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Differences in Driver Behaviour between Novice and Experienced Drivers: A Driving Simulator Study

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Abstract: This study is an extension of a previous work where differences between race-car drivers and normal drivers has been investigated in a high-speed driving task. The study focused on gaining knowledge about driver differences that can be helpful in designing an adaptive ADAS by introducing the driver into the control loop. The present study takes this research forward and is oriented around finding the differences between novice and normal (experienced) drivers while performing a double lane change maneuver and a high-speed cornering task. The study aimed at finding parameters capable of differentiating the two groups with special emphasis on steering behaviour. Part A of the test procedure required the participants to complete a double lane change at various speeds (from 70km/h to 105km/h). Data analysis showed that late initial steering input given by the novices compared to the experienced drivers was the main reason for their poor performance. Steering metrics like timing of steering input, average steering rate and average steering jerk showed statistically significant differences between the two groups. Part B of the experiment required the participants to drive around a flat oval track to achieve the fastest lap times. Analysis showed that higher steering activity and differences in path strategy were the main reasons for lower lap-times shown by the experienced drivers compared to the novice drivers. Steering metrics like average steering rate, steering jerk showed higher values for the experienced group.

1 INTRODUCTION

This research is an extension of previous research done to classify drivers into group of experienced and experts. In a previous study (also submitted at this conference) differences between expert and normal (experienced) drivers in a high- speed driving task on a racing circuit was analyzed. The present study focuses on analyzing differences between novice and experienced drivers in standardized driving situations such as lane change and high speed cornering which are relevant to normal driving. Thus in this chapter we try to study the behaviour of the young inexperienced drivers (novices) in normal driving situations. Details of the experiment have been explained below.This study focuses on analyzing differences between novice and experienced drivers in standardized driving situations such as lane change and high speed cornering which are relevant to normal driving. Details of the experiment are explained below. An experienced driver is one who has a certain level of expertise gained through driving experience, while a novice driver is one who is familiar with the task of driving but has limited driving experience.

2 METHODS

2.1 X-Car Simulator

The driving simulator used for the experiment is based on a dSPACE real-time (RT) computer. It executes a commercial RT vehicle-dynamics model (VDM), developed on an open MATLAB/Simulink block, from the dSPACE Automotive Simulation Model (ASM) package. The simulator consists of a dSPACE computer with two DS1005 boards in master–slave topology. The dSPACE interfaces with the environment via A/D (DS2002) and D/A (DS2102) boards. One desktop PC is used as a user station providing the interface to the simulator. It is also used to develop the VDM and control algorithms. The dSPACE simulator transmits the animation data over an Ethernet connection to three desktop PCs handling the graphics. Finally, three LCD monitors compose a horizontal viewing angle of 135 deg were used to display the visuals. A high-response ac brushless servomotor (Ultract II, type 708303) is used for providing steering force feedback ((Katzourakis et al., 2011)). The brake and throttle pedal originated from a real vehicle providing realistic passive feedback. All driving simulator data was recorded and stored at 100Hz.

2.2 Experiment Instructions, Part A: Double Lane Change

The experiment is divided into two parts, Part A and Part B. In Part A of the experiment, participants were instructed to drive a double lane change maneuver adopted from ISO 3888-1:1999-Part 1: Double lane change, which is shown in Figure 1 & 2 below. The lane change track has three lanes depicted by the cones, lane 1 is 15 m, lane 2 is 25 m and lane 3 is 15 m in length. Participants were instructed to keep the vehicle within the lane boundaries (depicted by the cones) during the complete maneuver. As compared to the ISO procedure the lane width was increased to 3 m, in order to make experiment completion feasible also for drivers without specific training. Before starting the testing trials a practice session of 5 minutes was given such that the participants were accustomed to the simulator environment and the test condition. The speed control for the experiment was automatic and thus the participant could only control the vehicle using the steering wheel. The experiment was started from a speed of 70km/h and 5 trials were given at 8 different speeds. After each trial the vehicle was automatically reset to the starting position and the next trial was started. After the 5 trials of each speed a 1-minute break was given during which the participant remained seated in the simulator. Speed increments were done in steps of 5km/h to 10km/h up to a speed of 105 km/h. In the end the experiment was repeated at 70 km/h to retest the first speed condition. Table 1 gives an overview of the test conditions. It was hypothesized that performance would degrade with speed and that this degradation would be stronger and would be occurring at lower speeds in novice drivers. Effects were expected in position accuracy and cone hits as well as poor stabilization at the end of the maneuver in Lane 3. Such a poor stabilization is associated with loss of control and road departure accidents, and can be remedied by an Electronic Stability Control system.

Table 1: Overview of Test Conditions.

Session	1	2	3	4	5	6	7	8
Speed	70	80	85	90	95	100	105	70

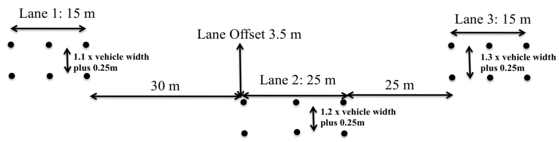

Figure 10: ISO Double Lane Change Maneuver

Figure 1: ISO Double Lane Change Maneuver.

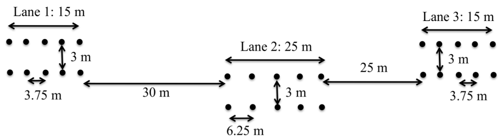

Figure 2: Adapted Double Lane Change Maneuver (Part A).

2.3 Experimental Instructions, Part B: High Speed Cornering

Part B of the experiment consisted of two sessions. In both the sessions participants were required to drive on a flat road with large corners (oval track). The track consisted of two straight road segments of 75 meters each and two large corners of 75-meter radius (Figure 3) and had a lane width of 6 meters. Session 1 required them to drive on a normal asphalt surface (μ=1) whereas Session 2 took place on a low friction surface (μ=0.4). It was hypothesized that experienced drivers would be more capable to sense the traction limits, select a curve speed approximating the maximum attainable speed, and accurately control the vehicle lateral position. Furthermore it was hypothesized that experienced drivers would be more capable to detect and assess the friction change and to adapt speed and steering control accordingly. The speed control in this part of the experiment was manual and the participants were asked to drive at maximum speed possible without losing control. Participants were only told that the friction of the road surface was reduced, but no information was given about the percentage reduction in the friction. For each session participants were given 12 minutes allowing multiple laps. Between the 2 sessions there was a 2-minute break during which they completed the NASA TLX questionnaire for measuring workload. The participant remained seated in the simulator during the break.

