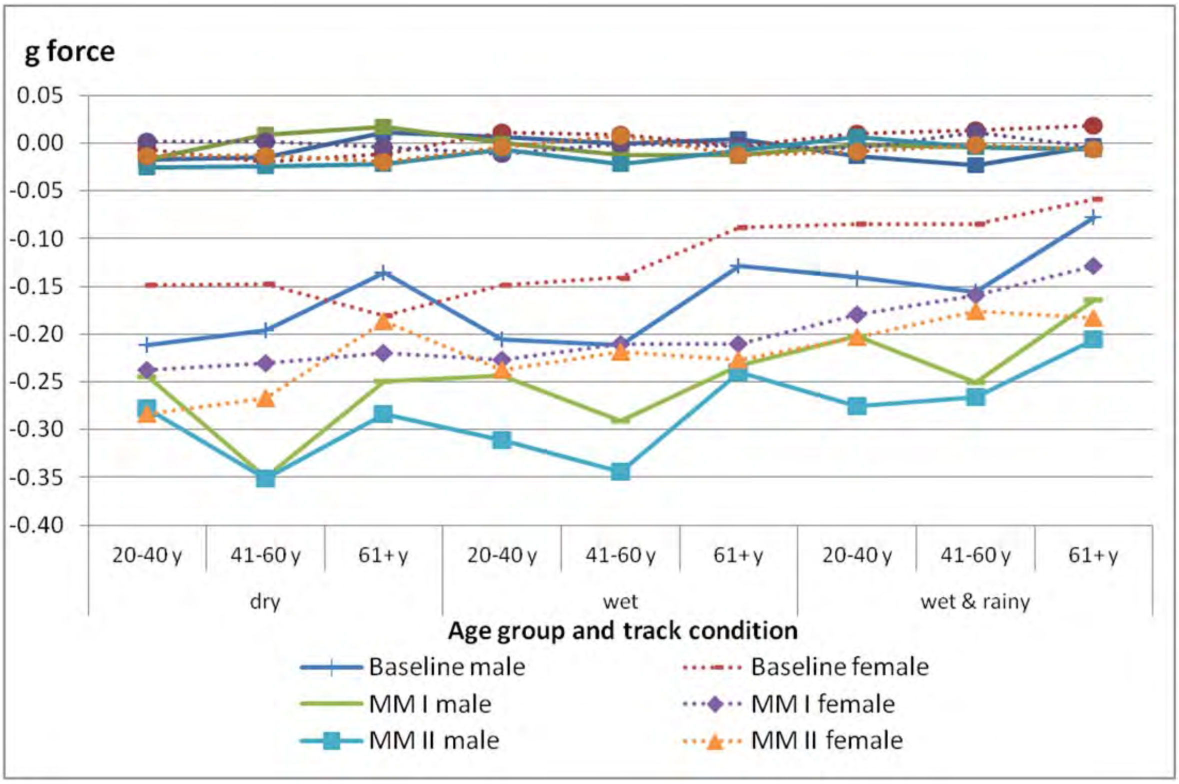


Figure 32. Sector 4 mean lateral and mean longitudinal accelerations (g) for different marking and track conditions by age group and sex

As this section was a left-hand bend, lateral acceleration g-values are negative and decrease[9] within the first and last track condition. Driving under the baseline marking condition differs very much for male and female test subjects. Lateral g-values under the marking condition II were highest, but not significantly different to other marking conditions when speed was included as covariate in the MANOVA analysis.

Longitudinal accelerations remain stable.

[9] As absolute values are shown, a decrease is expressed by values which are nearer to zero. As section 4 was a left hand-drive bend, the acceleration values are negative, which is in contrast to a right-hand bend, where lateral acceleration values are positive.

4.3.3.4. Sector analysis: sector 5:

Sector 5 (length 73m) was a right-hand bend, directly after the left-hand bend of sector 4.

