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Research Article

Mining of the association rules between driver electrodermal activity and speed variation in different road intersections

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ABSTRACT

It is commonly acknowledged that the human factor and the interaction between the human factor and the road environment are among the most common causes of road accidents. Physiological signals can provide a real-time assessment of the driver's state because they can be collected continuously without interfering with the driver's task performance or the drivers' perception of the road. This study presents a method for measuring and quantifying drivers' physiological responses when approaching T-junctions and roundabouts using electrodermal activity and speed variations. Speed and electrodermal activity were collected continuously during a driving study which took place on a test environment based at Cranfield University and surrounding roads. Twenty participants were involved in the study. The analysis focused on four crossing manoeuvres on two T-junctions and a roundabout. The association Rule with the Apriori algorithm was used in order to evaluate associations between the variables related to electrodermal activity, i.e. the number and amplitude of the SCR peaks (assessed by the Electrodermal Impact Index in aggregate form), and the variables related to speed, i.e. the speed variation and its sign (positive or negative), for each type of intersection. The main results of this study can be summarized as follows: 1) the rules obtained for the manoeuvres on the T-Junctions show that the T-junctions induce low variations in the electrodermal activity and are often associated with a significant speed increase (between 20% and 30%); 2) the rules obtained for the manoeuvres on the roundabout highlights that the roundabout induces high variations in the electrodermal activity and is associated with a significant speed reduction (between 20% and 40%).

1. Introduction

Physiological signals are a useful metric for providing feedback about a driver's state because they can be collected continuously without interfering with the driver's task performance or the drivers' perception of the road. When humans are subjected to stressors, such as those resulting from a significant workload during driving activity, they tend to show a variety of physiological responses such as pupil dilation, increased heart rate, slowed digestion, and a constriction of blood vessels, mechanisms that are collectively known as the 'fight-or-flight' response [1]. Starting initially in a driving simulator [2] and moving to field studies [3–5], previous work demonstrated that vehicle sensor and physiological measures can both be collected in real-time and do not interfere with the primary task. Examples include physiological measurements as a function of road infrastructure [6], or for different levels of automated driving [7]. The Autonomic Nervous System (ANS), responsible for involuntary activities, is made up of the Sympathetic and Parasympathetic nervous systems. Stressful events or emergency situations cause dynamic changes in ANS, where the activity rate in the Sympathetic Nervous System (SNS) increases and the Parasympathetic Nervous System (PNS) activity decreases. Alternatively, activities in the PNS dominate during resting activities. SNS and PNS regulate the electrodermal activity, heart rate variability, and brain waves, which are the main measures for stress reported in literature, and other physiological systems including blood pressure. Electrodermal activity, also known as galvanic skin response or skin conductance, is a reliable indicator of stress [8]. Electrodermal activity (EDA) refers to the variation of the electrical properties of the skin in response to sweat secretion. The whole mechanism is controlled by the sympathetic nervous system and can be used to control the functionality of the cognitive system. By applying a low constant voltage, the change in skin conductance (SC) can be measured non-invasively [9]. The time series of SC can be categorized into two components: tonic (i.e., skin conductance level;

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SCL) and phasic components (i.e., skin conductance response SCR) that have different time scales and relationships to external stimuli [10]. SCR could be a useful indicator of activities of the sympathetic branch of the autonomic nervous system because the sweat glands are innervated by the sympathetic nervous activities [11]. The sympathetic arousal stimulated by external stressors is reflected by a higher SCR. In this sense, EDA has been used to understand an individual's mental status related to sympathetic arousal (e.g., stress, attention, risk perception, etc.) in various situations such as occupational settings, human-computer interaction, traffic and automation, and marketing and product evaluation [12]. SCR could be a more useful index of the human response to external stimuli than other physiological signals such as heart rate, respiration rate, and skin temperature because SCR is the only autonomic physiological variable that is not contaminated by the parasympathetic branch of the autonomic nervous system [13].

It is well known that intersections are among the most complex road environments: their geometric configuration, the signs and markings, the road furniture, the qualitative and quantitative characteristics of traffic, the vehicular conflicts are all elements which weigh the driver workload, conditioning the driving behaviour and, consequently, affecting the risk of accident. In particular, it is well acknowledged that the safety performance of at-grade intersections varies significantly depending on the type of scheme adopted. One of the solutions for improving road safety in both urban and rural areas is to design roundabouts and convert intersections into roundabouts. Single-lane roundabouts are particularly highlighted as an example of a very safe intersection when compared to not-signalized and signalized at-grade intersections [14]. Therefore, the installation of roundabouts has become a popular and effective way to improve traffic safety. Several previous studies proved that appropriately designed roundabouts can be safer and more efficient compared to conventional intersections [15,16]. Converting standard intersections into roundabouts has been found to reduce the number of accidents, especially fatal accidents [17–19]. Studies on roundabouts in various countries have shown that roundabouts can significantly improve both operational characteristics (e.g., leg capacity, service levels, queue length) [20,21] and traffic safety [22,23]. Roundabouts have also been shown to be well accepted by drivers [24,25]. Several researchers have studied the relationship between geometric elements and safety benefits in roundabouts [26–28]. Safety benefits of roundabouts include a reduced number of conflict points, elimination of right-angle and turn-left head-on crashes, and lower approaching speeds which provide more time to react to potential conflicts. Roundabouts influence drivers' behaviour, forcing them to reduce speed in order to drive properly on the circulatory roadway. This significantly reduces the crash severity. For this reason, roundabouts are often used as traffic calming measures in residential areas. It can be said that one parameter strongly related to the safety level of road intersections is the speed at which drivers approach them. The more an intersection is able to reduce speed, the more both the frequency of accidents and the severity of collisions are reduced.