2.4 Participants

The participants were divided into two groups based on their age. Group one represents the novice drivers

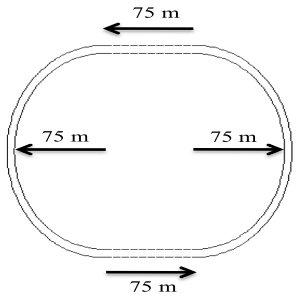

Figure 3: Oval Test Track (Part B).

(all male), aged from 18-21 years (Mean = 20.05, SD = 0.85) and consisted of 19 participants. Group two represents experienced drivers (all male), aged 25-35 years (Mean = 28.17, SD = 2.48) and consisted of 18 participants. All the participants were recruited from the Delft University of Technology campus. Before starting the experiment, the participants were asked to fill out a questionnaire regarding their driving experience and driving knowledge based on questions from the Driver behaviour Questionnaire (Reason et al., 1990) and Self-Assessment Questionnaire (M.Mckenna and J. Kear, 1990). All participants provided written informed consent and the research was approved by the Human Research Ethics Committee of the Delft University of Technology.

2.5 Dependant Measures

Each speed condition in experiment A had 5 sessions per driver and the mean of the dependant measures of the 5 sessions was taken. No sessions were excluded from the analysis. For experiment B first different laps were selected based on the vehicle position. Data for the two mentioned curves was then separated for each lap. The entry and exit of the curve was based on vehicle X-Y position (see Figure 4).

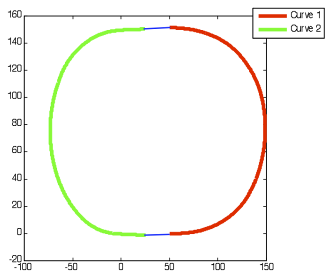

Figure 4: X-Y Position of the selected curves for analysis.

The cases in which all the four wheels left the track were considered as "loss of control" or "road departure". Laps with road departures were excluded from further analysis. Before analysis the steering data is filtered using a low pass Butterworth filter (2nd order, 3Hz). All the other data was filtered using a Butterworth 2nd order 10Hz low pass filter. The performance of the drivers was analyzed using different metrics discussed in Table 2 below. Wilcoxon-Mann-Whitney test was used to deal with the non-normal distributions.

Table 2: Dependant measures used for analysis.

METRIC	DESCRIPTION	UNITS
Root Mean Square Deviation Of The Lateral Acceleration **(Part A)**	First the mean lateral acceleration is calculated for the maneuver. The start and stop point of the maneuver is predefined based on the vehicle position (X-Direction). Thus for all the drivers the maneuver length is same based on the distance travelled. RMSD from the mean of the lateral acceleration is then calculated through the 5 sessions of every	m/s2
Root Mean Square Deviation from the Mean Path **(Part A)**	First the mean path taken by the driver while completing the maneuver is calculated at every speed. The start and stop point of the maneuver is predefined as explained above. Root mean square deviation from the mean path is then calculated for the 5 sessions of every speed.	m
Root Mean Square Deviation from the Mid-Path **(Part A)**	Root mean square deviation from the mid position of the lanes (defined by the cones) calculated for the 5 sessions of every speed.	m
Average Number Of Cones Hit **(Part A)**	Vehicle position data and the cone position data is used to calculate the average number of cones hit by each driver and every speed	
Maximum Steer Angle **(Part A)**	Three main steering inputs are given by the driver to complete the double lane change maneuver. These three maximum angles are thus recorded (See Figure 14).	deg
Position Of Steering Input **(Part A)**	Vehicle X-position when the three maximum angles mentioned above are reached is calculated.	m
Average Steer Rate **(Part A and Part B)**	Part A: Average steering rate used to achieve the 3 maximum steering angles (as mentioned above) is calculated. Part B: Average steering wheel rate from the initial steering input (Steering angle>3) to the curve exit point	deg/s
Average Steer Jerk **(Part A and Part B)**	Part A: Average rate of change of the steering wheel acceleration (jerk) used to achieve the 3 maximum steering angles (as mentioned above) is calculated. Part B: Average rate of change of the steering wheel acceleration (jerk) from the initial steering input (Steering angle>3) to the curve exit point	deg/s^3
Steering Reversal Rate **(Part B)**	Number or times the steering wheel input direction is changed with steering angle change < 3 degrees	reversal/ sec
Mean Lateral Acceleration **(Part B)**	Mean of the lateral acceleration from the entry to the exit point of the curve	g
Mean distance from inside of the curve **(Part B)**	Mean distance of the vehicle from the inside of the curve from the entry to the exit point of the curve	m
Deviation from inside of the curve **(Part B)**	Deviation of the vehicle position from the inside of the lane from the entry to the exit point of the curve. A low value for this parameter means that the driver tries to maintain a constant distance from the inside of the curve.	m
Deviation from the mean path **(Part B)**	Deviation from the mean path chosen by the drivers in various laps.	m

2.6 Questionnaire

Before the simulator experiment the participants were asked to fill in a questionnaire to judge their driving experience and driving knowledge. A part of the questionnaire required the participants to rate their ability to perform certain driving tasks out of a score of 10. They were also asked what they thought would be the rating of an average driver. The scores for the self-assessment and the average driver were subtracted and the overall sum for the entire 9-driving tasks was calculated (Table 3). A negative overall score meant that the driver assessed himself as better than an average driver, a score of 0 means that the driver put himself equal to an average driver and a positive score meant that the driver assesses himself as inferior to an average driver. All the experienced drivers rated themselves above average except one who rated himself equal to an average driver. 7 novice drivers rated themselves as above average, 1 driver rated himself equal to an average driver, and the rest put themselves below average. The participants were also asked vehicle dynamics related questions to judge their knowledge.

Table 3: Self Assessment score.

