Driver Perception-Reaction Times in Level 3 Automated Vehicles

Dr. Audrey DEMICOLI, Profs. George YANNIS, Dr. Odette LEWIS

ABSTRACT

In Level 3 automated vehicles (AVs) the driver may engage in secondary tasks but must re-engage in driving if alerted when roadside circumstances exceed the capacity of the AV technology. The research aim was to establish the Perception-Reaction Time (PRT) of drivers in a Level 3 AV in relation to person-specific characteristics, to scenarios with different in-vehicle distractions and type of alerts. This PRT value was compared to that used in road design in different countries to calculate Stopping Sight Distances (SSD). Such PRT is important because the driver needs a timely alert for safe handover from automated to manual vehicle control.

The data was collected through a web-based survey which provided demographic information about the respondent followed by a driving simulation in a Level 3 AV. Driver PRT was taken from the moment of the alert to the moment that participant reacted by clicking an on-screen box.

The results gave an average perception-reaction time of 4.23 seconds and showed that the younger age groups have lower PRTs for all scenarios than their older counterparts both for different alerts and secondary tasks. If the existing design standards for SSD are retained, such distances would not be sufficient to allow the driver to resume the driving task in a timely manner. It also resulted that the multisensory alert advantage over the visual alert is effective only until the cognitive capacity of the participant was not exceeded. Such was exceeded when the secondary distraction was reading and typing of a text message.

KEYWORDS

Automated vehicles, Perception-Reaction Time, Stopping Sight Distance,

1 Introduction

The demand for transport infrastructure will change in the coming future due to the introduction of automated vehicles as part of the latest development in motor vehicle technology (Maurer et al, 2016). The changes have probably not been fully understood and appreciated (ITS International, Nov/Dec 2014).

2 Literature Review

Vehicle automation is classified into different levels where the driver is the operator of the vehicle for Levels 0, 1 and 2, the driver is the supervisor and intervenes when required in Level 3 vehicles and the vehicle operates as driverless for Levels 4 and 5. The levels of automation increase with an increase in the technological development of the vehicles and deployment is estimated to be in the year 2025 for Level 3 and in the year 2030 for Levels 4 and 5 (Ross, 2014).

Vehicle automation technology is adopted in connected vehicles (CVs) and AVs and these differ in the way the respective technologies operate. CVs operate based on communications of V2V, V2I, V2D, V2X and vice-versa whilst the AVs operate using sensors and auxiliary devices (Winner et al, 2016; Eskandarian, 2012; Johnson, 2017; Zmud et al, 2016; Johnson, 2017). However, Schoettle (2017) concluded that AVs which are fully connected are the safest because it is difficult to emulate the rationality and perception of humans through technology and thus the AV technology still cannot seamlessly substitute a human and also the driver cannot necessarily make up for the limitations of automation.

Different driver response times and PRT were encountered in different research papers and this was due to different definitions used for PRT (Muttart, 2005). The definition for PRT used in this research document is as defined by Conference Europeenne des Directeurs des Routes (CEDR). Research also showed that age, alcohol consumption and the surprise factor of the stimulus affected PRT.

In respect of driver adaptation to vehicle automation, it resulted that although trust increases with use of AVs, however the acceptance does not increase (Merat & Lee, 2012). In this respect, research by Xiong et al (2012) and Merat & Lee (2012) showed that driver tendency to adopt risky behaviour in an AV was found to depend on driver education, experience and personality. When there is a failure in the vehicle automation system, serious problems are created in the human-machine system performance because the secondary in-vehicle tasks, the excess trust in the automation technology and the reduced monitoring of the automated driving task result in reduced situation awareness which poses serious performance consequences when automation fails (Wickens et al, 2010). However, when automated vehicles are provided with effective in-vehicle displays to address situation awareness and the drivers are trained to have realistic expectations of technology failure, such can reduce, eliminate or reverse the complacency issues (Bahner et al, 2008; Wickens et al, 2010). Research by Lee et al (2004) examined the effect of graded/single-stage alert and type of alert on driver distraction and attention in case of sudden braking showed that respondents responded similarly to haptic and auditory alerts and that the alert strategy adopted was most important.

