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

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Abstract: Safety is one of the major areas of concerns today in the field of automotive development. Different safety measures have and are being introduced in order to improve driver/passenger and pedestrian safety. Advanced driver assist systems (ADAS) are therefore becoming increasingly important in their role of reducing driver crash risk. A shortcoming of the ADAS systems is that the variability in drivers based on skill and experience is not taken into account and the system is often designed for average or worst case driver performance thereby compromising on the dynamic behaviour of the vehicle. This study focuses on understanding and quantifying the differences in drivers. This knowledge of driver differences can be helpful in designing an adaptive ADAS by introducing the driver into the control loop.

The study investigates differences between race-car drivers and normal (experienced) drivers in a high-speed driving task. The study analyses simulator data for 17 drivers on the Mallory Park test circuit. The driving task required the participants to drive around the circuit 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 expert race drivers compared to the non-expert drivers. Steering metrics like average steering rate, steering jerk showed higher values for the expert group and distance traveled around the corner showed a different path strategy adopted by the experts. Both groups showed improvement in performance based on lap-times across the different sessions. Thus the study shows that expert and non-expert drivers have different steering behaviour and path strategy, which can be attributed to differences in driving experience, vehicle dynamics knowledge and vehicle control skills.

1 INTRODUCTION

Through the years of automotive development safety has been one of the primary areas of concern. Inappropriate driver behaviour and insufficient skill are considered the primary cause of road accidents. (Brookhuis and Smiley, 1987) stated that more than 85% of total accidents could be directly attributed to the driver (59% driver error and 26% driver impairment due to alcohol or drug consumption, fatigue etc.). Over the years there have been many regulatory and technological advances designed to help reduce the risk of accidents. (Fildes and Lee, 1994) reviewed several studies and reported a reduction of 8-40% in road accidents in Belgium, Finland, France, Germany, UK and South Africa due to reduced speed limits.

Advanced driver assist systems (ADAS) are also becoming increasingly important in their role of reducing driver crash risk. Studies ((Weiner and Curry, 1980) and (NHTSA, 2009)) have shown that these systems are beneficial in improving the safety of the driver and the passengers, but at the same time they can also make the drivers complacent and relaxed thereby increasing the probability of a dangerous situation. Moreover, these regulatory and technical measures are not driver specific and often the average driver performance is used as the benchmark. It can be argued that the present safety measures are not designed to address the variance in the skill level of drivers. Knowledge of driver based differences in control and behaviour can hence help improve the development of ADAS.

Driver perception, knowledge and awareness, and vehicle control skills affect the driving task competency. (Fuller, 2005) stated that the total driving competency is based on initial driving skill and the knowledge and vehicle control skills gained through experience. (Malik, 2011) defined driver competency as the ability to use driving knowledge and skill for the successful and safe completion of the driving task i.e.

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proper and timely perception followed by appropriate action. Previous research has shown differences in control strategy for expert drivers compared to non-experts (Katzourakis et al., 2011) on a circular drive task. Further differences in steering control in a simulated environment were found by (Zhang et al., 2008), who showed differences in the frequency spectrum between expert and non-expert drivers during different lane change maneuvers. The difference in competency level between experts and non-expert drivers leads to differences in behaviour and performance.

This research is an extension of previous research done to classify drivers into groups of non-expert, experienced and experts. The research aims at objectively estimating the skill level of the drivers using a predefined task. The present study focuses on analyzing the differences between race drivers (experts) and normal (experienced) drivers in a high-speed driving task. An experienced driver is one who has a certain level of expertise gained through driving experience, while expert drivers are categorized by high level of driving proficiency (e.g. race car drivers, instructors in driving schools). The task required the participants to select the optimal speed and race line, and provide accurate and consistent control inputs while going around the corners in order to achieve minimal lap-time. The study focuses on the steering behaviour and the path strategy and consistency of both groups of drivers using a driving simulator test dataset.