Several studies analysed speed variations at intersections [29]. The main cue for speed perception is information derived from the optic flow field, which is perceived with peripheral rather than foveal vision [30]. In other words, the driver perceives speed based on the information (stimuli) present at the roadside. By giving the road user the impression of a higher speed in order to make them slow down, the environment should be enriched with objects. For instance, within built up areas short urban spaces with roundabouts will decrease the speed by influencing the drivers' choice and widen their angle of view for detecting the behaviour of other road users especially the vulnerable. Cavallo and Cohen [31] pointed out that the size of visual field is a factor, which significantly affects speed perception and correct speed estimation is significantly reduced when the size of the visual field and thus peripheral vision is diminished. Speed choice of the driver also depends on the field of view as well as the fixation point. The further away the fixation point is, the narrower the lateral field and the higher the driving speed will be. It should be also noted that drivers tend to underestimate the speed of other vehicles and overestimate the distance of oncoming cars. This limitation affects manoeuvres such as overtaking or crossing [32].

The aim of this research is therefore to search for a correlation between two parameters representing the human response to the stimuli coming from different road intersections: 1) electrodermal activity, described by the variations of SCR; 2) the variations of speed. Particularly, the study aims to understand if the behavioural differences in terms of variations of speed when approaching different types of at-grade intersections (T-junctions and roundabouts) correspond to different physiological responses in terms of variations of electrodermal activity.

While previous studies investigated the benefits of converting junctions into roundabouts in terms of crash rates and traffic conditions, to the authors' knowledge, few studies analysed how drivers' responses change between standard intersections and roundabouts in terms of physiological responses [33]. Seeking to overcome this gap, this study presents a method for measuring and quantifying drivers' physiological responses when approaching T-junctions and roundabouts using physiological signals and speed variations. Speed and electrodermal activity were continuously recorded during a driving study which took place on a test environment based at Cranfield University including 3 at grade intersections (1 roundabout and 2 T-junctions). The association Rule with the Apriori algorithm was used to evaluate associations between the variations of electrodermal activity and speed for each type of intersection.

2. Data and method

2.1. Experiment design

An experimental investigation which aimed to explore and capture the user's natural behaviours in the real-world was developed. The experiment was part of the “HumanDrive” project. 23 staff members were recruited from Cranfield University, 3 individuals participated within pilot trials and 20 individuals participated within the trials. An advert was placed on the Cranfield University website, and participants who showed interest were sent an email which included information about the study and a participant recruitment questionnaire. The questionnaire data was used to determine the appropriate participant sample and participants were invited to participate within the study. The 20 participants involved within the trial were evenly divided between males and females. Participants were aged 28 to 50 years of age. They were required to have held a driving license which would be valid in the UK for a minimum of 3 years. One participant was excluded from the analysis because of a problem during the data collection. The final sample therefore consisted of 19 participants (10 males and 9 females).

An ethics application was made for the experiment to the Research Ethics committee at Cranfield University and received approval. Participants gave their informed consent to take part in the experiment. They were informed that all information collected would have been dealt with in the strictest confidence and would have only been used for research purposes. Participants were also informed that they would not have been judged as for their ability as drivers and that the only aim of the study was to analyze the behaviour of a group of drivers to draw conclusions about drivers in general.

The ego vehicle driven by the participant was a Nissan Leaf. The vehicle was instrumented with 4 colour cameras (one forward facing, one driver facing, one steering wheel facing, one feet facing) and an OXTS RT1003 vehicle localization system. The RT1003 is a small GNSS-aided inertial navigation system for use in automotive applications where space and payload are restricted. It is designed to measure position, speed and orientation and output those measurements in real-time as well as logging them internally. Utilizing dual antennas, DGPS corrections, tight-coupling and advanced processing technology, the RT1003 delivers up to 2 cm position and 0.1° heading accuracy (2 m antenna separation) with up to 250 Hz output for all measurements. Specifically, the instrument measures:

- Vehicle position (latitude and longitude or distance from an agreed reference zero).
- Forward speed (assuming flat plane).
- Linear acceleration (X, Y, Z, SAE vehicle coordinates).
- Angular rates about the vehicle axes.
- Vehicle heading.
- Attitude (roll, pitch, yaw).
- GPS time (time duration from age to be agreed).

An Empatica E4 (Empatica Inc., Cambridge, MA, USA) wrist band sensor was worn by participants to collect physiological data. The wristband embeds four sensors: EDA, photo-plethysmograph, thermometer, and accelerometer. The E4 wristband EDA sensor uses the exosomatic method, which measures skin conductance (μS) by applying a small external current. The sampling frequency of the EDA sensor is 4 Hz (i.e., four samples per second). Participants wore the wristband on their right wrist. The instrument was used to record EDA continuously and unobtrusively during the experiment.

The study involved time for participants to familiarize themselves with the vehicle, participant 'within trial' data collection, followed by interviews to further understand their driver behaviour. Before the drive could be carried out the participant had to be familiar with the vehicle and how to control it. The ego vehicle dimensions, operation and automatic and electric drive train may be new to the participant. Therefore, a tutorial was provided to explain how the vehicle works, whilst the vehicle was stationary. Moreover, a familiarization period was built into the study to ensure that participants had adequate time to get familiar with the vehicle and a similar level of familiarization was achieved across all participants to prevent experimental bias. The familiarization drive was accompanied by a facilitator, sitting in the back of the vehicle behind the driving seat and issuing directions. The facilitator had to confirm during and/or at the end of the familiarization drive that the participant was confident driving. After this phase the driving study started. Participants were asked to drive naturally. As with the familiarization drive, directions were issued by the facilitator who was sat directly behind the driver's seat. Trials took place between 9 am and 4 pm, to ensure similar and bright visibility and to avoid busy commuter traffic. When adverse weather such as heavy rain, wind or snow were experienced, the trial was postponed.