	Experienced	Novices
OVERALL SELF ASSESSMENT FOR THE 9-DRIVING TASKS	-10	1
	-1	-4
	-1	20
	-15	-4
	-18	-16
	-13	-4
	-2	29
	-3	0
	-1	-1
	-8	8
	-17	3
	-14	6
	-8	-3
	0	6
	-8	2
	-8	12
	-5	6
	-2	-4
		1
Mean (SD)	-7.11 (6.39)	3.05 (9.79)

3 RESULTS A: DOUBLE LANE CHANGE

All the participants managed to perform the lane change at all speeds (from 70 km/h to 105 km/h). Increase in speed resulted in increase in the number of cones hit however the data was used for analysis as mentioned above irrespective of the number of cones hit. As explained in Table 2, the driver provides three main steering inputs while completing the double lane change maneuver as shown in Figure 5 below. Maneuver A-C: Steering input to the left to go from Lane 1 to Lane 2 Maneuver C-D: Steering input to the right to straighten the vehicle and to go from Lane 2 to Lane 3 Maneuver D-F: Steering input to the left for straightening the vehicle in Lane 3

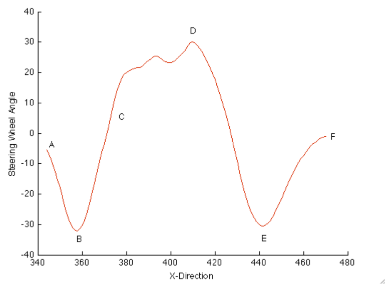

Figure 5: Double lane change steering trace.

The maximum steering angle metrics were determined at points B, D and E.

3.1 Path Followed

In the first step we analyze the path driven by the two groups of drivers. Figure 6 below shows the paths at increasing speeds from 70 to 105 km/h. As can be seen the experienced group shows better positioning of the vehicle in the middle of the lanes compared to the novices. Novices tend to be offset from the center position while entering the first lane.

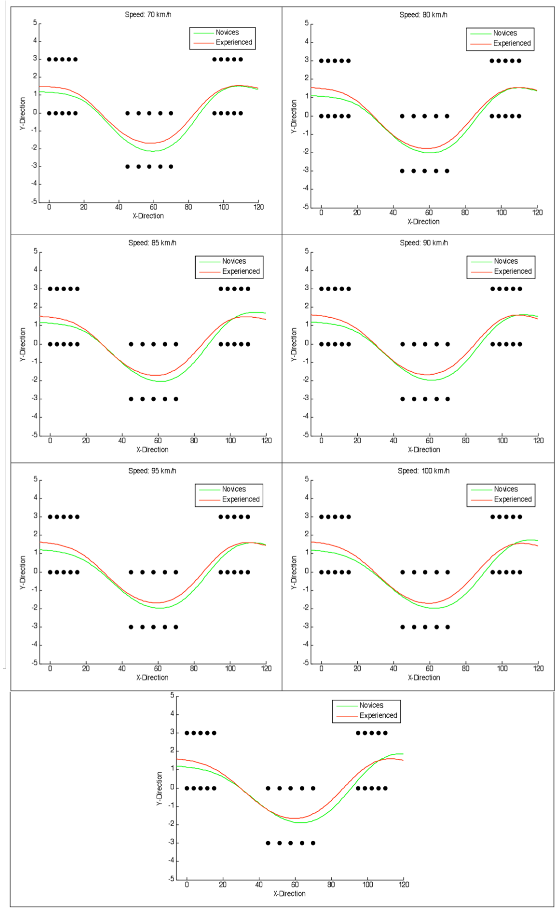

Figure 6: Path followed during the Double Lane Change test (Black dots represent the cone position).

This shows that the novice drivers are unable to judge the correct timing of the inputs and hence provide late inputs, which results in poor vehicle positioning as compared to the experienced drivers. This can be because the experienced drivers have a better and well-developed internal vehicle model and better perception skills, which enable them to judge the correct inputs and the timing. Moreover they are also better at anticipating the changes required in the control action on increasing the vehicle speed. In Figure 16 below the steering wheel angle as a function of the vehicle position is shown. As can be seen the input of the novices always lags behind the input of the experienced drivers. Figure 7 also shows that novices try to correct the inputs by either giving higher steering angle or faster steering inputs.

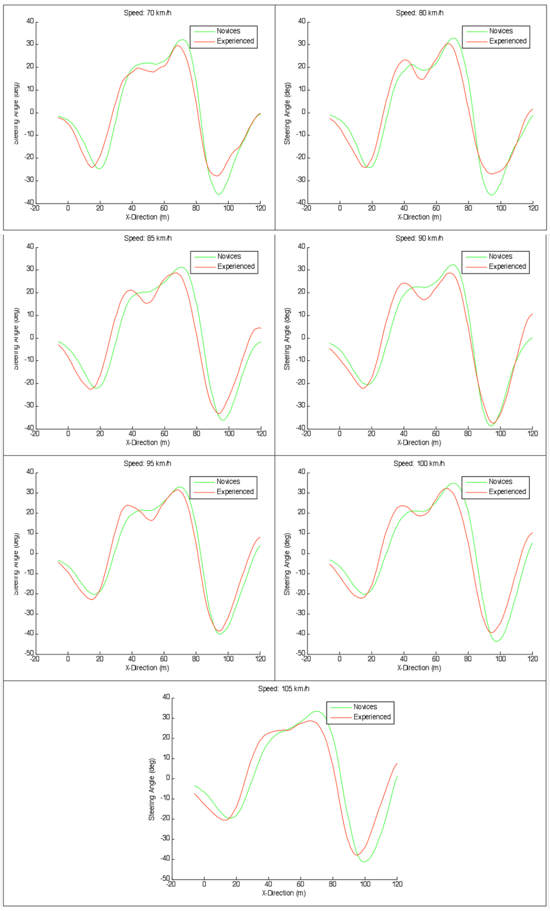

Figure 7: Mean Steering Input for Experienced and Novice drivers).

This can also be seen in the data in Table 4 below which shows the position at which maximum steering angles were achieved during the maneuver. The data shows (as also seen from Figure 7) that experienced drivers achieve the maximum steering angle earlier than novices. Table 11 shows that novices reach the maximum steering angle for the first input after Lane 1 exit whereas experienced drivers achieve the maximum angle before or at the exit of Lane 1.