2 METHODS

2.1 Apparatus

The experiment was conducted in a race-car simulator based on the chassis of a Formula Renault 2.0 racing car used for training purposes (Sim-Delft, 2013). The steering wheel, brake and throttle pedal were used from the original car and a direct drive motor provided force feedback. The throttle and brake pedal feedback was passive and calibrated to resemble a realistic formula car. The visual system consisted of three 52-inch LCD screens and provided a 130 degree horizontal and 27 degrees vertical field of view. The simulator was equipped with a steering wheel mounted dashboard showing speed, engine rpm, lap and lap sector times. The virtual environment, vehicle dynamics and force feedback were simulated by rFactor software (v1.255). The rTrainer vehicle model, a rear wheel driven formula style racecar (115 bhp, 573 kg), was used (Figure 1). All driving aids were disabled and gear shifting was automated. All driving simulator data was recorded and stored at 100Hz.

Figure 1: RTrainer Car.

2.2 Experiment Instructions

Participants were instructed to drive the fastest lap-time possible on an unfamiliar racetrack. The Mallory Park circuit was chosen for the experiment. Figure 2 below shows the outline of the circuit, consisting of: 1) a long right hand corner known as the Gerard's bend, which turns through nearly 200 degrees, 2) a 180 degrees hairpin corner know as the Shaw's Hairpin, and 3) a combination of two fast corners. The participants drove four sessions of 10 minutes and between sessions had a five-minute break. Participants received instructions prior to the start of the experiment about the application of the throttle and gas pedal and explanations regarding the information available on the steering wheel mounted dashboard. Participants were required to steer, accelerate and brake (gear shifting was automatic).

Figure 2: Mallory Park Test Circuit.

2.3 Participants

Seventeen drivers (all male), aged from 17 to 26 years (mean = 20.8, SD = 2.0) participated in the study. The non-expert group consisted of 10 drivers, students at the Delft University of Technology having no experience in racing with an average age of 21.6 years (SD = 1.8). The expert group had 7 drivers, professional racing drivers from various (international) racing classes (e.g. Formula 3, GP2 and Porsche Supercup) with an average age of 19.9 years (SD = 2.0).

2.4 Dependant Measures

To analyze the performance of the participants three curves were selected on the test circuit:

1. 1) Long right hand curve, which turns through nearly 200 degrees
2. 2) Combination of two fast curves
3. 3) 180 degrees hairpin curve

Figure 3 below shows the selected curve and each curve was analyzed separately. Data analysis and the results are shown below. Each session was analyzed separately per curve. The data for the three mentioned curves was selected for every lap and analyzed. The curve entry and exit point was determined by the X-Y position of the vehicle, ensuring that it was situated before the point where drivers start giving any vehicle control inputs (steering, brake, or throttle) relating to the entry of the corner. Similarly, in determining the exit point it was verified that the vehicle was in straight-line steady state condition (Figure 4) The steering data was 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 first part of the analysis was to remove road departures from the data. The cases in which all the four wheels left the track were considered as "road departure". This was done separately for all the three curves and laps with road departures were excluded from the performance analysis. They were studied separately to understand the crash behaviour of the two groups, but have not been included in this study.

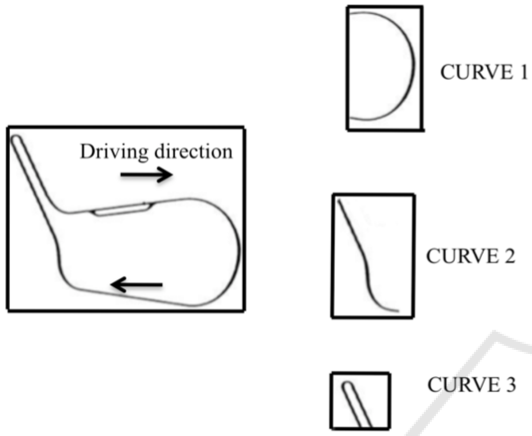

Figure 3: Track breakdown into different curves for analysis.

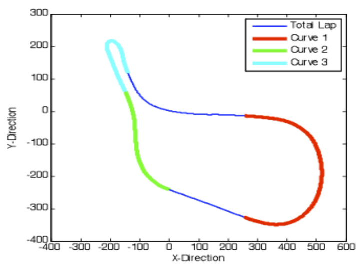

Figure 4: X-Y position of the selected curves for analysis.