2.2. Study area

The driving study took place on the MUEAVI (Multi-User Environment for Autonomous Vehicle Innovation) test environment based at Cranfield University and surrounding roads. MUEAVI is a controlled and instrumented stretch of road, located on the edge of the University Campus. Both public roads and campus roads link to the MUEAVI facility, these roads were also incorporated within the trial, particularly to further assess interactions with the roundabouts and intersections. Fig. 1 shows the study location and the driving route. It can be seen the driving route composed by the loop around Cranfield and the MUEAVI (central quadrant) and the familiarization drive (upper left quadrant). Participants drove the route multiple times continuously and therefore they made different manoeuvres through the different intersections situated on the driving route.

This study focuses on the variations of speed and electrodermal activity of drivers approaching the roundabout R and the two T-junctions T1 and T2 shown in Fig. 1. The roundabout has three perpendicular legs and a diameter of about 45 m. The T-junctions have three perpendicular legs and have similar dimensions.

The variations of speed and electrodermal activity were evaluated for one crossing manoeuvre was for each T-junction (manoeuvre 1 and manoeuvre 2 in Fig. 1) and for two crossings manoeuvres on the roundabout (manoeuvre 3 and manoeuvre 4 in Fig. 1). Participants had the right of way while crossing the T-junctions, while had to yield while crossing the roundabout. We chose to compare crossing manoeuvres, rather than right-turn or left-turn manoeuvres, because speeds are usually higher for crossing manoeuvres. Since the final aim of the study was to evaluate how the type of intersection affects driver behaviour, only the manoeuvres where the traffic had no effect on driver behaviour (no traffic or really low traffic at the intersection during the execution of the manoeuvres) were analysed.

2.3. Speed evaluation

In order to evaluate drivers' speed variation when approaching the intersections, a speed profile was built for each manoeuvre for each participant. The speed profiles were calculated considering the spatial

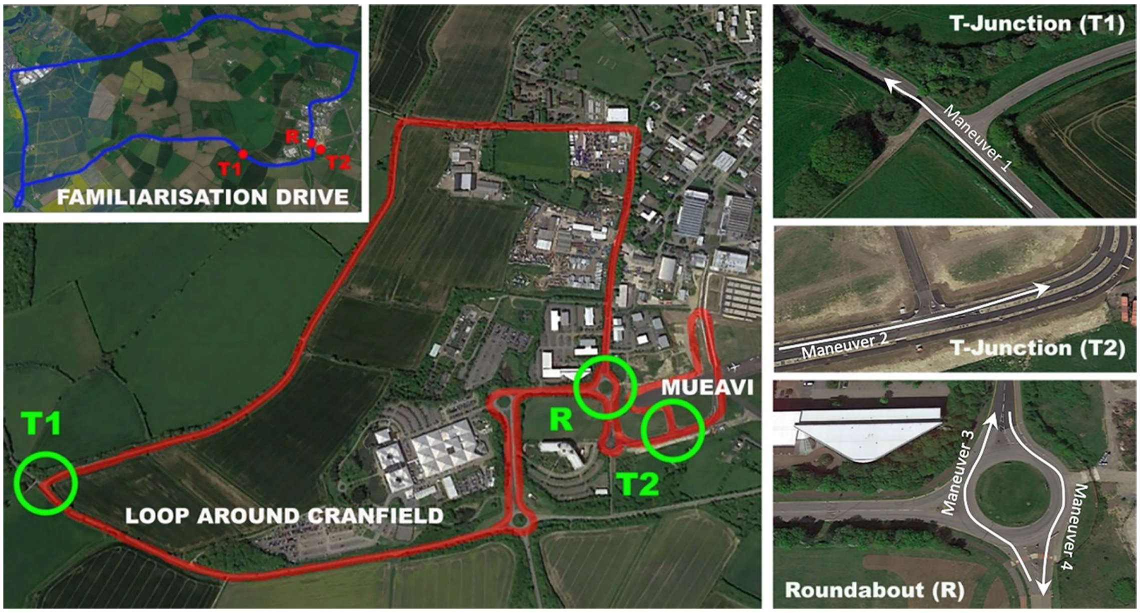


Fig. 1. Study area.

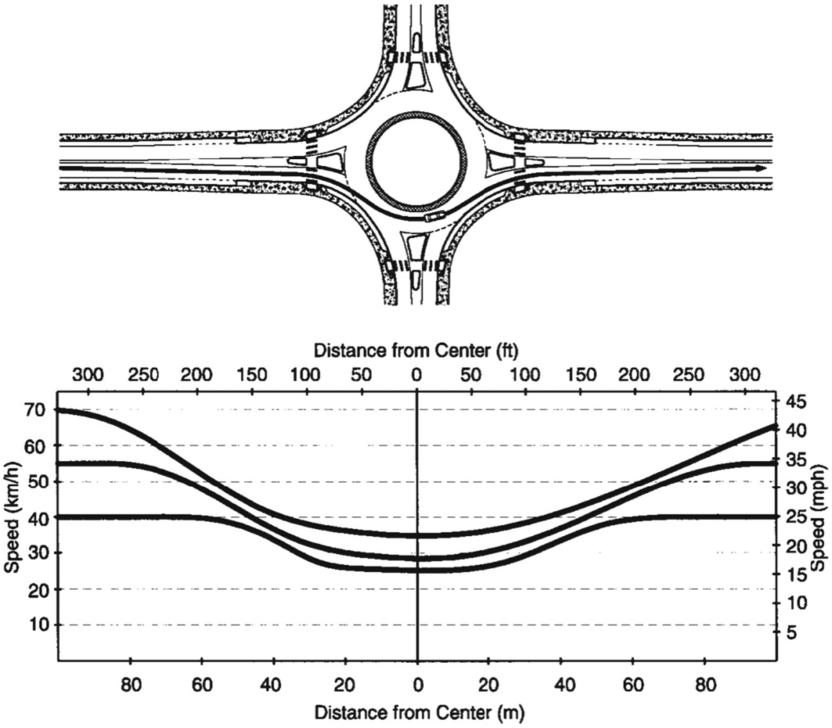


Fig. 2. Sample theoretical speed profile (FHWA, 2000).

interval where there is a speed variation due to the presence of the intersection. Fig. 2 shows operating speeds of typical vehicles approaching and negotiating a roundabout [34]. Approach speeds of 40, 55, and 70 km/h about 100 m from the centre of the roundabout are shown. Deceleration begins approximately at this distance with circulating drivers operating about at the same speed on the roundabout. The relatively uniform negotiation speed of all drivers on the roundabout means that drivers are able to easily choose their desired paths in a safe and efficient manner.