Research also concluded that increased vehicle automation causes the driver to increase the chance of engaging in secondary tasks other than driving (Merat & Lee, 2012). This means that vehicle automation increases driver distraction and thus increases the PRT to resume manual control. Disengaged/distracted drivers took longer to resume the driving task and hence had longer PRT (Louw et al., 2015). In this respect, the type of secondary task has an impact on driver PRT whereby reading and writing an sms, watching a DVD or sleeping were found to be a highly likely secondary tasks to engage in (de Winter et al, 2014). Also, it was concluded that the determining factor affecting PRT is if the driver was actually in control of the vehicle or not prior to needing to resume control (de Winter et al, 2014).

Age factors, musculoskeletal, neurological disabilities and other related disabilities together with a number of person-specific characteristic resulted in having an impact on the perception-reaction time because the driving task is a multi-tasking operation which necessitates the full control of the vehicle (Dobbs, 2005; BMV, 2015; CogniFit, 2019). However, no research was encountered where the perception-reaction time of disabled persons was examined in relation to the driver as an operator in a Level 3 automated vehicle.

The aspect of driver engagement should be the basis of any strategy for the driver to re-engage in the driver task because the transfer of the vehicle control from the system to the driver is the most critical (Louw et al

2015). None of the research which was reviewed examined different types of in-vehicle alerts in relation to different types of secondary tasks, in an AV or AV simulator, and none compared the PRT in relation to age, gender, driving experience, disabilities and country of residence. Studies also suggested that the 2.5 seconds PRT for non-automated driving should be revised because the results showed that such value is higher for unexpected hazards for vehicles proceeding at higher speeds (Dixit et al. 2016; Blanco et al, 2015). This revision was suggested for the non-automated vehicle where the driver is engaged in driving and not in a secondary task. Hence, such revision is even more important for the case of automated vehicles where the driver is engaged in a secondary task.

Driver PRT is important to many areas of road design and road safety and new indicators need to be measured for AVs, one of them being the time to collision (Innamaa et al., 2018). Such is a similar indicator of PRT and it translates to and is reflected in the SSD for road design and thus it is a necessity for the redesign of transport networks to address the needs of AVs (Shawarby ey al, 2008; Lefevre et al, 2014). It resulted that the different countries which were reviewed use the same mathematical theory to calculate SSD however the parameters used differ between countries. The mathematical calculation is as follows (Schoon, 2019; Civil Engineering Terms, 2013):

SSD=Distance travelled during perception-reaction time + Braking Distance

Thus, $SSD = 0.278V_0\,t + (V_0^2/254f)$ …………………………………………… (1)

The United States, Canada, South Africa and Australia use PRT values on the upper end of the range at 2.5 sec whilst Austria, the United Kingdom, France, Germany, Greece and Sweden use values towards the lower end at 2.0 sec. The main assumptions used to determine SSD values are perception-reaction distance and braking deceleration distance based on coefficient of friction values (Harwood et al, 1998). The SSD calculation takes into consideration a safety hazard on the road and that the driver of the vehicle approaching this hazard must detect its existence of such hazard and then must be able to brake to a halt.

For most of the cases reviewed, stimuli, alerts and driving conditions were not for Level 3 automated vehicles but are important as they provide background information and understanding of experiments carried out and their methodology. They are also required to verify if conditions, alerts and stimuli in Level 3 vehicles, would yield different reaction times which would in turn have an impact on the design standards for Stopping Sight Distances used in various sectors of road design and engineering which are critical to ensure road safety.

2.1 Limitations of Existing Research

The scope of the research carried out by Lee et al (2004) was to examine how the alert strategy and modality determined the effectiveness of collision warning systems in mitigating driver distraction however visual alert warnings were not considered, the group of participants was small and the experiments were carried out using collision warning systems as the only automation in the vehicle. Similarly, the research carried out by Shoettle and Sivak (2016) was to determine the type of alert which the driver preferred when in a Level 3 automated vehicle and what was required for the driver to be alerted to resume the driving task. However this research by Shoettle and Sivak (2016) did not include the investigation of the impact of these types of alerts on the perception-reaction time of the driver.