The performance of the drivers was analyzed using different dependant measures discussed in Table 1 below. As the data was found to be non-normal (using q-q plots), differences between the experts and the non-experts were assessed using the Wilcoxon-Mann-Whitney test, which is better at dealing with non-normal distributions than the t-test.

Table 1: Dependant Measures.

Metric	Description	Units
Average Steering Rate	Average steering wheel rate from the initial steering input (Absolute Steering angle>3) to the curve exit point	deg/sec
Average Steering Jerk	Average rate of change of the steering wheel acceleration (jerk) from the initial steering input (Absolute Steering angle>3) to the curve exit point	$(deg/s)^3$
Mean Lateral Acceleration	Mean of the lateral acceleration from the entry to the exit point of the curve	g
Curve Time	Total time taken from the entry to the exit point of the curve	seconds
Distance Covered	Total distance travelled from the entry to the exit point of the curve	meters
Braking Point	Total distance between the points when the driver first brakes after the curve entry point to a predefined X-Y position on the curve (same for all the drivers). Only Curve 2 and Curve 3 are studied for this measure, as these are low speed corners, which require the drivers to brake. Curve 1 was excluded from the analysis because not all drivers brake before or during Curve 1 but instead just released the throttle to reduce the speed.	meters

3 RESULTS

3.1 Road Departures

Experts showed a higher percentage of road departures compared to non-expert drivers in Curve2, session 2-4. A significant improvement in the number of road departures over sessions can be seen for the non-expert drivers in all curves (p=0.031), while the experts remain at a constant level of road departures (p=0.343). Table 2 below shows the number of laps with road departures for every session and both groups.

Table 2: Number of Road Departures.

Session	Curve 1			Curve 2			Curve 3			
	Experts	**Non-Experts**	**P value**	**Experts**	**Non-Experts**	**P value**	**Experts**	**Non-Experts**	**P value**	**Total Crashes***
1	8	21	0.108	18	18	0.718	10	25	0.752	72/125 (58%)
2	8	10	0.709	29	17	**0.008**	9	14	0.538	70/147 (48%)
3	12	10	0.302	25	7	**0.008**	7	13	0.679	60/148 (41%)
4	11	13	0.946	24	8	**<0.001**	7	11	0.923	65/153 (43%)
Mean	9.25 (1.5)	13.50 (5.20)	0.171	24.00 (4.55)	12.50 (5.80)	0.057	8.25 (1.50)	15.75 (6.29)	**0.029**	66.75/143.25 (47%)

* Total number of road departures for experts and non-experts combined / Total number of laps

3.2 Curve Times

Experts show lower lap-times and curve times compared to the non-experts. Experts are faster than non-experts on average across all the sessions by a margin

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of 0.8-1.5 seconds in curve 1, 0.4-0.9 seconds in curve 2 and 1.0- 2.3 seconds in curve 3.

Table 3: Average curve-times for all session and all curves.

Session		Total lap-time	Curve 1	Curve 2	Curve 3
1	**Experts**	56.58 (1.78)	18.02 (0.53)	9.33 (0.30)	12.65 (0.36)
	Non-Experts	60.99 (5.90)	18.61 (.46)	9.64 (0.26)	14.58 (2.46)
	p-value	**<0.001**	0.082	0.082	0.052
2	**Experts**	55.71 (1.41)	17.59 (0.42)	9.14 (0.35)	12.17 (0.19)
	Non-Experts	58.85 (2.94)	18.89 (1.12)	9.93 (0.97)	14.48 (3.64)
	p-value	**<0.001**	**0.01**	**0.03**	**0.001**
3	**Experts**	55.13 (0.37)	17.40 (0.32)	8.95 (0.10)	12.14 (0.19)
	Non-Experts	59.80 (4.68)	18.90 (1.08)	9.88 (0.84)	13.12 (0.44)
	p-value	**<0.001**	**<0.001**	**<0.001**	**0.001**
4	**Experts**	55.25 (1.11)	17.47 (0.21)	8.95 (0.09)	12.17 (0.20)
	Non-Experts	59.36 (3.91)	18.54 (1.02)	9.80 (0.69)	13.34 (1.18)
	p-value	**<0.001**	**0.001**	**<0.001**	**<0.001**
Session 1 to 4 difference	**Experts (p)**	0.072	0.063	**0.031**	**0.031**
	Non-Experts (p)	0.066	0.063	0.063	0.063