Starting from this result, the speed profiles were built based on the following considerations: 1) 100 m before the roundabout can be considered as the distance where drivers begin to vary their speed due to the presence of the intersection; 2) the centre of the intersection can be considered as the point where the driver reach a constant circulating speed; 3) 100 m after the roundabout can be considered as the point where the driver reach a higher constant speed after accelerating while exiting the roundabout.

The spatial interval corresponding to 100 m before and 100 m after the centre of the intersection was therefore considered for calculating the speed profiles both for the roundabout and for the two T-junctions.

QGIS 3.6 open source software was used to identify the spatial interval corresponding to 100 m before and 100 m after the centre of each intersection starting from the GPS traces. For each of the 4 manoeuvres examined, two speed variations were calculated, both expressed as a percentage: 1) the speed variation ΔS_{100_0} between 100 m before the centre of the intersection and the centre of the intersection; 2) the speed variation ΔS_{0_100} between the centre of the intersection and 100 m after the intersection centre.

2.4. Electrodermal activity evaluation

The tonic level of electrodermal activity, known as skin conductance level (SCL), slowly varies and changes slightly on a time scale of tens of seconds to minutes. The SCL changes for an individual respondent, depending on their hydration, skin dryness, or autonomic regulation. The tonic level can also differ markedly across individuals. This has led some researchers to conclude that the actual tonic level on its own is not that informative [13]. The phasic response rides on top of the tonic changes and shows significantly faster alterations. Variations in the phasic component are visible as EDA peaks. The phasic response is also labelled skin conductance response (SCR) as it is sensitive to specific emotionally arousing stimulus events (event-related SCRs, ER-SCRs). These bursts occur between 1 and 5 s after the onset of emotional stimuli. By contrast, non-specific skin conductance responses (NS-SCRs) happen spontaneously in the body at a rate of 1–3 per minute and are not a consequence of any eliciting stimulus. SCRs may reflect stimulus-specific responses or non-specific responses. An SCR shows a steep incline to the peak and a slow decline to the baseline. The succession of SCRs usually results in a superposition of subsequent SCRs, as more often than not, a subsequent SCR occurs during the decay of a previous one. Hence SCR does not show distinct peaks of phasic activity, but rather is characterized by the superposition of extended responses, which eventually complicates the assessment of responses [12].

Continuous decomposition analysis [35] was used in this study for extracting SCRs peaks, as it enables separate detection of superimposed responses. The data were therefore, analysed by determining the number of peaks in the skin conductance response (SCR) that participants had while driving on each intersection through the following procedure. The phasic data (SCR) was extracted from the EDA signal by using a median filter. For each sample, the median EDA score of the surrounding samples was calculated based on a +/− 4 s interval centred on the current sample. This value was then subtracted from the current sample to obtain the phasic data. Peak onset/offset thresholds were set to 0.01 μS and 0 μS respectively [35]. The peak onset value represents the starting point in time where a peak is detected, while the offset value represents the time when a peak has passed. To avoid false positives, the onset value was not counted if it is less than 0.01 μS. The maximum original EDA data within each pair of onsets and offsets is an SCR peak. SCR peak amplitude is the amplitude at the peak minus the amplitude at onset. A peak was only considered if its amplitude was higher than 0.005 of the onset value. Also, a signal jump threshold that accounts for false peaks - caused by noise - is set to 0.02 μS. After continuous decomposition analysis, onsets for each individual SCR were obtained. Onsets served as the basis to subsequently calculate the number of SCR peaks and their amplitude. SCR amplitude rate (i.e. the amplitude at the peak divided the amplitude at the onset) was then calculated for each peak [13,33]. Based on the values of the SCR amplitude rate, SCR peaks were divided into *high peaks* (amplitude rate higher than 1,1) and *low peaks* (amplitude rate lower than 1,1). SCR peaks were evaluated using a moving window approach with the temporal interval corresponding to 100 m before and 100 m after each intersection, already identified for the analysis of speed.

To better understand the relationship between driving stress and electrodermal activity (EDA), Electrodermal Impact Index (EEI) values were also assessed in relation to driving manoeuvres while crossing the two intersections. The Electrodermal Impact Index is defined [33] as the product of the number of SCR peaks and the average amplitude of the SCR peaks during the execution of each manoeuvre. It is a useful index for further evaluation of driver's risk perception for T-junctions and roundabouts and for evaluation of stress level caused by each type of junction [33].

2.5. Association rule mining

The Association Rule with Apriori algorithm was used in order to find associations between drivers' electrodermal activity (EDA) and speed variations when approaching the intersections studied. The variable related to electrodermal activity is *Electrodermal Impact Index (EEI)*, which takes into account the number and the amplitude rate of SCR peaks when approaching the intersection, i.e. between 100 m before the intersection and the centre of the intersection. The variables related to speed are: *Speed Variation (SV)*, which takes into account the speed variation ΔS_{100_0}, i.e. the speed variation between 100 m before the intersection centre and the intersection centre; *Sign of speed variation (SSV)*, which takes into account the sign of the speed variation ΔS_{100_0} (positive or negative).