The research carried out by Blanco et al (2015) was to evaluate which human-machine interfaces were effective and efficient in alerting the operator in the automated vehicle to resume the driving task of a Level 3 automated vehicle and to identify the perception-reaction times of the operator in relation to the alert systems (Blanco et al, 2015). The gaps in this research are that the results were not differentiated between different age groups and did not factor any disabilities of the participants nor did they establish how such person-specific characteristics affect the perception-reaction times. Also the research did not differentiate between different secondary tasks being performed and how they influence the effectiveness of the type of alert given.

Muttart (2005) identified variables which influence driver response times however neither AVs and nor AV simulators were used to collect the data, the drivers did not have any secondary tasks hence they were not distracted. Similarly, the research carried out by Merat et al (2014) was to establish the time period required for drivers to engage in manual based on observable driving performance and eye tracking. The gaps in the research were that in-vehicle different alert types were not used and the group of participants was small so no correlation between sex, age and driving experience was possible.

Triggs & Harris (1982) established the time delay between the creation of a stimulus and the response of the driver however the participants were all alert young drivers, the stimuli were coming from the roadside environment, the drivers were not distracted and the experiment was not conducted on an AV.

The scope of the research carried out by Merat & Lee (2012) was to examine the research carried out by others in relation to driver interaction with advanced automated technology and to establish a guide for the design of AVs. The relevant gaps in this research were that different alert systems or a combination of such were not used and only one type of distraction, namely watching a DVD, was considered.

2.2 Scope and Importance of the Research

Merging sensor-based and connectivity-based technologies provides the fail-safes and redundancies needed to produce safer automated vehicles (ERSO, 2018). Connecting vehicles to each other and to the roadside infrastructure enables the enhanced predictability and safety for both manual and automated vehicles (Traffic Technology International, Oct/Nov 2018; Johnson 2017). The most critical limitation of the AV on-board sensors is the line of sight because they cannot perceive through an obstruction or round a bend giving the AV a restricted view of the roadside environment thus reducing the safety margin of its driving strategy (Orosz et al, 2017). The time period required for the driver to resume the driving task may exceed the time available to react to a critical situation from the moment of the alert for takeover based on the line of sight of the AV sensors (Sandt & Ownes, 2017).

Although all the research described above highlights the importance that an AV perceives a hazard in sufficient time in advance to alert the driver to resume the driving task safely, however none of the research specifies nor examines the value of this minimum time period required to allow for the driver to safely resume the driving task. The scope of this research is to provide the minimum time required in advance of a hazard to enable the driver to resume the driving task in sufficient time prior to collision.

This minimum time period is translated into the minimum SSD required by the driver to bring the AV to a halt following the in-vehicle alert. Hence the AV must perceive and alert the driver within the respective SSD measured form the position of the AV to the potential point of collision, where the SSD depends on the design speed of the road.

This research was intended to establish the perception-reaction time in a Level 3 for the driver to resume the driving task from the moment of alert and determine how the design guidelines for Stopping Sight Distances (SSD) would need to be adjusted to safely accommodate such time period in a Level 3 AVs on the road network. This is important because the added complexity of the perception-reaction time of the driver in a Level 3 AV, especially within the roadside environment consisting of a traffic mix between Level 3 AVs and normal vehicles, might need a longer time period to accommodate longer perception-reaction times because of reduced driver alertness as a result of in-vehicle secondary tasks. This would necessitate longer distances for the vehicle to stop thus resulting in the need to revise the current standards for SSD to take this consideration into account.

3 Research Strategy

3.1 Outline Methodology of the Research and the Questionnaire

Primary data was collected through the creation of a computer programme which simulated a driver in a Level 3 vehicle engaged in a secondary task, other than driving, and who is alerted to engage in driving. The first part of the programme explained the scope of the questionnaire, giving a background regarding the different levels of automated vehicles and a guide to the first group of questions regarding demographic data related to the age of the driver, driving experience, any driver disability, gender and country of origin. These demographic details were important to establish the correlations between the various data groups.