Both the groups show near significant improvement in lap times from session 1 to 4. The two groups perform significantly differently in terms of curve times from Session-2 to Session-4, as can be seen from the p-values indicated in the table below.

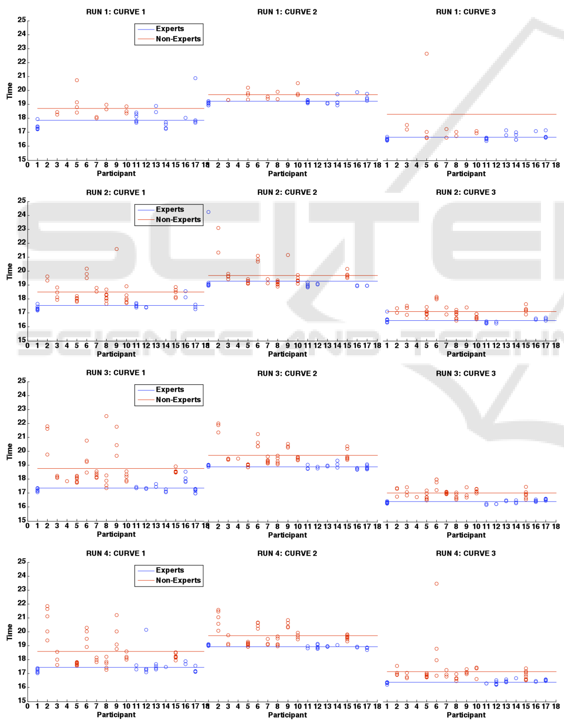

Figure 5: Comparison of curve times for the three curves from session 1 (top) to 4 (bottom) (blue and red lines represent the mean curve times for experts and non-experts respectively). Each circle represents the curve time for one lap during a curve section from the respective participant.

The overall difference in curve-times for all the three curves between experts and non-expert drivers is around 2.2 -4.6 seconds whereas the difference in lap-times is between 3.2-4.7 seconds. This shows that the experts maintained a higher speed in the straight road segments also, which maybe because of the higher corner exit speeds of the experts. Table 3 above does not indicate the improvement in the average curve times for curve 1 from session 1 to 4, which can be seen in Figure 5. Similar differences are shown in curve 2 and curve 3 also with experts having lower curve times as compared to non-expert drivers. Both the groups show improvement across the sessions. Experts show significant improvement in curve-times in curve 2 and curve 3 between session 1 and session 4. Experts show more consistency in the results as can be seen from Figure 5.

3.3 Lateral Acceleration

Experts maintain higher levels of lateral acceleration as they went around the curves during sessions 1 to session 4 compared to the non-expert drivers. In curve 1 the expert drivers maintain 0.06-0.12 g higher lateral acceleration, in curve 2 the difference is 0.07-0.14 g and in curve 3 there is 0.07-0.09 g difference as compared to the non-expert drivers. No significant improvement was seen in the performance of the two groups in terms of lateral acceleration from session 1 to session 4 for the non-experts whereas the experts show significant increase in lateral acceleration for curve 1 from session 1 to session 4. non-experts have

Table 4: Average Lateral Acceleration for all sessions and all curves.