The speed and electrodermal activity data are related to a crossing manoeuvre for the T-junction T1 (manoeuvre 1), a crossing manoeuvre for the T-junction T2 (manoeuvre 2) and two crossing manoeuvres for the roundabout R (manoeuvres 3 and 4). In order to evaluate how the type of intersection affect electrodermal activity and speed variations, the variables *Electrodermal Impact Index (EEI)*, *Speed Variation (SV)* and *Sign of speed variation (SSV)* were considered for each type of intersection. The *Intersection Type Roundabout (ITR)* therefore, groups together manoeuvre 3 and manoeuvre 4, while the *Intersection Type T-junction (ITT)* groups together manoeuvre 1 and manoeuvre 2.

Table 1 shows the variables used for the Association Rule with Apriori algorithm and the items considered for each variable.

Apriori algorithm AR is one of the most popular data mining techniques, first introduced in 1993 for discovering buying patterns [36]. In recent years, the AR method in data mining has been successfully applied to uncover potential patterns or rules in a variety of fields, such as road traffic safety [37–39]. AR analysis is the method of effectively identifying sets of items that occur together in a given event. It is based on the relative frequency of the number of times the sets of items occur alone and jointly in a database. AR is a standard approach that starts with a dataset containing transactions and aims to construct frequent item sets by setting up a user specified thresholds, namely Support, Confidence, and Lift.

The Support (S) for a particular association rule A ⇒ B is the proportion of transactions in the database containing both A and B and is formulated as eq. [1]:

$$Support(A \rightarrow B) = \frac{P(A \cap B)}{N} = \frac{number\ of\ transactions\ containing\ both\ A\ and\ B}{total\ number\ of\ transactions} \tag{1}$$

The Confidence (C) of the association rule A ⇒ B is a measure of the accuracy of the rule, which is determined by the percentage of transactions in the database containing A that also contains B and is defined as eq. [2]:

$$Confidence\ (A \rightarrow B) = \frac{P(A \cap B)}{P(A)} = \frac{number\ of\ transactions\ containing\ both\ A\ and\ B}{number\ of\ transactions\ containing\ A} \tag{2}$$

Lift (L) is defined as a simple correlation that measures if A and B are independent or dependent and correlated events and is expressed by the eq. [3]:

$$Lift\ (A \rightarrow B) = \frac{P(A \cap B)}{P(A)P(B)} = \frac{number\ of\ transactions\ containing\ A\ or\ B}{number\ of\ transactions\ containing\ A\ x\ number\ of\ transactions\ containing\ B} \tag{3}$$

If a particular rule has a Lift of one, it indicates that the probabilities of A and B are independent. When two events are independent, there is no rule drawn involving these two events. In contrast, if a particular rule has a Lift greater than one, it indicates A and B are dependent and positively correlated. The higher the Lift, the greater is the strength of the association rule.

It is desirable for the rules to have a large Confidence factor, a high level of Support, and a Lift value greater than one. Since some events of interest in this analysis are low frequency (e.g., "SV3 = Speed Variation between 30% and 40%" in T-junctions), the Support for some rules of interest could be quite low. It essentially means that the Lift value is more important for determining the strength of an association rule than the other two criteria.

Hence, in the present application the rules will be evaluated based on the Lift values. It is not to say that the other two criteria are of no importance. The rules discovered by the algorithm still need to have Support greater than a minimum threshold. The threshold, however, will have to be set lower (but in any case, at least 5%) compared to a marketing application [40]. The threshold ensures that the pattern identified by a rule is observed in the database with at least some reasonable frequency. If one only relies on the Lift value and not use a threshold for minimum Support, it is possible to identify rules based on very few cases. These rules would be of little practical value.

The parameter Confidence provides a measure for how confident one can be of the fact that a given condition occurs in one of the two

Table 1
Items of the variables for Association Rule.

IT – Intersection Type	EEI – Electrodermal Impact Index	SV – Speed Variation	SSV - Sign of the Speed Variation
ITR = Roundabout ITT = T-Junction	EEI_0 = No Peak (EEI =0) EEI_1 = Between 1 and 2 EEI_2 = Between 2 and 3 EEI_3 = Between 3 and 4	SV0 = Up to 10% SV1 = Between 10% and 20% SV2 = Between 20% and 30% SV3 = Between 30% and 40% SV4 = Between 40% and 50% SV5 = Over 50%	SSVP = Positive sign (speed increase) SSVN = Negative sign (speed reduction)

types of intersections considered. Confidence is especially important when dealing with characteristics that always exist or with high probability, such as "SV0 = Speed Variation up to 10%" (68.8%) in T-junctions or as "EEI_2 = Electrodermal Impact Index between 2 and 3" (80,0%) in roundabouts.

Specifically, to identify strong associations, threshold values for Support, Confidence, and Lift were set as follows: S ≥ 5%, C ≥ 50%, and L ≥ 1. Analyses were performed using R software, which is an integrated suite of software facilities for data manipulation, calculation and graphical display.

3. Results

3.1. Analysis of variations in electrodermal activity

Electrodermal activity profiles for the interval corresponding to 100 m before and 100 m after the centre of each intersection were obtained for all participants for each of the 4 crossing manoeuvres. Fig. 3 shows an example of EDA trend (participant 9, manoeuvre 1 and manoeuvre 3). Electrodermal activity is expressed in micro-Siemens (μS) while the distance from the intersection centre is expressed in meters (m). It can be seen that there is not a substantial EDA variation for the T-junction T1 (manoeuvre 1). For the roundabout, instead, the driver manifests a significant physiological reaction in approaching the intersection, as evidenced by the EDA values which oscillate approximately between 0.3 μS and 0.35 μS. Furthermore, in proximity of the centre of the roundabout there is a reduction of EDA with values around 0.25 μS.