3.2 Strategy and Performance

Figure 8 below shows the comparison between the experienced and the novice drivers based on the deviation of the root mean square acceleration achieved by the drivers while completing the task. As can be seen the experienced group shows lower deviation at all speeds compared to the novices. This indicates that the experienced drivers have a particular strategy, which they follow repeatedly, thereby showing less deviation. The repeatability in behaviour can also be seen in terms of the root mean square deviation from the mean path followed by the drivers (Figure 8). The experienced drivers show much less deviation from the mean path compared to the novices. This can be because of better vehicle control skills, which enables them to execute their strategy repeatedly. There is an increase in the deviation with increase in speed for both the groups. (No clear effect of speed was seen on performance)

Table 4: Vehicle X-position when maximum steering input is given.

SPEED (km/h)	70	80	85	90	95	100	105
LANE 1							
EXPERIENCED	15.27 (2.70)	15.40 (3.08)	14.4 (3.52)	14.16 (3.84)	14.27 (3.32)	13.45 (3.44)	11.25 (4.68)
NOVICES	20.30 (3.22)	19.82 (2.93)	19.14 (3.40)	19.10 (2.88)	17.55 (3.54)	17.83 (3.39)	17.85 (2.72)
p-value	**< 0.001**	**< 0.001**	**0.001**	**<0.001**	**0.008**	**<0.001**	**<0.001**
LANE 2							
EXPERIENCED	66.45 (5.44)	63.23 (3.94)	62.55 (3.18)	61.60 (4.60)	59.20 (6.13)	62.04 (6.94)	58.03 (7.09)
NOVICES	65.38 (6.88)	66.84 (7.34)	66.92 (5.11)	67.01 (5.40)	64.81 (7.30)	69.87 (4.68)	69.11 (5.89)
p-value	0.573	0.079	**0.007**	**0.004**	**0.043**	**0.001**	**<0.001**
LANE 3							
EXPERIENCED	94.69 (4.11)	97.38 (3.51)	95.46 (3.37)	97.09 (2.79)	96.40 (3.19)	96.56 (2.80)	98.57 (4.35)
NOVICES	95.67 (3.40)	97.42 (4.16)	97.95 (3.86)	96.88 (3.78)	98.33 (3.95)	99.87 (2.90)	101.67 (4.50)
p-value	0.455	0.820	0.070	0.337	0.110	**0.002**	**0.043**

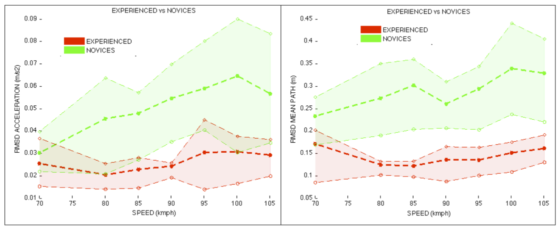

Figure 8: Repeatability in performance with respect to root mean square deviation in lateral acceleration and mean path (Bold dotted lines represent the mean whereas the upper and lower boundary represents the 25th and 75th percentile).

Deviation from the mid-position of the lane reveals the performance of the two groups. Figure 9 shows the experienced group has much smaller deviations from the mid path, which directly relates to better task performance. The same can also be seen in terms of the number of cones hit by the drivers (Figure 9).

Figure 10 shows the relation between the overall assessment score from Table 3 and the number of cones hit per session at different speed.

Table 5 shows the Pearson correlation coefficients for the two groups at the different speed conditions. It can be seen that the assessment scores have a good correlation with performance for the experi-

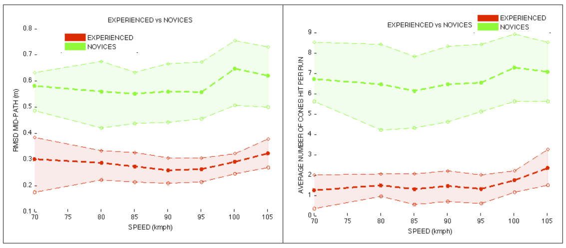

Figure 9: Performance in terms of root mean square deviation from the mid path and the number of cones hit (Bold dotted lines represent the mean whereas the upper and lower boundary represents the 25th and 75th percentile).

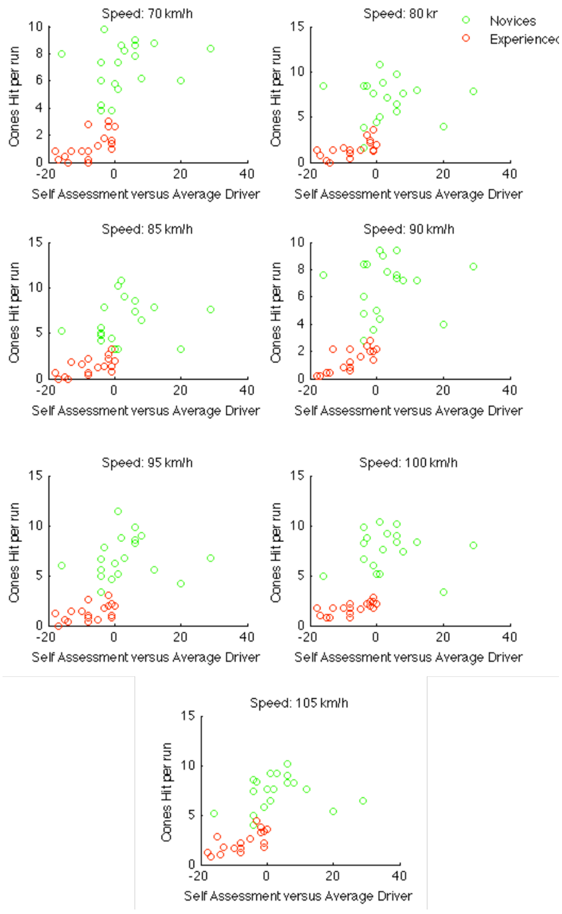

Figure 10: Performance in terms of root mean square deviation from the mid path and the number of cones hit (Bold dotted lines represent the mean whereas the upper and lower boundary represents the 25th and 75th percentile).

enced group. Novices on the other hand show very poor correlation between the two parameters. Table 12 clearly shows that the novices are poor at assessing themselves and often tend to overestimate their abilities. Experienced drivers on the other hand have a good self-assessment of their own abilities.

Table 5: Correlation coefficient of Self-Assessment versus number of cones hit.