The second part of the questionnaire was an analytical survey to establish the relationship and association between the attitudes of the respondents and the objective of the questionnaire. This part of the survey was a roadside driving simulation where the respondents were alerted by two different types of alert, namely a visual alert and a combined visual and auditory alert. The respondent was required to react to the alert and the Perception-Reaction Time was measured. The respondent had three different scenarios. In the first scenario the driver was involved only in driving without any distractions, and therefore, no secondary task followed by two other scenarios in which the driver was involved in two different secondary tasks, namely texting and watching and listening to a music video.

The sampling method used to collect the raw data for this research was Convenience Sampling. Participation of individuals in this research study was through email invitations to access the internet link, adverts in news portals and through social media. There were a total of 514 respondents to the survey.

3.2 Relationship between Expected and Unexpected Perception-Reaction Time

This methodology for the collection of the necessary PRT data for the scope of this research was possible because of the research carried out by Johansson and Rumar (1971) who examined the unexpected surprise and anticipated surprise perception-brake reaction times (PBRT) for drivers proceeding along the rural highways in Sweden subsequent to an auditory alert signal.

These results obtained by Johansson and Rumar (1971) concluded that a correction factor can be established which can be applied to data collected under expected conditions. The data which was collected was used to establish an empirical correction factor between a surprise perception-brake reaction time and anticipated perception-brake reaction time as follows:

Correction Factor = Surprise PBRT / Anticipated PBRT = 1.35

4 Results and Discussion

Statistical Package for the Social Science (SPSS) programme which was used to analyse the data collected from the online survey, with a total of 514 respondents, and a number of statistical theories and methods were used to analyse such data, namely the Binomial Test, Null Hypothesis, p-Value, Alternative Hypothesis and the One-Way Analysis of Variance, Shapiro Wilk Test, Kolmogorov Smirnov Test, Kruskal Wallis Test, Gamma Regression Model and Backward Procedure, Ordinal Regression Model and Cluster Analysis.

For the purposes of the analysis, the different driving scenarios in the online survey were denoted as follows:
P2:Driving scenario without secondary task and with visual alert
P3: Driving scenario without secondary task and with visual and auditory alert
P4:Driving scenario with secondary task of watching a video and with visual alert
P5: Driving scenario with secondary task of watching a video and with visual and auditory alert
P6:Driving scenario with secondary task of sending and reading sms messages and with visual alert
P7:Driving scenario with secondary task of sending and reading sms messages and with visual and auditory alert

4.1 Results and Statistical Analysis using SPSS

4.1.1 Binomial Test

The Binomial Test was used to test whether the 85% Percentile of driver perception-reaction time is 2 seconds or larger than 2 seconds. The Null Hypothesis specifies that the 85th Percentile perception-reaction time is 2 seconds and it is accepted if the p-value exceeds the 0.05 level of significance. This is because statistical significance is when the p-value is smaller than 0.05 level of significance. The Binomial Test was considered the most adequate test for the purposes of this research because the gives the option to change the test proportion from 0.5 to 0.85 to test the 85thPercentile. Other tests, such as the One-Sample T-Test, do not allow to change the test proportion and compares only the mean values. For the purposes of this study it was essential to compare the 85th Percentile value for PRT because this 85th Percentile value was used to establish SSDs of existing standard specifications.

4.1.2 Alternative Hypothesis

The Alternative Hypothesis specifies that the 85th Percentile perception-reaction time is greater than 2 seconds and it is accepted if the p-values are less than the 0.05 criterion. For all the six driving scenarios, the p-values yielded by the Binomial Test (approximately 0), shown in Table 1, are less than the 85th Percentile perception-reaction times and thus differ significantly from the CEDR value of 2 seconds.