Session		Curve 1	Curve 2	Curve 3
1	**Experts**	0.77 (0.05)	0.71 (0.07)	0.47 (0.04)
	Non-Experts	0.71 (0.04)	0.64 (0.06)	0.40 (0.04)
	p-value	0.126	0.125	**0.03**
2	**Experts**	0.80 (0.03)	0.78 (0.04)	0.49 (0.03)
	Non-Experts	0.69 (0.06)	0.65 (0.08)	0.40 (0.05)
	p-value	**0.01**	**0.003**	**0.004**
3	**Experts**	0.82 (0.03)	0.78 (0.03)	0.497 (0.02)
	Non-Experts	0.70 (0.06)	0.64 (0.09)	0.42 (0.03)
	p-value	**<0.001**	**<0.001**	**<0.001**
4	**Experts**	0.82 (0.02)	0.78 (0.03)	0.49 (0.02)
	Non-Experts	0.72 (0.07)	0.64 (0.08)	0.42 (0.03)
	p-value	**0.002**	**0.004**	**0.002**
Session 1 to 4 difference	**Experts**	**0.031**	0.156	0.219
	Non-Experts	0.313	0.313	0.188

lower values of acceleration probably because their primary goal is to successfully negotiate the curve without any road departures, whereas experts try to keep the vehicle at the limit to achieve the best performance. Thus experts also have higher road departures as compared to non-expert drivers (Table 2).

3.3.1 Steering Performance

Experts show higher steering activity compared to non-expert drivers based on steering wheel rate and steering jerk. Steering jerk values are different for the two groups but only curve 1 (session1 and session 2) and curve 2 (session 1, session 3 and session 4) show significant differences ($p < 0.05$). Steering jerk values shown by the experts were approximately 1.5-2

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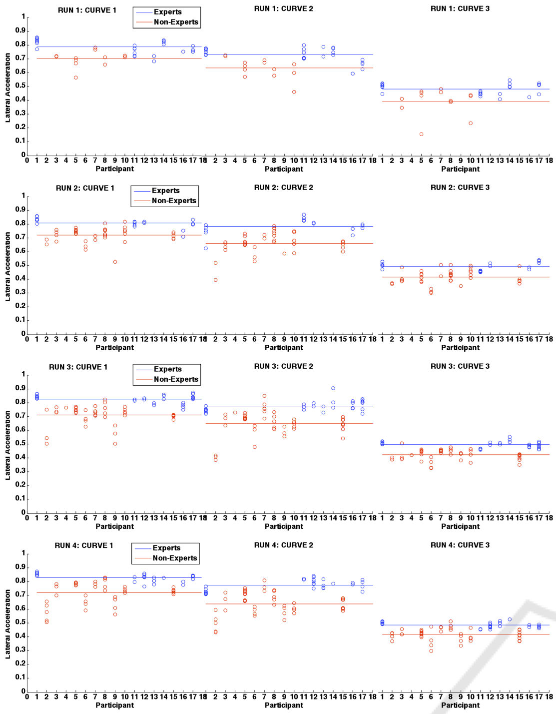

Figure 6: Comparison of average lateral acceleration (g) for all the curves from session 1 to 4 (blue and red lines represent the mean curve times for experts and non-experts respectively). Each circle represents the mean lateral acceleration during a curve section from the respective participant.

times higher than the non-expert drivers for curve 1 and 2. Reduction in the average steering jerk values can be seen for experts from session 1 to 4 for all the curves but only curve 3 shows significant difference (p<0.05).

Table 5: Steering metrics for all sessions and all curves.