	Speed (km/h)	70	80	85	90	95	100	105
Experienced	Correlation Coefficient	0.65	0.63	0.64	0.76	0.52	0.67	0.68
	p-value	**0.004**	**0.005**	**0.004**	**<0.001**	**0.028**	**0.002**	**0.002**
Novices	Correlation Coefficient	0.22	0.05	0.17	0.09	0.09	0.03	0.11
	p-value	0.357	0.830	0.486	0.705	0.718	0.914	0.647

3.3 Control Strategy

As can be seen from Figure 11 below, the novices maintain higher steering rate at all speed conditions compared to the experienced group. The experienced group shows continuous increase in the rate with increase in speed. The novice drivers show no clear trend. The value of average steering jerk also shows the same trend with novices having higher values as compared to the experienced group (Figure 11). The

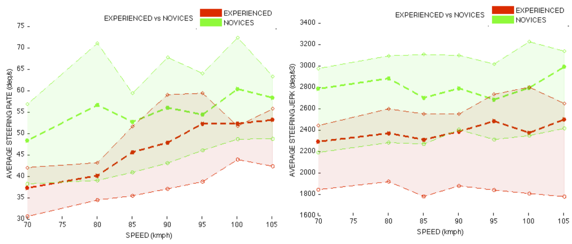

Figure 11: Comparison of Average steering rate and Average Steering Jerk between Novices and Experienced drivers (Bold dotted lines represent the mean whereas the upper and lower boundary represents the 25th and 75th percentile).

maximum steering angles at three positions achieved in the maneuvers at different speed conditions are shown in Figure 12 below. It can be seen that the novices have lower steering angle for the first maneuver i.e. going from Lane 1 to Lane 2 at higher speeds (speed >85kmph), but for the other two maneuvers the novices maintain a higher steering angle. As shown in Figure 13, the input given by the novices is later compared to the experienced drivers. The combined effect of the lower and late inputs results in novices lagging behind in terms of input versus vehicle positioning. Thus in the second and third maneuver they try to compensate for this lag and hence have higher steering activity, which is shown in Figure 11 & 12.

In the final steering maneuver it can be seen that novices try to compensate for the above-mentioned lag, showing higher steering activity than the experienced drivers. Figure 13 represents the steering maneuver for two representative drivers at 85km/h. As can be seen, steering input of the novice driver is lagging behind the experienced driver. During the final steering maneuver between positions C-E the novice driver tries to compensate for this lag and thus shows

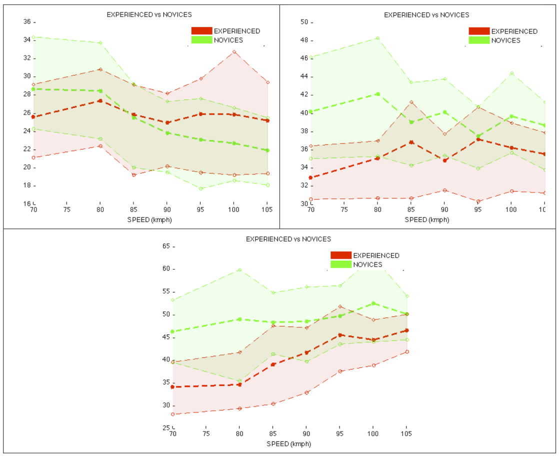

Figure 12: Maximum Steering Wheel Angle for the three steering inputs (See Figure 5). Top left represents the mean of the maximum steering angle in the first maneuver, top right represents the mean in the second maneuver and bottom represents the mean in the third maneuver (Bold dotted lines represent the mean whereas the upper and lower boundary represents the 25th and 75th percentile).

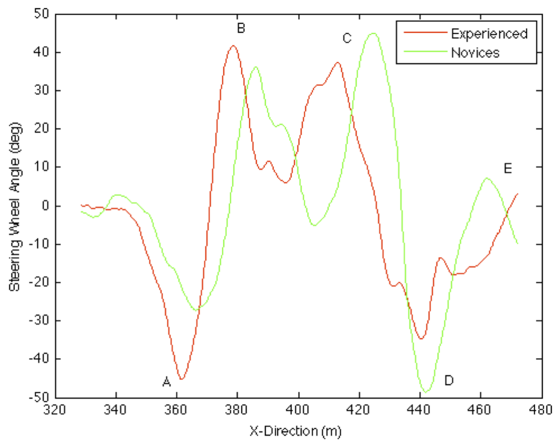

Figure 13: Steering input comparison between Experienced and Novice driver).

higher steering activity in terms of steering angle (position C and E), steering rate and steering jerk.

The results of the steering metrics (rate and jerk) are shown in Table 6. It can be seen that novices have higher steering activity compared to the experienced drivers. There is significant difference between the two groups as can be seen from the p-values.

Figure 14 shows the mean lateral acceleration for experienced and novice drivers. As can be seen, novices maintain a higher mean lateral acceleration as compared to the experienced drivers at all speeds, which could possibly be attributed to higher steering activity shown by the novices especially in the later stages of the maneuver.

Table 6: Steering Rate and Steering jerk (Steering Input C-E).

	Speed	70	80	85	90	95	100	105
Steering Rate (rad/s)	**Experienced**	46.28 (12.01)	46.38 (11.93)	55.98 (18.91)	60.23 (17.46)	65.73 (22.03)	66.99 (13.70)	67.56 (13.39)
	Novices	60.78 (23.29)	73.04 (33.52)	69.51 (20.96)	76.01 (27.15)	73.85 (23.50)	86.39 (29.87)	84.03 (24.88)
	p-value	**0.035**	**0.003**	**0.040**	0.062	0.218	**0.032**	**0.008**
Steering Jerk (rad/s^3)	**Experienced**	2498 (718)	2547 (761)	2440 (820)	2547 (865)	2740 (1029)	2591 (858)	2809 (928)
	Novices	3278 (1435)	3382 (1351)	3124 (700)	3337 (900)	3198 (871)	3364 (810)	3776 (1658)
	p-value	**0.032**	**0.022**	**0.004**	**0.004**	**0.050**	**0.003**	**0.020**

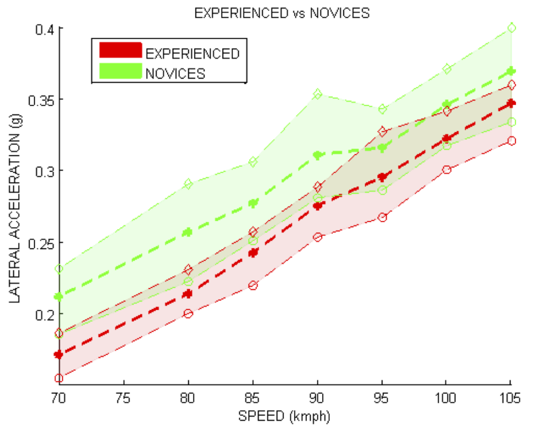

Figure 14: Mean lateral Acceleration at all speeds (Bold dotted lines represent the mean whereas the upper and lower boundary represents the 25th and 75th percentile).