Table 2 shows the SCR peaks amplitude of all participants during each crossing manoeuvre on the two T junctions (manoeuvres 1 and 2) and during each crossing manoeuvre on the roundabout (manoeuvres 3 and 4). Table 2 distinguishes the peaks that occurred approaching the intersection (i.e. between 100 m before the intersection centre and the intersection centre) from those that occurred after (i.e. between the intersection centre and 100 m after the intersection centre). Table 2 also shows the Electrodermal Impact Index (EEI) values associated with the manoeuvres for crossing both intersections.

To answer the question of whether the variation in electrodermal activity was influenced by the type of intersection (roundabout or T-junctions) at which the crossing manoeuvre was performed, statistical tests were first developed.

First of all, the shape of the distribution of the variable EEI was examined, also to understand if there were any outliers. For this purpose, a boxplot was made for both types of road intersections (Fig. 4).

From the analysis of the graph in Fig. 4 it can be seen that:

a) the heights of the two boxes are very different, making it clear that 50% of the EEI values for the two types of intersections considered have different distributions: between 0 and 1 (approximately) in the case of the T-junctions and between 0 and 2.2 (approximately) in the case of the roundabout;
b) the dispersion of values above the third quartile, which are not classified as outliers, is very different for the two types of intersection considered;
c) there is only one outlier, which is therefore excluded from further processing;

The Kolmogorov-Smirnov and Shapiro Wilk tests for normality, confirmed that the two distributions of the variable EEI deviate from the normal distribution in the case of both T-junctions and roundabout ($p < .05$).

Since it was found that the two distributions of the EEI variable were not comparable to Gaussian distributions, it was not possible to perform any of the parametric tests for analysis of variance. However, the non-parametric tests Median Test and Mann-Whitney *U* test were performed. Both tests rejected the null hypothesis and confirmed that the two distributions of EEI for the T-junctions and for the roundabout are statistically significantly different.

3.2. Analysis of speed variations

Speed profiles for the interval corresponding to 100 m before and 100 m after the centre of each intersection were obtained for all participants for each of the 4 crossing manoeuvres. Fig. 5 shows an example of speed profile (participant 9, manoeuvre 1 and manoeuvre 3). It can be seen that the approach speed variation in the case of the T-junctions (manoeuvre 1) is very low: the speed remains almost constant, approximately equal to 52 km h, between 100 m before the intersection centre

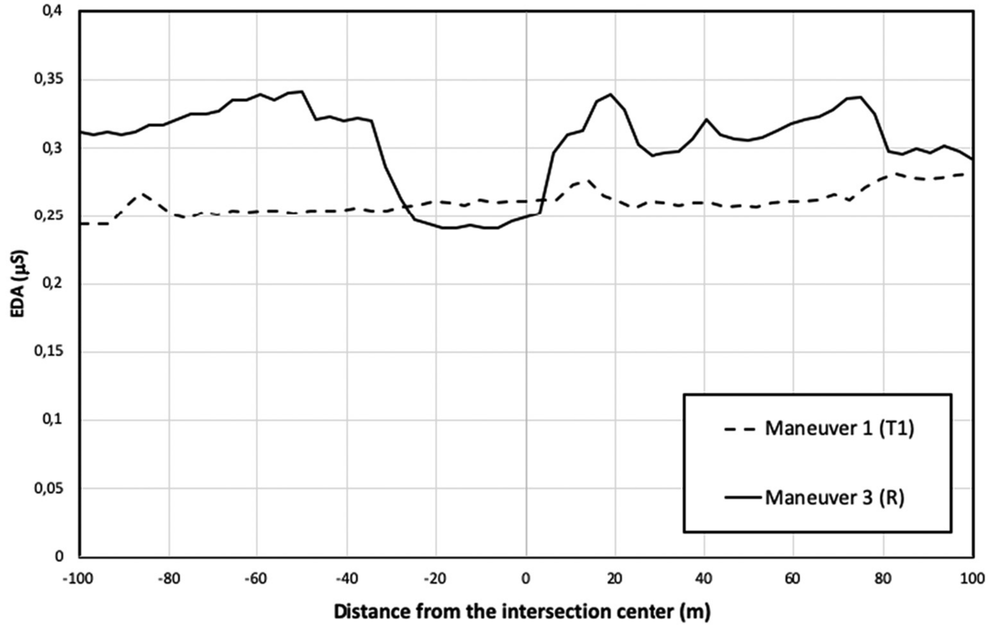


Fig. 3. EDA trends for participant 9 during manoeuvre 1 (T-junction T1) and manoeuvre 3 (Roundabout R).

Table 2
Distribution of SCR peaks and EEI for all participants during each crossing manoeuvre at the two T-junctions (T1 and T2) and during each crossing manoeuvre at the roundabout (R).