Session		Curve 1		Curve 2		Curve 3	
		Steer Rate	Steer Jerk	Steer Rate	Steer Jerk	Steer Rate	Steer Jerk
1	Experts	21.82 (11.31)	4791 (2139)	22.10 (10.57)	5216 (2876)	28.47 (8.44)	5904 (1342)
	Non-Experts	13.28 (4.79)	2378 (608)	14.94 (5.63)	2657 (687)	31.24 (6.21)	5328 (759)
	p-value	0.330	**0.017**	0.247	**0.017**	0.429	0.247
2	Experts	18.33 (9.78)	3923 (2542)	16.5 (6.01)	3783 (1562)	24.9 (6.96)	5255 (1339)
	Non-Experts	10.85 (4.03)	1943 (843)	13.8 (3.41)	2302 (747)	23.5 (6.56)	4229 (1557)
	p-value	0.09	**0.03**	0.44	0.07	0.9	0.3
3	Experts	14.87 (7.62)	3092 (2025)	15.7 (5.85)	3629 (1285)	21.45 (6.53)	4660 (1336)
	Non-Experts	10.48 (4.02)	1805 (708)	11.7 (2.27)	2038 (702)	20.89 (6.8)	3860 (999)
	p-value	0.27	0.11	0.08	**0.01**	0.96	0.22
4	Experts	14.44 (4.54)	2912 (1306)	14.7 (4.5)	3188 (815)	21.82 (6.2)	4407 (1469)
	Non-Experts	10.05 (3.15)	1733 (631)	12.1 (3.67)	2025 (1032)	20.32 (5.42)	3467 (1187)
	p-value	0.07	0.07	0.07	**0.023**	0.92	0.25
Session 1 to 4 difference	Experts	0.219	0.094	**0.031**	0.063	0.156	**0.031**
	Non-Experts	0.188	0.313	0.313	0.188	0.188	0.188

non-expert drivers also show reduction in steering jerk values but it was not statistically significant. Data also shows high standard deviation among the experts. non-expert drivers have lower values but also show smaller deviations in the group, see Table 5 for an overview of the data. Average steering rate is also higher for the expert group compared to the non-expert drivers but it is not significantly different. There is a reduction in average steering rate values for the non-expert drivers from session 1 to 4 but it is not statistically significant. Experts also show reduction but only curve 2 shows significant difference (p<0.05).

3.4 Path Strategy

3.4.1 Braking Point

Lower values of standard deviation, especially in Curve 2, show that experts find a suitable braking point and follow it consistently. As can be seen from Table 6, the experts brake approximately 94 meters before the curve 2 entry point during all the 4 sessions. On the other hand the non-expert drivers brake later and show variation in the braking point through the different sessions. non-expert drivers also have a higher standard deviation within a session compared to the experts. The braking point in Curve 3 is later for the experts, and reaches significance in the last session. No significant difference was seen in experts or the non-expert drivers from session 1 to 4 (p>0.05).

Table 6: Braking point for all sessions and curves 2&3 (in curve 1 braking was not always observed).

Session		Curve 2	Curve 3
1	Experts	93.82 (0.76)	355.29 (1.11)
	Non-Experts	93.75 (0.31)	356.25 (0.63)
	p-value	0.126	0.052
2	Experts	94.1 (0.16)	355.07 (1.07)
	Non-Experts	92.9 (2.25)	355.88 (1.02)
	p-value	**0.03**	0.11
3	Experts	94.08 (0.12)	355.2 (0.82)
	Non-Experts	91.8 (5.64)	356 (0.9)
	p-value	**0.003**	0.07
4	Experts	94.07 (0.14)	355.13(0.6)
	Non-Experts	93.55 (0.5)	356.2 (0.9)
	p-value	**0.01**	**0.01**
Session 1 to 4 difference	Experts	0.999	0.844
	Non-Experts	0.125	0.313

3.4.2 Path Strategy

In figures 7 to 9 the path taken by experts and non-expert drivers is shown for all curves in session 4. Differences in path strategy between the two groups can be seen from the graphs. In curve 1, as can be seen from Figure 7, non-expert drivers try to keep the vehicle close to the inside of the track at all times. Experts on the other hand first go towards the outside of the curve and then give a sharp steering input to exit from the curve. As a result, they maintain a larger distance from the inside of the curve as compared to the non-expert drivers. In curve 2, as seen

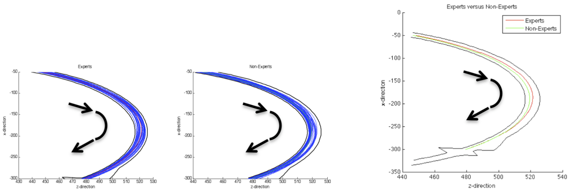

Figure 7: Session 4-Curve 1: Path Followed: Blue lines indicate the individual paths for the experts (right) and non-expert drivers (center) in session 4, whereas red line (for experts) and green line (for non-expert drivers) indicates the mean path of all the laps. Thin black lines indicate the lane boundaries of the track and the arrows indicate the direction of travel.