3.4 Test Re-test Repeatability

After finishing all the speed selections (70-105 km/h), the participants performed the double lane change test again at 70 km/h. This was done to study the learning among the drivers. It can be seen from Table 7 that the experienced and novices show no significant improvement in terms of deviation from the mean and mid path. Thus there is no significant improvement in task performance. Experienced drivers show a significant reduction in the values of the steering metrics of rate and jerk (p-value < 0.001). This indicates that the whole group shows the same trend. Similarly novices also show a significant reduction in the steering rate values (p-value = 0.003). Both the groups also advance their steering inputs significantly as can be seen from the lower value of steering position, which indicates the X-position at which the first steering input was given.

Table 7: Change in performance for 70 km/h double lane change.

	RMS_MEAN	RMS_MID	Steering rate	Steering jerk	Steer Position
EXPERIENCED					
1st Trial	0.16 (0.11)	0.28 (0.10)	37.24 (9.88)	2289 (596)	165.42 (2.70)
2nd Trial	0.10 (0.03)	0.26(0.06)	29.86 (13.78)	1838 (518)	163.03 (3.87)
p-value	0.059	0.325	**<0.001**	**<0.001**	**0.008**
NOVICES					
1st Trial	0.24 (0.09)	0.59 (0.14)	48.27 (14.44)	2782 (854)	170.42 (3.26)
2nd Trial	0.22 (0.09)	0.54 (0.14)	36.25 (12.10)	2414 (932)	167.60 (3.11)
p-value	0.382	0.089	**0.003**	**0.173**	**<0.001**

4 RESULTS PART B: CORNERING

During Session 1 (normal friction road surface), experienced drivers had 104/400 (26%) road departures whereas novices had 131/364 (36%) road departures. The reason behind the higher percentage among novices could be that they take more time to adapt to the simulator environment as compared to experienced drivers. During Session 2 (low friction surface) the amount of road departures was 89/281 (31%) for the experienced drivers and 98/279 (35%) for novices.

4.1 Curve Times and Lateral Acceleration

Experienced drivers have lower curve times and maintain a higher lateral acceleration while going around the curves compared to novices (Table 8 & 9). Drivers were closer to the traction limit in Run 2 (0.2g- 0.3g) than in Run 1 (0.4g-0.5g). Experts were faster than novices by a margin of 1.7 seconds in Session 1 and by 1-1.5 seconds in Session 2. The two groups perform significantly different as can be seen from the p-values indicated in Table 8 & 9 below.

Table 8: Curve-Times (sec).

	Curve 1	Curve 2
Session1 (Normal Friction)		
Experienced	13.26(1.02)	13.14 (1.04)
Novices	14.94 (1.32)	14.89 (1.26)
p-value	**<0.001**	**<0.001**
Session2 (Low Friction)		
Experienced	18.95 (1.07)	19.10 (1.31)
Novices	20.45 (1.31)	20.21 (1.06)
p-value	**<0.001**	**0.011**

4.1.1 Steering Performance

Table 10 shows that experienced drivers have higher steering activity in terms of steering jerk and steering reversal rate. The two groups show significant difference in steering jerk and steering reversal rate for curve 1 and curve 2 in both the sessions. Steering rate showed no significant difference between the groups for Session1. In Session 2 experienced drivers showed significantly higher steering rate values as compared to the novices. Results are similar to what was found in the first experiment (study 3). In Session 2 there is a reduction in steering metric values, which is because of low coefficient of friction of the road. Thus the two groups adapted to the situation by reducing the speed of the vehicle and reducing the magnitude of control inputs. The percentage road departures are approximately same for the two groups as discussed earlier. As seen in Table 10, both group of drivers show differences in steering behaviour. To understand the reason behind the difference in steering strategy we analyze the under-steer/over-steer behaviour of the vehicle. Under-steer/over-steer coefficient is calculated using the front and rear slip angles values. Table 11 shows that for both the curves in session 1, half the drivers from the experienced group drive the vehicle in an over- steer state and half in under-steer state. The novices on the other hand show more over-steer behaviour as compared to the experienced group (Table 11). The percentage of under-steer driving shows significant difference between the two groups ($p<0.05$). In session 2, the experienced drivers adopt a more over-steer strategy as compared to the novices. The difference is significant in curve 2 of session 2 ($p<0.05$).

Table 9: Mean Lateral Acceleration (g).

	Curve 1	Curve 2
Session1 (Normal Friction)		
Experienced	0.49 (0.13)	0.47 (0.11)
Novices	0.42 (0.07)	0.42 (0.07)
p-value	**0.022**	**0.043**
Session2 (Low Friction)		
Experienced	0.29 (0.06)	0.29 (0.05
Novices	0.25(0.05)	0.25 (0.04)
p-value	**0.037**	**0.004**

Table 10: Steering Metrics.

	CURVE 1			CURVE 2		
	Steer Rate	Steer Jerk	SRR	Steer Rate	Steer jerk	SRR
Session1 (Normal Friction)						
Experienced	28.71 (5.65)	2593 (348)	1.20 (0.16)	28.40 (3.91)	2570 (290)	1.19 (0.14)
Novices	32.56 (10.88)	2320 (400)	0.98 (0.18)	32.71 (10.06)	2357 (442)	1.01 (0.19)
p-value	0.294	**0.010**	**0.001**	0.176	**0.032**	**0.003**
Session2 (Low Friction)						
Experienced	22.7 (5.97)	2490 (376)	0.88 (0.20)	25.46 (8.52)	2596 (575)	0.88 (0.21)
Novices	18.39 (5.00)	2121 (209)	0.78 (0.18)	20.28 (4.72)	2139 (152)	0.81 (0.15)
p-value	**0.037**	**0.002**	0.111	**0.043**	**<0.001**	0.308

Table 11: Percentage Under-steer.