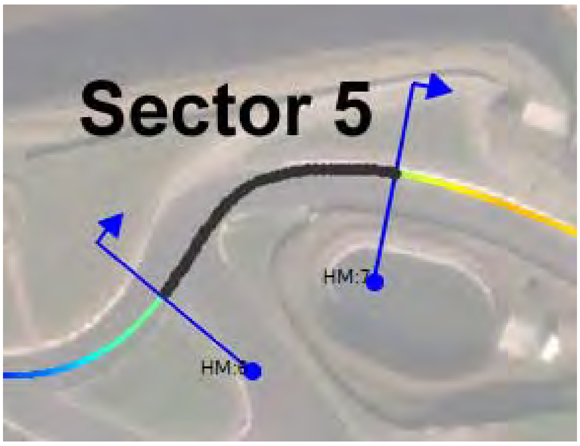


Figure 33. Sector 5, 73m

The next illustration shows the distribution of mean sector times within sector 5:

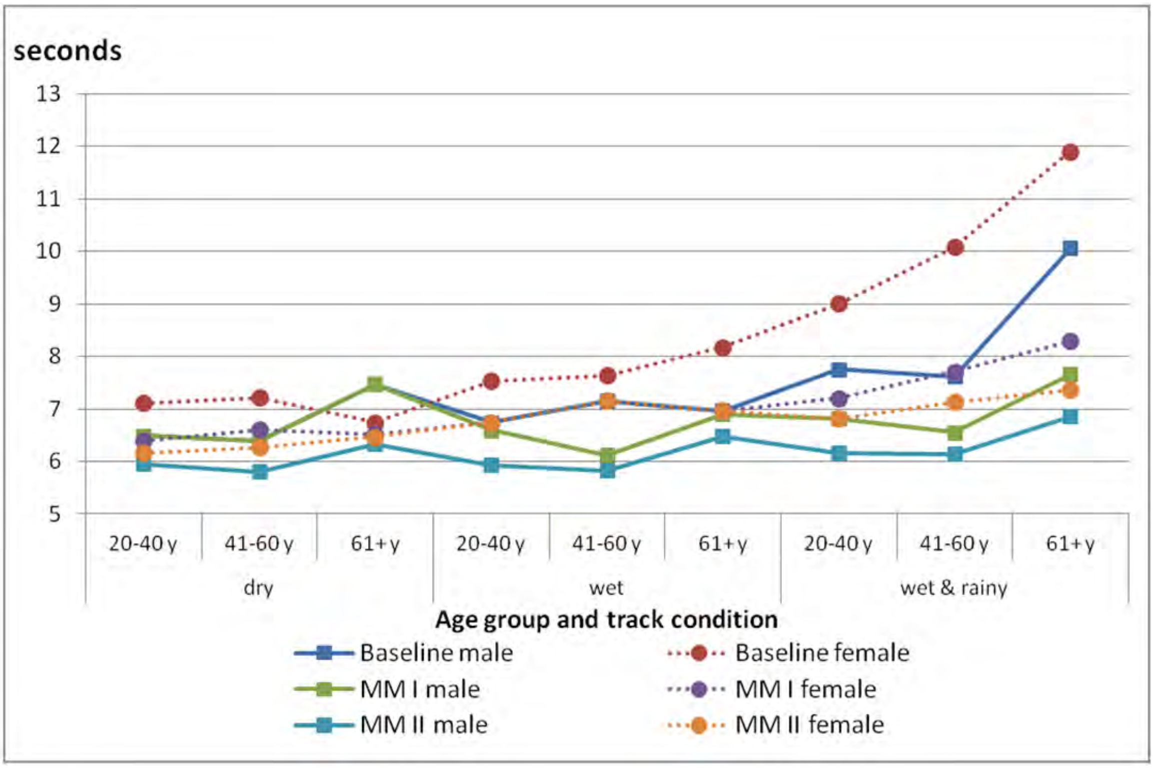


Figure 34. Sector 5 mean times for different track and marking conditions for different age groups by sex

The most apparent difference between the different conditions is that older female and male subjects took more time completing this part of track slower under wet & rainy conditions compared to other. As already in other sectors observed, lap times within condition marking material II were fastest within both sex group, followed by lap times under condition marking material I, although time differences in dry and wet conditions in these marking conditions were smaller than under baseline condition.