from Figure 8, non-expert drivers give a higher initial steering input to keep the vehicle closer to the inside of the track. Experts, on the other hand, have smaller steering inputs and keep the vehicle closer to the outside of the track while exiting the corner, compared to non-expert drivers. In Curve 3 as seen from Figure 9,

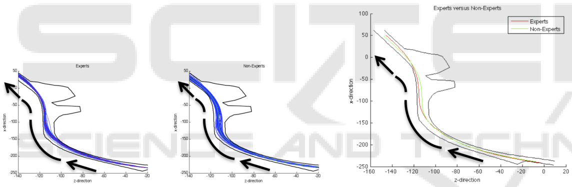

Figure 8: Session 4-Curve 2: Path Followed: Blue lines indicate the individual paths for the experts (right) and non-expert drivers (center) in session 4, whereas red line (for experts) and green line (for non-expert drivers) indicates the mean path of all the laps. Thin black lines indicate the lane boundaries of the track and the arrows indicate the direction of travel.

the non-experts try to remain close to the inside of the curve while entering and try to maintain a constant distance from the inside of the corner. The experts on the other hand, drive away from the inside of the curve while entering and remain close to the inside of the curve while exiting. Difference in path strategy is also represented in the distance travelled by the two groups while negotiating the corner (Table 7). As can be seen from Table 7, experts take a longer path in curve 1 (significantly different for Session 2 and Session 4 with p<0.05) which is because they maintain a higher distance from the inside of the curve (see Figure 7) as compared to non-expert drivers. Similar pattern is seen in curve 2 (significantly different for Session 3 and Session 4 with p<0.05) where the experts keep the vehicle towards the outside of the curve

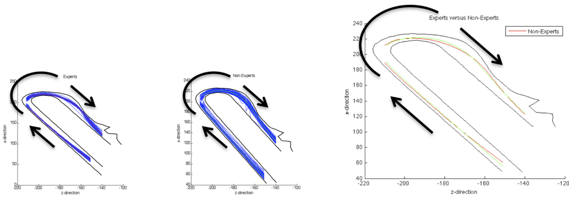

Figure 9: Session 4-Curve 3: Path Followed: Blue lines indicate the individual paths for the experts (right) and non-expert drivers (center) in session 4, whereas red line (for experts) and green line (for non-expert drivers) indicates the mean path of all the laps. Thin black lines indicate the lane boundaries of the track and the arrows indicate the direction of travel the track.

while exiting (see figure 8). Curve 3 does not show any significant difference in terms of distance travelled. There is no significant difference for distance travelled from session 1 to 4 for both the groups.

Table 7: Distance traveled for all sessions and all curves.

Session		Curve 1	Curve 2	Curve 3
1	Experts	723.81 (1.91)	359.97 (4.29)	306.02 (4.40)
	Non-Experts	722.54 (0.92)	355.65 (2.07)	306.53 (3.96)
	p-value	0.429	0.052	0.999
2	Experts	726 (1.45)	361.2 (3.8)	304.05 (8.18)
	Non-Experts	723.2 (2.17)	357.01 (3.56)	303.62 (6.96
	p-value	**0.02**	0.07	0.9
3	Experts	725.6 (2.06)	360.12 (3.06)	304.41 (6.04)
	Non-Experts	723.4 (2.08)	356.7 (3.28)	303.92 (5.8)
	p-value	0.07	**0.050**	0.73
4	Experts	727.4 (2.17)	360.14 (2.16)	305.07 (5.4)
	Non-Experts	723.7 (2.14)	356.2 (3.4)	307.03 (6.96)
	p-value	**0.01**	**0.01**	0.68
Session 1 to 4 difference	Experts	0.063	0.844	0.188
	Non-Experts	0.125	.063	0.999