	Curve 1	Curve 2
Session1 (Normal Friction)	**% Under-steer**	**% Under-steer**
Experienced	50.99 (10.05)	52.35 (13.59)
Novices	37.93 (10.59)	40.12 (15.64)
p-value	**0.001**	**0.017**
Session2 (Low Friction)		
Experienced	38.04 (11.46)	34.34 (11.97)
Novices	42.01 (12.80)	43.60 (10.71)
p-value	0.616	**0.018**

4.2 Path Strategy

Table 12 below describes the path strategy followed by experienced and novice groups of drivers while taking the corner. The first column of Table 19 indicates the mean distance of the vehicle from the inside of the curve (D1). Column 2 represents the deviation of the vehicle position from the inside of the lane (D2). A low value for this parameter means that the driver tries to maintain a constant distance from the inside of the curve. Column 3 represents the deviation from the mean path (D3) chosen by the drivers in various laps. This parameter represents the repeatability of drivers in following their own strategy. As can be seen experienced and novices follow the same strategy and have a mean distance of 1.92 and 1.95 meters during Session 1 and 1.85 and 2.0 meters during Session 2. The deviation from the inside of the curve is also the same for both groups of drivers in the range of 0.51 and 0.59 meters for Session 1 and 0.71 and 0.67 meters for Session 2. Table 12 shows

Table 12: Path Strategy (D1: Mean distance from inside of the curve; D2: Deviation from inside of the curve; D3: Deviation from the mean path.

	CURVE 1			CURVE 2		
Session1	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**
Experienced	1.94 (0.39)	0.50 (0.14)	0.52 (0.18)	2.07 (0.38)	0.50 (0.07)	0.53 (0.15)
Novices	1.93 (0.42)	0.58 (0.16)	0.70 (0.18)	1.89 (0.43)	0.57 (0.16)	0.67 (0.17)
p-value	0.704	0.207	**0.005**	0.150	0.207	**0.007**
Session2						
Experienced	2.04 (0.40)	0.80 (0.42)	1.25 (0.47)	1.85 (0.45)	0.64 (0.29)	0.93 (0.41)
Novices	1.95 (0.62)	0.63 (0.31)	0.88 (0.56)	2.12 (0.58)	0.60 (0.22)	1.06 (0.67)
p-value	0.595	0.149	**0.019**	0.066	0.796	0.750

that the two groups maintain approximately the same mean distance from the inside of the curve. To see if there is any difference in the path chosen between the two groups we analyze the vehicle positioning by the drivers while taking the corner. For this the driver with the mean performance and the best performance based on the lap-times were selected. Figure 15 shows the path chosen by drivers. As can be seen there is no particular strategy that can be related to the particular group. Two types of path strategies were found in both groups. The first strategy relates to the driver entering the curve a constant distance from the inside of the curve and then moving towards the outside of the curve while cornering and exiting. This can be seen in the mean performance of experienced group in Figure 15 (bottom left). Most of the novice drivers tried to follow this strategy. In the second strategy the driver enters from the outside of the curve, while cornering goes close to the inside of the curve and then moves towards the outside of the curve while exiting, thus following a racing line. This can be seen in the best performance of experienced and novice group in Figure 15 (middle left and right). Most of the experienced drivers tried to follow this strategy. In both the groups, best performance in terms of lap-time was achieved follow the second strategy. Best performance shown by experienced driver in Figure 15 had a mean curve-time of 12.19 seconds which is 1.07 seconds faster than the mean of the group. Best performance shown by novice driver in Figure 15 had a mean curve-time of 13.51 seconds which is 1.43 seconds faster than the mean of the group. Mean performance for an experienced driver shows both the above mentioned strategies, whereas for the novices no particular repeatable strategy can be seen in Figure 15 (bottom right). Moreover novice drivers were poor at following any particular strategy, as can be seen from Table 19 above. Parameter D3 that gives the deviation from the mean path shows significant difference between the two groups with experienced drives showing lower deviation compared to the novices in Session 1. The deviation is higher for the experienced group on the low friction surface in Session 2, maybe because experienced drivers tried to achieve the better lap-times and hence drove the vehicle at higher lateral acceleration, whereas the novices' main aim was to keep the vehicle on track.

5 CONCLUSION

5.1 Experiment A

As can be seen from the results presented in the above sections, the experienced group shows better performance in the double lane change maneuver in terms of lower root mean square deviation from the mid path and lesser average number of cones hit. One of the reasons for the poor performance shown by the novices was the improper positioning of the vehicle while entering lane 1. The novices were always offset

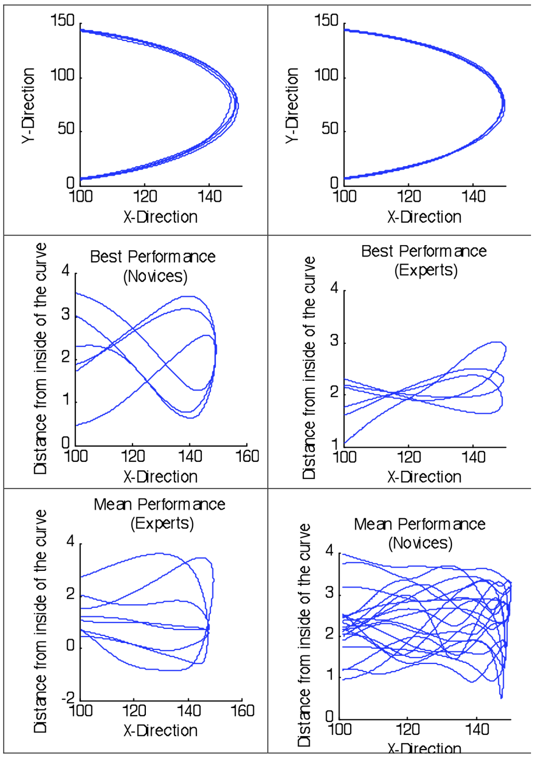

Figure 15: Deviation from inside of the curve: Top (left for novice and right for expert) is the path followed; Middle left is the best performance by experienced driver; Middle right is the best performance by novice driver; Bottom left is the mean performance by experienced driver; Middle right is the mean performance by novice driver.