Table 1: Results of the Binomial Test

Binomial Test

		Category	Sample Size	Observed Prop.	Test Prop.	P-value (1-tailed)
P2Duration	Group 1	≤ 2	36	0.08	0.85	0.000
	Group 2	> 2	414	0.92		
P3Duration	Group 1	≤ 2	89	0.18	0.85	0.000
	Group 2	> 2	396	0.82		
P4Duration	Group 1	≤ 2	100	0.21	0.85	0.000
	Group 2	> 2	380	0.79		
P5Duration	Group 1	≤ 2	152	0.31	0.85	0.000
	Group 2	> 2	341	0.69		
P6Duration	Group 1	≤ 2	97	0.21	0.85	0.000
	Group 2	> 2	362	0.79		
P7Duration	Group 1	≤ 2	58	0.12	0.85	0.000
	Group 2	> 2	415	0.88		

4.1.3 Tests of Normality and the Kruskal Wallis Test

The tests of Normality were carried out and since the p-values of Shapiro Wilk tests and of the Kolmogoriv Smirnov Test are less than the 0.05 level of significance, this implies that the PRT distribution do not satisfy the normality assumption so a non-parametric test was used, this being the Kruskal Wallis Test. The Tests of Normality show that the PRT distributions are skewed to the right as per Table 2.

Table 2: Results of the Tests of Normality

Tests of Normality

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	P-value	Statistic	df	P-value
P2Duration	.411	363	.000	.678	363	.000
P3Duration	.344	363	.000	.723	363	.000
P4Duration	.338	363	.000	.717	363	.000
P5Duration	.277	363	.000	.771	363	.000
P6Duration	.326	363	.000	.785	363	.000
P7Duration	.353	363	.000	.785	363	.000

The One-Way ANOVA Test was used to compare mean perception-reaction times between several groups of participants. The groups were clustered by gender, age group, years of driving experience, country of origin and disabilities. However the p-values obtained for the One-Way ANOVA Test cannot be used for the purposes of this research because this test assumes that the data has a normal distribution.

The Kruskal Wallis Test does not give the descriptive tables which are required for the purposes of this research but it assumes that the data distribution is not normal. Thus, the descriptive tables were obtained using the One-Way ANOVA tests and the p-values obtained were replaced by the p-values of the Kruskal Wallis Test.

It is to be noted that the results of the p-values obtained for the One-Way ANOVA Test and for the Kruskal Wallis Test, although some are different, however the vast majority of these p-values vary marginally and thus the two tests complement each other and give the same conclusions. This very slight variation of the p-values for these two different tests shows that the data obtained and the model are very robust because the p-values vary very little with changes.

4.2 Results of Person-Specific Characteristics in relation to Perception-Reaction Times

The results of the analysis for the person-specific data in relation to gender, country of origin, driving experience, disabilities and age groups resulted in the following:

1. Maltese EU Citizens are scoring significantly higher perception-reaction times than the Maltese in the P2 and P3 scenarios only (control scenarios without an in-vehicle distraction). There was no significant difference for the P4, P5, P6 and P7 scenarios;
2. Females scored significantly higher perception-reaction times for the P4 scenario only however when gender and age are combined, both these two predictors are statistically significant and that for the P2, P3 and P6 scenarios there is a perfect distinction between males and females.
3. The perception-reaction time increased with age and years of driving experience, which are correlated, except for the P7 scenario where there was no significant difference;
4. The perception-reaction time was lowest for the younger age groups for all scenarios; Similarly, for each scenario, the Cluster Analysis revealed that the 18-30 year age group is statistically significant and formed one or more clusters in each scenario;
5. With regards to the scenarios having a distraction, there was no significant difference in the perception-reaction time between the disabled and non-disabled groups of participants'.

The results of the Gamma Regression Model, shown in Table 3 estimated the impact of the predictors (Age, Gender, Driving License, Driving Experience, Country of Residence, Disability) collectively on the dependent variable (perception-reaction time) for each different driving scenario.