4 CONCLUSION

In this study differences between expert race-car drivers and non-expert drivers were investigated. As seen from the data presented in this study, experts show better performance in terms of lap-times and higher tire utilization as compared to the non-expert drivers. Higher lateral acceleration shown by the expert drivers means that they had a higher speed throughout and exiting the corner. This enabled them to maintain a higher straight-line speed, resulting in faster lap-times achieved by the experts as compared to the non-expert drivers. non-expert drivers had more road departures in the first session, which could be because they were not familiar with the simulator and took some time to adjust to driving in the simulator environment, and getting accustomed to the racing task and the race-track. In sessions 2 to 4 experts had higher percentage of road departures as compared to the non-experts, which is possibly because experts took more risk trying to keep the vehicle on the limit to achieve best performance as can be seen from the lower lap-times and higher tire utilization values, compared to the non-expert drivers. Probably, the primary goal of the non-expert drivers was to successfully negotiate the curve without any road departures, sacrificing some curve time performance.

The results show differences in steering behaviour between the two groups. Expert drivers show higher steering activity in terms of steering rate and steering jerk. These results are consistent with previous research which showed higher steering activity among expert drivers in terms of steering wheel angle, average steering jerk and frequency of steering inputs ((Hollopeter, 2011); (Zhang et al., 2008)). Driving is a combination of open and closed loop processes. Precise timing and accurate control inputs can enable the driver to negotiate the race task in a largely open loop state. While entering a corner a driver anticipates the speed and steering angle that should be used, representing the feed-forward part of the control loop. But deviation from the desired path (vehicle positioning on the track) due to imprecise control inputs, lag in the system or changing vehicle and environment conditions, requires additional control inputs to correct for the deviations from the desired path. This represents the feedback control of the drivers. Possible best performance can be achieved with a combination of feed-forward and feedback control. Therefore, the higher steering activity shown by the experts might be attributed to higher feed-forward and feedback gain as compared to the non-expert drivers. Lower steering activity shown by the non-expert drivers might be correlated to lower feed-forward gain, which resulted in poor vehicle positioning while entering the corner, and lower feedback gain, which resulted in insufficient correction in vehicle path while taking the corner. Thus higher steering activity shown by the experts can possibly be attributed to optimizing the desired path. Another possible explanation for higher steering activity especially in the racing task can be that the experts are not only optimizing the path followed but are also trying to keep the vehicle at the traction limit and hence providing continuous steering corrections to stabilize the vehicle. Overall this is evidence that experts have a better developed internal vehicle model, which enables them to understand what the current situation demands, what should be the control inputs, and also how the vehicle will respond to the given control inputs. The promptness in steering action and the ability to provide faster inputs could be the result of practice. non-expert drivers on the other hand might not be capable of giving such fast inputs, lacking motor control skills, or maybe they do not dare to give faster inputs, as they do not know how the vehicle might respond, which is evidence of inferior vehicle dynamics and response knowledge. This is consistent with the definition of competency ((Fuller, 2005)), which states that competency is a combination of initial personal biological characteristics and knowledge and skill gained through training and experience.

We also see a difference in strategy between the two groups in terms of braking point and the path chosen to negotiate the corner. The non-expert drivers show inconsistency in the braking point. This can be evidence that the non-experts are inaccurate in perceiving the curvature of the corner and hence are unable to judge the correct timing and magnitude of control action. While cornering, non-expert drivers try to maintain a constant distance from the inside of the corner whereas the experts tried to follow the racing lane, keeping towards the outside of the corner while entering and exiting and going close to the inside of the corner in the mid-section. The different path strategies of the two groups is similar to the one found by (Treffner et al., 2002).

In summary, it can be concluded that experts who had greater experience in the racing environment performed better than the non-expert drivers in terms of lower lap-times. Higher steering activity, different braking and path following strategy and consistency in following the chosen strategy significantly differentiated the two groups. The data also showed that lap-time, steering jerk and distance travelled metrics could be used to differentiate between expert and non-expert drivers. Steering jerk metric showed the largest difference between the two groups with experts approximately 1.5-2 times higher than the non-expert drivers for curve 1 and 2.

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