(right) of the mid-path, which could be evidence of poor perception of the vehicle width and lane width. It was hypothesized that task performance would degrade with increase in speed and that this degradation would be stronger and would occur at lower speeds in novice drivers. The experiment was unable to prove this hypothesis, as there was no clear degradation in performance of the novice or experienced drivers in terms of number of cones hit.

Novices show poor repeatability in following their own strategy in terms of higher root mean square deviation from the mean path and mean lateral acceleration. Poor repeatability can be evidence that either the novices did not have any particular strategy and were using hit and trial method to get the best performance, or they had a particular strategy but were not able to follow it due to poor vehicle control skills.

As the speed of the maneuver was constant during each trial (controlled automatically) and the lane boundaries were defined, the double lane change test was effectively an open loop test. But the drivers showed some closed loop behaviour towards the end of the maneuver to correct for the deviation in vehicle positioning. Unlike the results from the experiment explained in study 3, the DLC test results show that the novice drivers have higher steering activity compared to the experienced drivers. As described in above sections the DLC maneuver has three main steering inputs. It is hypothesized that the first and second steering inputs are more open loop whereas the third input is a more closed loop compensatory action. It is seen that the novices have a lower maximum value of first steering input at higher speeds (speed>85 kmph) as compared to experienced drivers. This can be indicative of poor perception of the width of the road and the distance between the lanes. It was also seen that novices tend to give late steering input in the initial stages of the maneuver as compared to the experienced drivers. Novices show inaccuracy in judging the correct timing of the control action and hence provide late initial steering input (similar to the experiment one result of experts having a more precise and accurate braking point). The novices seem to try to compensate for the delay in steering input in the later stages, thereby showing higher steering activity in terms of steering wheel angle, average steering rate and average steering jerk. Results also show that the novices maintained a higher mean lateral acceleration at all speeds as compared to experienced drivers. This can be correlated to novices showing higher steering activity especially in the later stages of the maneuver.

Data revealed that the novices show a decrease in the value of maximum steering angle for the first steering input with increase in session speed. Increase in speed (and hence required lateral acceleration) essentially requires higher slip angles and a larger steering wheel angle. The reason for this behaviour might be evidence that the novices have a poor internal vehicle model and hence are unable to update their control actions in changing driving scenarios. The increase in speed increases the speed of visual flow and hence novices might find in difficult to perceive and judge the required control inputs. Moreover maybe the novices are not comfortable in providing high steering inputs as they have rarely been in such situations and are unaware of how the vehicle will react to the control inputs. Experienced drivers on the other hand realize that the change in condition (here increasing speed) requires change in control actions and hence adapt their inputs accordingly.

The results also show that the novices are poor at self-assessment compared to the experienced drivers. Performance versus self-assessment showed strong correlation for the experienced group. Comparing the first and last session at 70 km/h no significant learning was seen in any of the groups in terms of improvement in performance although significant reduction in steering metric values was shown within the groups. It can be concluded from the results that steering metrics of timing/position of steering input, average steering rate and average steering jerk can be used to differentiate novice and experienced group of drivers, and are apparently more discriminative than performance based metrics. The significant effects of learning indicate that effects of increasing speed might be confounded by effects of learning, but as stated above limited effects of speed were observed.

Thus the study shows correlation between experience and performance with experienced drivers performing better than the novices. Late and insufficient steering inputs and higher steering activity separated the novice drivers from the experienced group. The data also shows that steering rate, steering jerk and position of steering input metrics can be used to differentiate novice and experienced drivers.

5.2 Experiment B

A high speed cornering experiment was performed to quantify the differences in performance and strategy between novice and experienced drivers. Results showed better performance for experienced drivers in terms of lower lap-times and higher average lateral acceleration as compared to the novices. The first experiment session (normal friction road surface) showed more road departures for novices as compared to the experienced drivers. This could possibly be because novices take time to adapt to driving in a simulator environment and understanding test procedure. It can also be possible that the novices took a longer time to judge the correct maximum speed and appropriate control inputs in order to go around the track without road departures, which can be evidence of lower vehicle dynamics and response knowledge.

The results also show that there is a difference in steering behaviour between the two groups. Expert drivers show higher steering activity in terms of steering rate, steering jerk and steering reversal rate. These results are consistent with past research, which showed higher steering activity among expert drivers in terms of steering wheel angle, average steering jerk and frequency of steering inputs. As discussed in study 3, the driving task is a combination of feed-forward and feedback control. High steering activity shown by the experienced drivers could possibly be evidence of higher feed-forward and feedback gain as compared to the novices. Possibly the lower steering activity shown by the novices can be attributed to inaccurate perception of the road curvature, hence imprecise judgment of the required control inputs. Experts might be better at perceiving the information from the surroundings and might have a better vehicle dynamics knowledge, allowing them to better judge the correct control inputs.

No single path strategy was found to define the group behaviour for the two groups. The path strategy of entering from the outside of the curve, going close to the inside of the curve while cornering and then moving towards the outside of the curve while exiting showed the best performance for both the groups in terms of curve-times. This strategy is similar to the one shown by the experts in (Treffner et al., 2002). Experienced drivers showed better repeatability in following their strategy in terms of deviation from their mean path as compared to the novices. Poor repeatability can be evidence that either the novices did not have any particular path strategy and were using hit and trial method to get the best performance or they had a particular strategy but were not able to follow it due to poor vehicle control skills. The data also revealed that the novices drive in an over-steer condition in both the sessions whereas the experienced drivers drove in under-steer state during session 1 but shifted to a more over-steer strategy in session 2. This could possibly be attributed to novices braking while cornering hence inducing over-steer in the vehicle during session 1. In session 2 the experienced drivers were close to the traction limit and hence probably applied an over-steer strategy to control the vehicle.

Summarizing, it can be concluded that the experienced drivers performed better than the novices in the high-speed cornering task. Higher steering activity shown by the experienced drivers was possibly the reason for better performance. Differences in driving strategy and repeatability in following the path strategy most clearly separated the experienced from the novice drivers. Metrics like steering rate, steering jerk and steering reversal rate used to differentiate the two groups of drivers showed major and significant differences.

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