Table 3: Summary of Results of the Gamma Regression Model showing Significant Predictors

Scenario	Predictors				
	Age	Gender	Driving License	Driving Experience	Country of residence
P2	Not significant	Not significant	Not significant	Group <10 yrs experience have 1.163sec av. PRT less than 41+ yrs group	Maltese have 0.213sec av. PRT > than EU counterparts
P3	Group <30yrs have 0.830sec av. PRT < than 61+ yrs group	Males have 0.303sec av. PRT < than females	Not significant	Not significant	Not significant
P4	Group <30yrs have 0.693sec av, PRT < than 61+ yrs group	Males have 0.257sec less av. PRT than females	Licensed drivers have 1.281sec av. PRT < than non-licensed	Not significant	Not significant
P5	Not significant	Males have 0.239sec av. PRT less than females	Not significant	Group <10 yrs experience have 0.208sec av. PRT less than 41+ yrs group	Not significant
P6	Group <30yrs have 1.230sec av. PRT < than 61+ yrs group	Not significant	Not significant	Not significant	Not significant
P7	Not significant	Not significant	Licensed drivers have 0.910sec av. PRT > than non-licensed	Group <10 yrs experience have 0.187sec av. PRT less than 41+ yrs group	Maltese have 0.285sec av. PRT < than EU counterparts

The results of the Gamma Regression Model show the following important points:

i. the results of the P6 and P7 scenarios show that gender is not a significant predictor when the secondary task is writing and reading an sms;
ii. the Age and Driving Experience predictors complement each other and either one or the other results as a significant predictor in all scenarios. Similarly, age was found to be a significant predictor in the Cluster Analysis. For all cases, the younger age group/least driving experience group have shorter average perception-reaction times than their older counterparts. This is also reflected in the results obtained in the Ordinal Regression Model;
iii. comparing the P4 and P5 results shows that, although males have shorter average perception-reaction time than females for both scenarios, however with the multi-sensory alert, this difference between

male and female average perception-reaction time is less. Therefore multi-sensory alerts may potentially reduce the gender difference in relation to the dependent variable. However for the P6 and P7 scenarios, where the cognitive capacity of the human is exceeded, there is no statistically significant difference between males and females;

iv. comparing the results for P6 and P7, both of which have different alerts but the same secondary task, and considering that the age and driving experience predictors complement each other, it results that the younger age group have a shorter average perception-reaction time than their older counterparts;
v. comparing the P4 and P6 results shows that, with the same type of visual alert but different secondary tasks for both cases, the respondents who do not exceed 30 years of age have shorter average perception-reaction times than their older counterparts exceeding 61 years of age;
vi. comparing the P5 and P7 results shows that, with the same type of multi-sensory alert but different secondary tasks, respondents who have less than 10 years driving experience have shorter average perception-reaction times than respondents with more than 41 years of driving experience.

In the Cluster Analysis, the most significant variables, as established by using the backward procedure and eliminating the non-significant variables, were used and such remaining significant variables were the gender and age. The clusters show that the predictors with similar characteristics can be grouped together to establish the most significant variables determining the Perception-Reaction Time. Similarly to the results of the Gamma Regression Model, for all scenarios in the Cluster Analysis, the younger age group/least driving experience group have shorter average perception-reaction times than their older counterparts.

In the Gamma Regression Model, the Perception-Reaction Time was taken as a continuous parameter. Hence an Ordinal Regression Analysis was carried out where the PRT was taken as an ordinal variable. The same results of the Gamma Regression Model were also reflected in the results obtained in the Ordinal Regression Model.

4.3 Results for the 85th Percentile Perception-Reaction Times

The 85th Percentile value perception-reaction times of the data set obtained for each driving scenario can be calculated using the definition of the z-score. The z-score is defined as (Pierce, 2017):

$$z = (x-\mu)/\sigma \text{ and thus } x = \mu + z\,\sigma \ldots\ldots\ldots\ldots \quad (2)$$

where: x is the value, μ is the mean and σ is the standard deviation.

For a normal distribution, the value can be calculated from the z-score. The value of the z-score for the 85th Percentile can be found in various tables and has a value of 1.036.
(see:http://www.pindling.org/Math/Statistics/Textbook/Chapter2_descript_stat/Graphs/z_scores_table.htm).