Figure 35 presents mean longitudinal and lateral acceleration values for section 5:

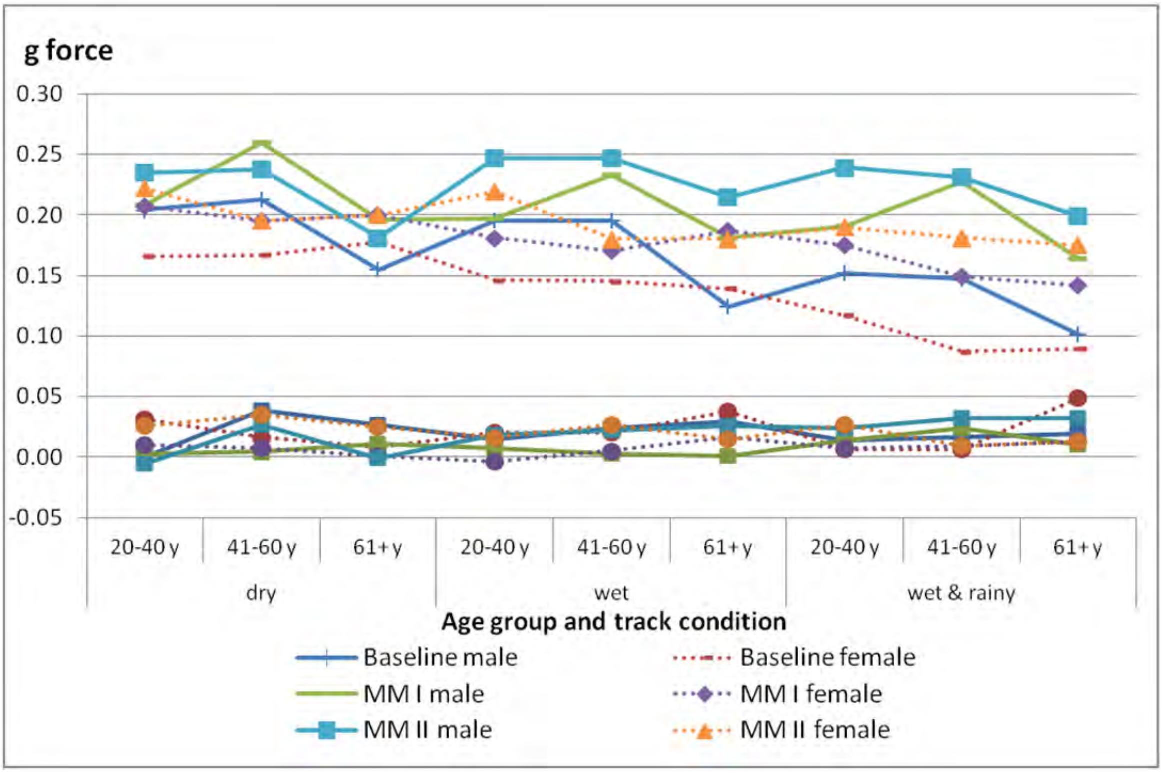


Figure 35. Sector 5 mean lateral and mean longitudinal accelerations (g) for different marking and track conditions by age group and sex

Mean lateral acceleration g-forces (upper 6 lines) are somewhat higher in dry and wet conditions than in condition “wet & rainy”. Mean lateral acceleration g-values stay on level close to 0.

4.3.3.5. Sector analysis: sector 7:

As sector 6 (length 107m) had to be omitted from the analysis, the next analysed sector was sector 7 (length 79m). This part of the track was a relatively sharp right-hand bend leading to sector 8. Within sector 7, an ascending slope has its end, just before the right turn commences.

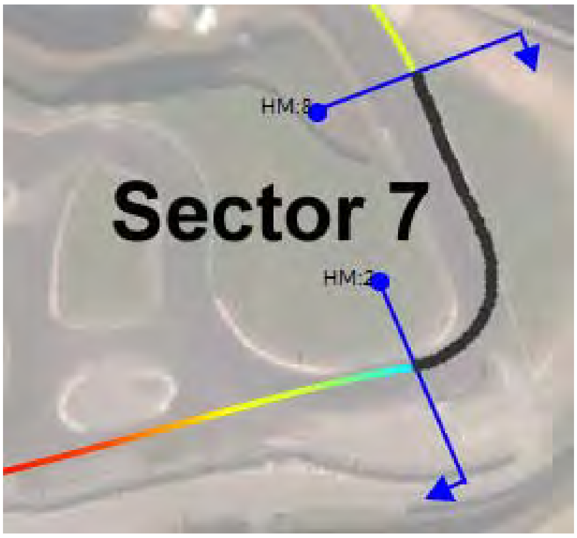


Figure 36. Sector 7, 79m

The distribution of mean sector times for sector 7 is shown in the figure below:

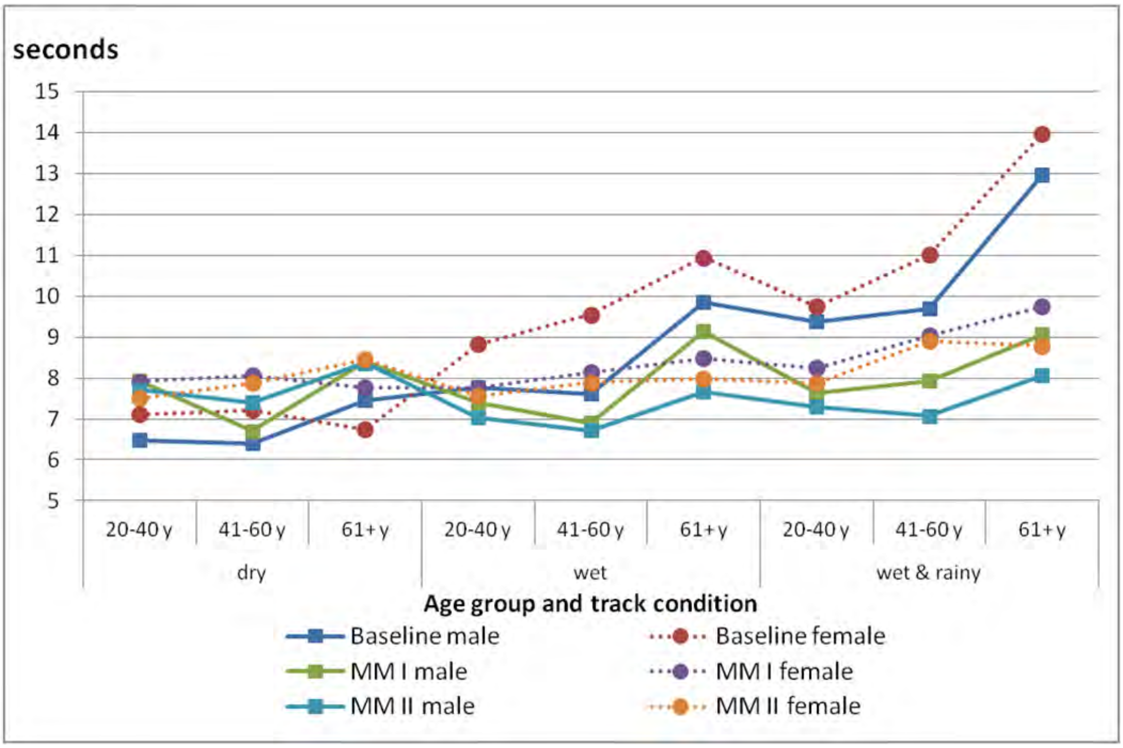


Figure 37. Sector 7 mean times for different track and marking conditions for different age groups by sex

Under baseline condition "dry" subjects completed section 7 fastest in general. As stated earlier, this has to be interpreted with care as due to weather conditionsonly half of the sample completed this condition. In the "wet" and "wet & rainy" marking conditions, the same order compared to other sections of mean lap times, i.e. marking condition II fastest, followed by marking condition I and lastly baseline, could be observed.

Mean g-force lateral (upper 6 lines) and longitudinal (lower 6 lines) acceleration values are presented in Figure 38:

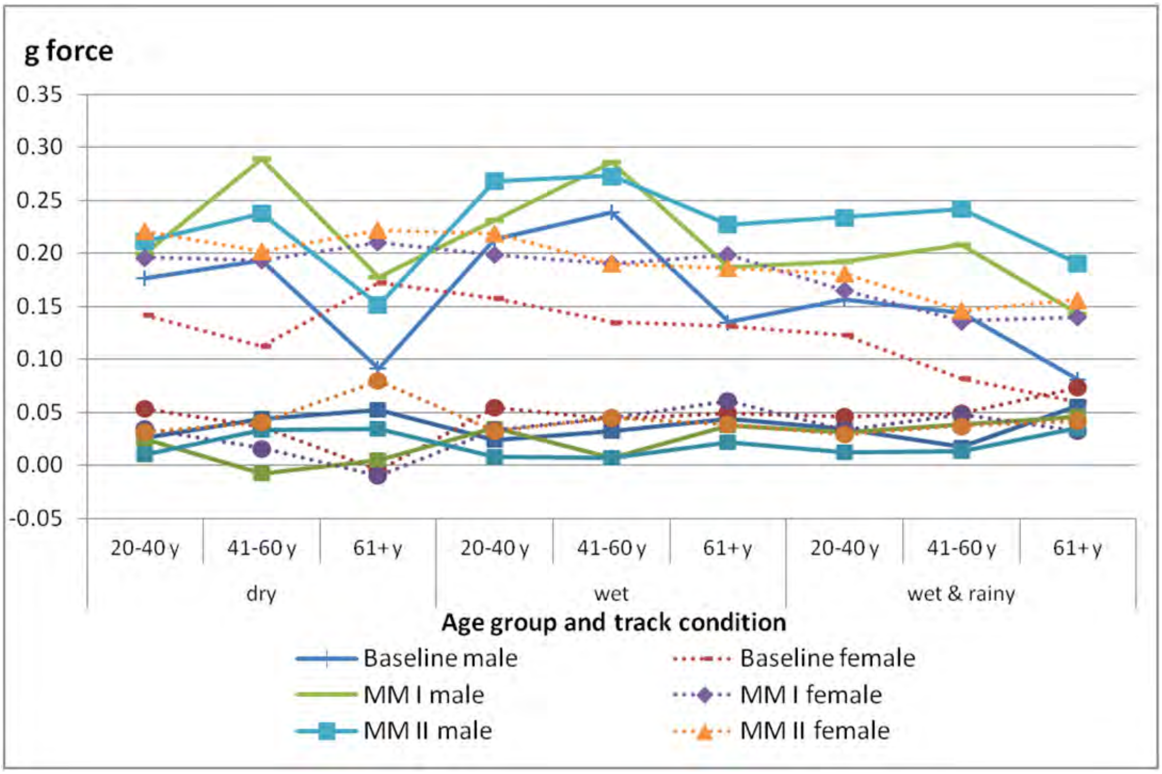


Figure 38. Sector 7 mean lateral and mean longitudinal accelerations (g) for different marking and track conditions by age group and sex

When controlled for speed, no significant differences occurred, neither within lateral nor longitudinal mean accelerations. However, the graphs indicate that values within the baseline conditions seem to be lowest, and generally highest within condition marking material II. Longitudinal acceleration forces remain low throughout all conditions.

4.3.3.6. Sector analysis: sector 8:

Sector 8 of the track was a straight, nearly 300m long. At the end of the straight, subjects finished the test run by leaving the track on the left side.

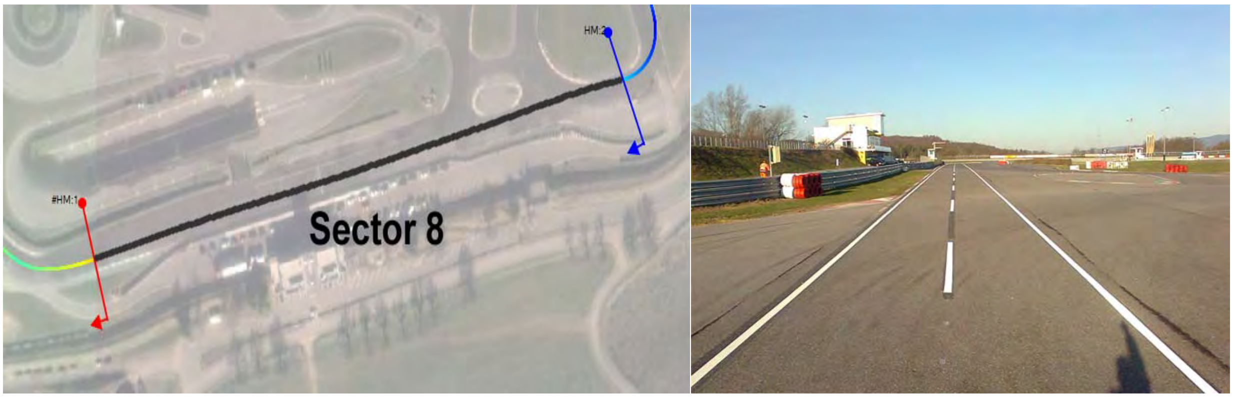


Figure 39. Sector 8, 296m

The figure presented next provides an overview regarding the distribution of mean sector times on the straight:

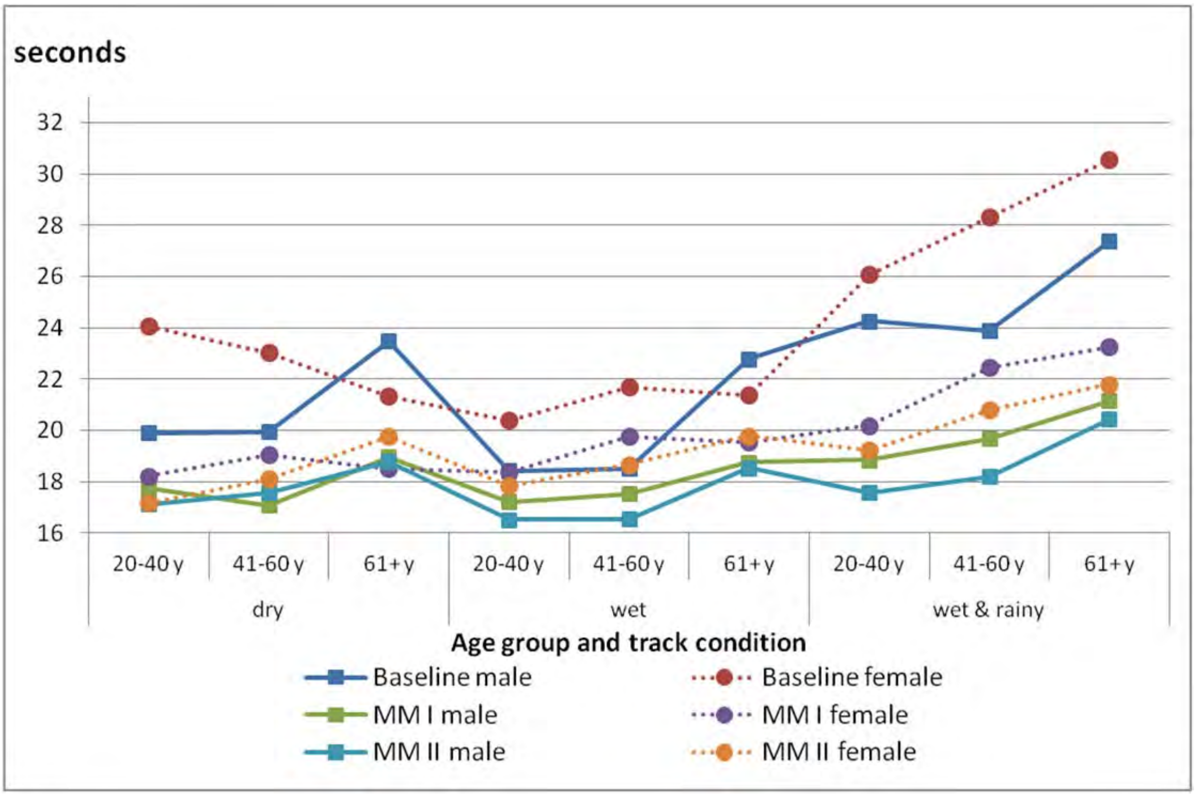


Figure 40. Sector 8 mean times for different track and marking conditions for different age groups by sex

In sector 8, mean sector times indicate that the baseline condition within all track conditions was passed slowest (both sexes), wheras sector times within condition marking material II and marking material I were generally faster.

Figure 41 shows mean lateral accerleartion g- values (lower 6 lines) and mean longitudinal accleration g-values (upper 6 lines) for all marking and track conditions:

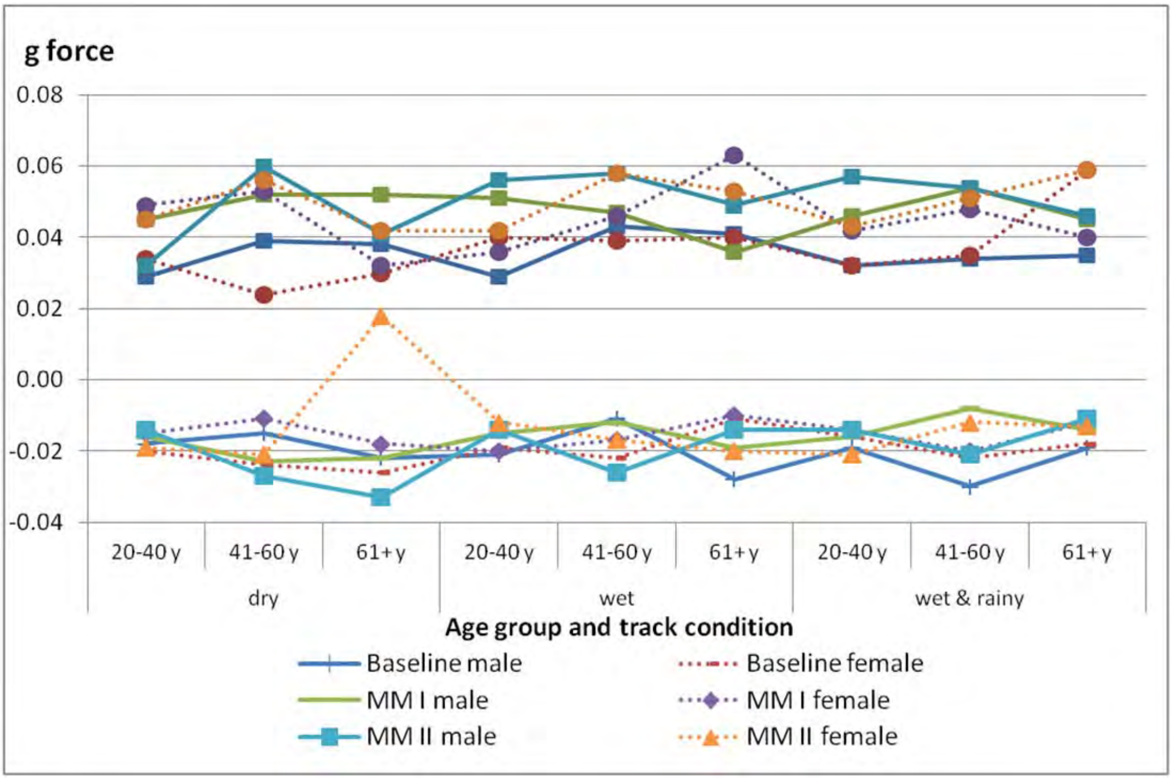


Figure 41. Sector 8 mean lateral and mean longitudinal accelerations (g) for different marking and track conditions by age group and sex

As this section was a straight, it could be expected that the variation among lateral accelerations are low, but also longitudinal accelerations remained relatively low. Again, no significant differences occurred when controlled for sector time.

5. DISCUSSION

The aim of the research study was to assess the impact of the visibility of different pavement markings (non-reflective, dry reflective material I, wet reflective marking material II) in different track conditions (dry, wet, wet & rainy) at night by measuring driver comfort levels and driving behaviour. Therefore, a field experiment was carried out on a road safety and motorsport track in Lower Austria.

To assess the impact of different marking materials, driving data of a selected sample of test subjects was measured by an in-vehicle data-logger, measuring position, speed and acceleration forces. Additionally, subjective stress and comfort levels were surveyed directly after the test runs with a questionnaire.

Marking materials differed by means of retro-reflective characteristics, specifically under wet and wet & rainy weather conditions. Wet condition was realised by moistening the track, “wet & rainy” condition was simulated by specifically prepared water sprinklers on the edge of the track, thus moistening not only the track but also the windshield of test subject vehicles.

First results from the track test indicate that driving comfort as well as clearness and perceptibility of track trajectory was assessed best when marking material II (wet-reflective) was applied on the track.

In unknown driving circumstances, especially when there is no road marking, an application of marking material surely provides more driving comfort, decreasing the driver’s uncertainty when following the roadway.

This holds especially true in adverse weather condition, e.g. at night and wet and/or rainy conditions. Surely, it can be expected that safer feeling regarding following the roadway has a positive impact on road safety in general. From that, it can be concluded that the more salient a marking material is perceived, the higher the subjective comfort and safety is experienced.