	T-Junctions						Roundabout					
	Manoeuvre 1 (T1)			Manoeuvre 2 (T2)			Manoeuvre 3 (R)			Manoeuvre 4 (R)		
Part.	SCR Peaks ampl.	Peaks 100 m - center	EEI 100 m - center	SCR Peaks ampl.	Peaks 100 m - center	EEI 100 m - center	SCR Peaks ampl.	Peaks 100 m - center	EEI 100 m - center	SCR Peaks ampl.	Peaks 100 m - center	EEI 100 m - center
1	1.069	Yes	1.069	–	–	0	1.125	Yes	3.933	1.090	Yes	2.504
	–	–		–	–		1.276	Yes		1.414	Yes	
	–	–		–	–		1.532	Yes		–	–	
2	1.004	No	0	1.088	Yes	1.088	1.020	Yes	1.020	–	–	0
	–	–		–	–		1.005	No		–	–	
3	1.004	Yes	1.004	1.005	Yes	1.005	1.002	Yes	2.136	1.085	Yes	2.205
	–	–		–	–		1.134	Yes		1.120	Yes	
4	–	–	0	–	–	0	1.054	Yes	2.068	1.192	Yes	2.243
	–	–		–	–		1.014	Yes		1.051	Yes	
5	–	–	0	–	–	0	–	–	0	–	–	0
6	–	–	0	–	–	0	–	–	0	1.015	Yes	1.015
7	1.017	Yes	1.017	1.007	Yes	1.007	1.320	Yes	3.639	1.660	Yes	1.660
	–	–		–	–		1.110	Yes		–	–	
	–	–		–	–		1.209	Yes		–	–	
8	1.004	No	0	–	–	0	1.001	Yes	1.001	1.098	Yes	1.098
	–	–		–	–		1.155	No		–	–	
9	1.009	Yes	1.009	1.023	Yes	1.023	1.042	Yes	3.244	1.053	No	0
	–	–		–	–		1.142	Yes		1.040	No	
	–	–		–	–		1.060	Yes		–	–	
10	1.029	Yes	1.029	–	–	0	1.014	Yes	1.014	–	–	0
11	1.025	Yes	1.025	1016	No	0	–	–	0	–	–	0
12	1.213	Yes	1.213	1180	No	0	1.400	Yes	2.472	1.110	Yes	1.110
	–	–		–	–		1.072	Yes		–	–	
13	1.333	No	0	–	–	0	1.162	Yes	1.162	1.036	Yes	1.036
14	1.006	Yes	1.006	–	–	0	1.017	Yes	1.017	1.016	Yes	1.016
	–	–		–	–		1.034	No		–	–	
15	1.027	Yes	1.027	–	–	0	–	–	0	1.045	No	0
16	1.099	Yes	3.644	1228	Yes	2.345	1.257	Yes	3.396	1.121	Yes	3.408
	1.240	Yes		1117	Yes		1.090	Yes		1.067	Yes	
	1.305	Yes		–	–		1.049	Yes		1.220	Yes	
	–	–		–	–		1.036	No		1.033	No	
17	1.048	Yes	2.054	1.137	Yes	1.137	1.214	Yes	2.218	1.018	Yes	1.018
	1.006	Yes		–	–		1.004	Yes		–	–	
18	1.006	Yes	1.006	1011	Yes	1.011	1.041	Yes	1.041	1.289	Yes	2.298
	–	–		–	–		1.008	No		1.009	Yes	
	–	–		–	–		–	–		1.291	No	
19	1.180	Yes	1.180	–	–	0	1.288	Yes	1.288	1.103	Yes	2.399
	–	–		–	–		1.245	No		1.296	Yes	

and the intersection centre. As for the roundabout (manoeuvre 3), instead, the speed is equal to 35 km/h 100 m before the intersection centre and goes down to approximately 28 km/h at the intersection centre. The approach speed decreases therefore by 21% approximately between 100 m before the intersection centre and the intersection centre.

Table 5 shows the speed variations ΔS_{100_0} and ΔS_{0_100} evaluated for each manoeuvre.

To answer the question of whether the speed variations during the crossing manoeuvres were significantly influenced by the type of intersection (roundabout or T-junctions), statistical tests were first performed.

First of all, the shape of the distribution of the variable ΔS100_0 was examined, also to understand if there were any outliers. For this purpose, a boxplot was made for both types of road intersections (Fig. 6).

From the analysis of the graph in Fig. 6 it can be seen that:

a) the heights of the two boxes are very different, making it clear that 50% of the ΔS100_0 values for the two types of intersections considered have different distributions: between −10% and + 20% (approximately) in the case of the T-junctions and between −30% and −10% (approximately) in the case of the roundabout;
b) the dispersion of values above the third quartile, which are not classified as outliers, is very different for the two types of intersection considered;
c) there are four outliers, which are therefore excluded from further processing.

The normality tests of Kolmogorov-Smirnov and Shapiro Wilk confirmed that the two distributions of the variable ΔS100_0 are statistically similar to the normal distribution in the case of both T-intersections and roundabouts ($p > .05$).

Since it was found that the two distributions of the ΔS100_0 variable were comparable to Gaussian distributions, parametric tests for analysis of variance were performed. Specifically, the Levene's Test for Equality of Variances and *t*-test for Equality of Means were performed. These tests allowed to conclude that the two distributions of ΔS100_0 related to T-junctions and roundabout are statistically significantly different ($p < .05$).

3.3. Analysis of association rule mined

Association rule analysis with Apriori algorithm was applied to further investigate drivers' behaviour while approaching different types of at grade intersections.

Fig. 7 shows the entire set of rules represented using the graph-based visualization provided by the R-extension package arulesViz. This view is particularly suitable for displaying very small rule sets of