The standard deviation, σ, is a measure of how spread out the numbers are and is explained by the formula as follows (LaMorte, 2016):

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

However when the sample is used as an estimate of the whole population, the Standard Deviation formula changes to Sample Standard Deviation, s, and is explained by the formula as follows (LaMorte, 2016):

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where: $\bar{x}$ is the sample mean instead of μ (population mean), s is the Sample Standard Deviation instead of σ and N-1 is used instead of N as Bessel's Correction.

The Population Deviation, σ, is unknown however the Sample Standards Deviation, s, is a good estimation of σ, particularly where the sample size is large as in this case with a sample size of 514 participants.

The values for μ and σ for the six scenarios P2, P3, P4, P5, P6 and P7 are as follows, as obtained from the SPSS and shown in Table 4:

Table 4: Descriptive Statistics

Descriptive Statistics

	P2Duration	P3Duration	P4Duration	P5Duration	P6Duration	P7Duration
N Valid	450	485	480	493	459	473
Mean	3.05	2.69	2.68	2.48	2.84	3.12
Std. Deviation	1.100	.906	.979	.937	1.174	1.235

The results of the survey gave the anticipated perception-reaction times for drivers performing a secondary task in a Level 3 automated vehicle. A Correction Factor of 1.35 was multiplied with the anticipated perception-reaction times to obtain the unexpected perception-reaction times. These anticipated perception-reaction time were obtained from the survey.

Hence, for each different driving scenario, the 85th Percentile Unexpected Perception-Reaction Time is as follows in Table 5. This was calculated using the z-score formula and corrected using the Correction Factor of 1.35 as established by Johansson and Rumar (1971):

As explained previously, the first two scenarios, hence P2 and P3, did not include a simulated in-vehicle distraction and the participant had the possibility to familiarize with what was expected from the web-based survey following the written instructions which had been provided. These first two scenarios acted as a learning tool for the participant prior to attempting the simulation of the P4, P5, P6 and P7 scenarios which included a simulated in-vehicle distraction.

For the purposes of establishing a value for the unexpected perception-reaction time, the scenarios P4, P5, P6 and P7 were considered because they are the results of the data set for the simulation in a Level 3 automated vehicle where the driver is performing a secondary task.
With reference to the scenarios P4 and P5, where the driver was simulating a secondary task of watching a video with sound, the average unexpected perception-reaction was 3.57 seconds. In the scenarios P6 and P7, where the driver was simulating a non-auditory secondary task of writing an sms, the average unexpected perception-reaction time is 4.23.

Table 5: Results of Web-based Survey showing Perception-Reaction Time, Type of Alert and Type of Distraction for the Different Driving Scenarios

Driving Scenario	**85th % Unexpected PRT**	**Type of Alert**	**Type of Distraction**
P2	4.19	Visual	No distraction. Control
P3	3.63	Visual & Auditory	
P4	3.69	Visual	Watching a video. Cognitive, visual & auditory.
P5	3.45	Visual & Auditory	
P6	4.06	Visual	Typing & Reading a Text Message. Cognitive, visual & biomechanical.
P7	4.40	Visual & Auditory	

The results of the above table show that:

i. the multi-sensory alert gave lower perception-reaction times for the P2, P3, P4 and P5 scenarios;

ii. the multi-sensory alert had a longer perception-reaction time for the P7 scenario than for the P6 scenario. This is because there are higher demands on the cognitive resources of the participants results in causing the perception-reaction performance to degrade thus resulting in higher perception-reaction times.

iii. it is thus also being suggested that the audio-visual alert advantage over the visual alert is effective only up to the point determined by the demand on the cognitive resources of the participant where, in this research, this point was reached for the reading and typing of a text message distraction.