Regarding driving behaviour by means of speed choice (measured as lap times), test subjects drove slowest in the baseline condition, faster under condition with applied marking material I (dry reflective, type I), and slightly faster under condition with applied marking material II (wet reflective, type II). This result holds especially true for older persons like the subjects in the oldest age group in this study as an age interaction could be observed here. As the lap times can be interpreted as “time needed for solving the driving task” it can be concluded that it takes significantly longer for aged male persons to grasp the driving situation and/or the driving path under adverse conditions when there is no road marking. Within the female subjects, a statistical trend indicates a similar effect. The higher speed should not be generally associated with a reduction in traffic safety. The speed increase was small and obviously well balanced with the increased visibility of the road marking material. Both stress and comfort level of the test subjects was lower with the higher speeds. The differences in speed remained on a generally low level between condition marking material I and marking material II, equalling to 2-5 km/h difference on the whole track on average. Compared to the baseline marking, driving speed was higher in both marking conditions.

Analysing the speed behaviour of older drivers, we can conclude that the more adverse the driving and/or weather conditions are the driving task gets disproportionally complex for older driver. In order to neutralize this disadvantage i.e. situation complexity for older drivers, establishing road markings at non-equipped locations could make traffic situations more fair and solvable for this group of traffic participants.

When analysing driving behaviour in terms of mean lateral and longitudinal accelerations, no statistically significant differences occurred after controlling for lap time or sector time. If time/speed it isolated from lateral accelerations, the remaining parameter is curve radius. As no significant differences occurred after controlling for time/speed, subjects did not follow the track trajectory differently in various conditions by means of different driven radius, e.g. cutting corners.

From the track test, it finally can be concluded that wet-reflective marking material (type II) does increase driving comfort and allows slightly increased driving speed compared to standard reflective marking material. For practical implementations, the research findings in real driving environments and under naturalistic driving conditions (WP4, on-site tests) should be considered.

5.1. LIMITATIONS

Some limitations of the study are worth to be mentioned:

Firstly, due to unfavourable weather conditions, only half of the planned sample carried out the test runs in the “dry” condition baseline conditions. This fact narrowed statistical power for mentioned procedures and study validity. Hence, some procedures have been carried out without the missing sample.

Secondly, it was hard to recruit the planned test subjects within the older test group of 61+ years, especially female test persons. This has to be taken into account for subsequent studies where older female drivers have to be recruited.

For a deeper view regarding stress levels during driving, it would have improved the validity of the study to include some physiological stress parameters, such as e.g. galvanic skin responses, heartbeat and/or heart rate variability.

Furthermore, in order to investigate lane keeping behaviour more thoroughly, eye glance behaviour would have increased study validity.

Lastly, it was discussed within the project that lane keeping could not only been collected by lateral accelerations, but with a lateral offset to a given reference line. Differences between realised driving trajectories and a reference line could be used to express lane keeping behaviour more precisely.

However, the latter approaches were discussed beforehand but dismissed due to increased analysis and budgetary efforts.

5.2. FUTURE RESEARCH

For future research activities in this field, a combination of on-road tests with naturalistic driving methodology is suggested in order to see how drivers react to different applications in real driving circumstances. On road tests are carried out in WP 4 within this project. A study by means of a naturalistic driving data collection could enrich on-road results including the driver’s perspective, especially by adding test subject interviews regarding enhanced information on participant’s views, attitudes and knowledge. The latter method would likely add meaningful qualitative data providing better insight into subjects’ thoughts and opinions about how different marking materials are perceived.

5.3. IMPLICATIONS

From a traffic safety point of view, it could be clearly shown that both marking materials are experienced as more comfortable and guiding by drivers compared to the baseline marking. Applying pavement marking material has a positive effect on the subjective feeling of safety of drivers, especially in adverse weather / driving conditions which were simulated in this experiment. Under night-time und rainy driving conditions, the marking material II (wet retro-reflective material) ensured clear trajectories of the driving path, thus providing anticipatory stimuli of road environment and taking substantial workload off the driver.

Driving data analysis suggest that enhanced visibility and driving comfort is correlated with substantial higher speed choice compared to the baseline condition, and slightly higher speed choice compared with marking material I.

From this study however, the main difference in terms of traffic safety lies in the question whether to apply or not to apply marking material. If the decision for road authorities is to apply marking material on certain roads, the better choice would be to use wet retro-reflective marking material instead of non-reflective material as the mentioned benefits (subjective driver comfort and better anticipation of road trajectory) outweigh the disadvantages (slightly higher speed choice) for drivers.

6. REFERENCES

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