5 Conclusion

The minimum stopping sight distance on the road is to be long enough to enable a vehicle travelling at the design speed to come to a stop before colliding with an object. All standards use a fixed perception-reaction time. This is 2 seconds for Design Manual for Roads and Bridges (DMRB), CEDR, Austroads and Richtlinien für die Anlage von Autobahnen (RAA) and 2.5 seconds for the American Association of State Highways and Transportation Officials (AASHTO) and National Cooperative Highway Research Programme (NCHRP) and this means that the model is not sensitive to the actual behaviour of a human where this value would probably change depending on the vehicle speed and type of roadside scenario.

a. Use of 85th Percentile Perception-Reaction Time in Design Guidelines of Different Countries

The perception-reaction time varies from one driver to another because it is person specific and hence it is defined by a distribution and not by a fixed value. For the scope of this research document, the perception-reaction time of 4.23 seconds was established as the 85th percentile values of the data sets and the respective SSD values were calculated at Table 6.

b. Comparison of PRT with CEDR, AASHTO, DMRB, Austroads and RAA values

The following Table 6 hereunder, is a summary of the SSD values for the different standards and parameters being reviewed as follows:

Table 6: Summary of Stopping Sight Distances for CEDR, AASHTO, NCHRP, DMRB, Austroads and RAA

Criteria	This research	CEDR[1,6]	AASHTO[2]	NCHRP[2]	DMRB[3]	Austroads[4]	RAA[5]
PARAMETERS							
Coefficient of Friction	0.377	0.377	from 0.4 for 30km/h to 0.28 for 120km/h	-	0.25	0.36	from 0.35 for 60km/h to 0.15 for 120km/h
Deceleration Rate(m/s^2)	-	-	-	3.4	-	-	
PRT(sec)	**4.23**	2.0	2.5	2.5	2.0	2.0	2.0
DESIGN SPEED	Stopping Sight Distance						
30	45	26	29.6	31.0	31	27	-
40	64	39	44.4	45.9	47	40	-
50	85	54	62.8	63.1	70	55	-
60	108	71	84.6	82.5	90	73	65
70	134	90	110.8	104.2	120	92	85
80	161	111	139.4	128.2	145	114	110
90	191	135	168.7	154.4	178	139	140
100	222	160	205.0	182.9	215	165	170
110	256	188	246.4	213.7	252	193	210
120	291	217	285.6	246.7	295	224	255

Sources: Weber et al. (2016)[1], Design Manual for Roads and Bridges (2002)[3], Fambro et al (1997)[2], Fanning et al (2016)[4], Harwood et al (1998)[5], Petegem et al (2014)[6].

The above table yields the following conclusions:

i. The perception-reaction time in a Level 3 Automated Vehicle is greater than the perception time in a Level 1 and 2 vehicles for all standards adopted in road design and accident investigation;

ii. From the existing guidelines and standards for SSD, DMRB have the longest SSD because they adopt a lower coefficient of friction;

iii. The AASHTO SSD values are slightly less than those for DMRB because they adopt a greater coefficient of friction. Although the perception-reaction time is greater however it affects only the first part of the model equation to establish the time travelled during perception-reaction time;

iv. NCHRP recommends amendments to the AASHTO standards and such changes to the parameters resulted in lower SSD;

v. The SSD for CEDR are the lowest distances which were examined in this report because the parameters consist of the highest coefficient of friction and the lower perception-reaction time. This thus resulted in both lower distances travelled during perception-reaction time and lower braking distances;

vi. The results obtained for the perception-reaction time parameter in this research resulted in the longest SSD values except for the SSD at and above 120km/h which are slightly less than those for DMRB;

vii. The greatest difference in SSD values between the values established through this research and other established values are most prominent for speeds of and exceeding 80km/h. These values are the most critical as they are the SSD values which lie beyond the visual capabilities of the driver for detecting small during daytime and for detecting larger objects with low contrast at night-time;

viii. The SSD values established by this research document exceed the values in the existing standards and guidelines except for the SSD value in DMRB for a design speed of 120km/h. However, if a lower coefficient of friction were to be used to establish the recommended SSDs for this research document, the distances would considerably exceed the DMRB values.

The results of this research show that for Level 3 automated vehicles 4.23 seconds perception-reaction time is required for the driver to resume the driving task and this value exceeds the perception-reaction time values of the design guidelines referred to above. This confirms the validity and the importance of the results of this research document. If the existing design standards for SSD are retained, such distances would not be sufficient to allow for the driver to resume the driving task in a timely manner.

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