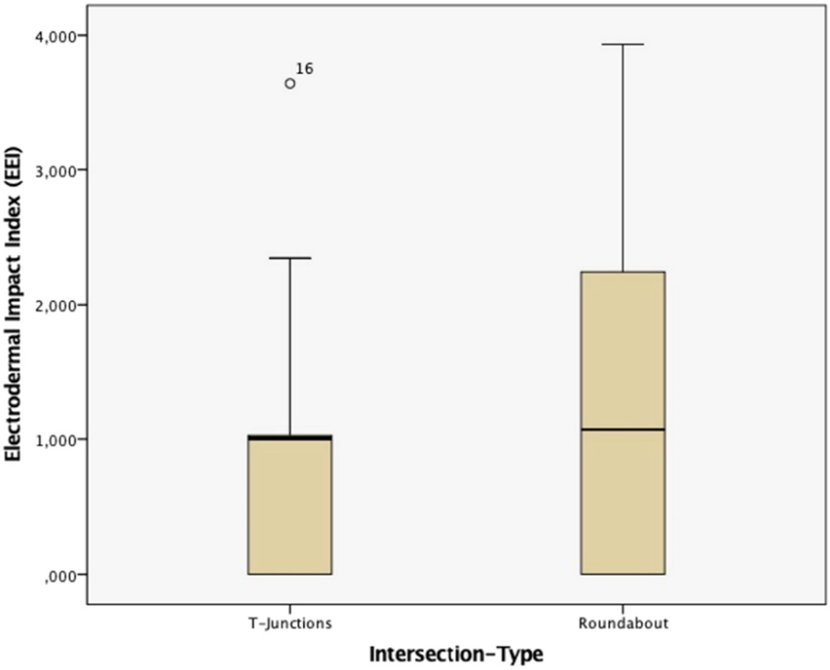


Fig. 4. EEI boxplots for T-Junctions and Roundabout.

rules [41]. In particular, Fig. 7 shows the output view with the graph containing the connexions between the total of 97 derived rules. In the bottom right corner, there is also the summary table of the rule set generated after the input database was processed by the R software. The layout used in the visualization moves items contained in many rules and rules that have many elements in common to the center of the plot. Items contained in very few rules are pushed to the periphery of the plot. Interestingly, rules with high support are also on the edge of the plot. This is due to the fact that rules with high lift levels typically appear at the minimum support/confidence boundary and low-support items are part of fewer rules and are therefore pushed to the edge of the graph.

The variable *Intersection Type* was chosen as the consequent result for the AR model to evaluate how the two types of intersection (*Intersection Type T-Junction* ITT and *Intersection Type Roundabout* ITR) affect speed and electrodermal activity of the 19 drivers.

The association algorithm identified 35 rules with Support greater than 5%, Confidence greater than 50%, and Lift greater than 1 (16 rules for *Intersection Type T-Junction* and 19 rules for *Intersection Type Roundabout*).

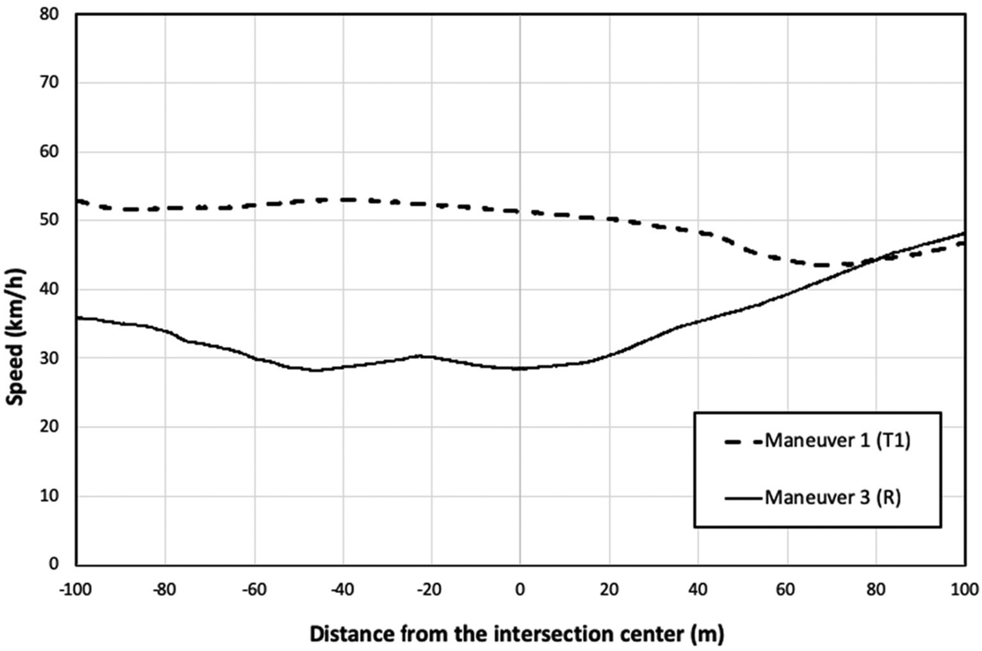


Fig. 5. Speed profiles for participant 9 during manoeuvre 1 (T-junction T1) and manoeuvre 3 (Roundabout R).

Table 5
Distribution of speed differences for all participants at each crossing manoeuvre at the two T-junctions (T1 and T2) and at each crossing manoeuvre at the roundabout (R).

	T-Junctions				Roundabout			
	Manoeuvre 1 (T1)		Manoeuvre 2 (T2)		Manoeuvre 3 (R)		Manoeuvre 4 (R)	
	ΔS_{100_0} (%)	ΔS_{0_100} (%)	ΔS_{100_0} (%)	ΔS_{0_100} (%)	ΔS_{100_0} (%)	ΔS_{0_100} (%)	ΔS_{100_0} (%)	ΔS_{0_100} (%)
Participant n.1	+15.9	+14.4	+14.6	−13.9	−26.2	+80.4	−38.3	+37.4
Participant n.2	−15.7	−14.6	+42.4	−4.3	−22.2	+57.9	−30.8	+25.9
Participant n.3	−6.6	−16.7	−14.5	+13.8	−22.5	+58.4	−34.3	+37.9
Participant n.4	−13.5	−14.2	+20.2	−15.8	−15.8	+44.4	−12.2	−2.4
Participant n.5	−4.0	−25.1	+32.3	−7.7	−4.1	+48.8	−21.3	+0.2
Participant n.6	−5.3	−10.7	+28.3	−12.6	−25.6	+48.6	−26.2	+13.5
Participant n.7	−20.6	−3.4	+35.3	−16.6	−8.5	+32.4	−23.4	−5.1
Participant n.8	−7.9	−15.3	+29.1	−6.7	+11.8	+50.6	−17.9	−11.6
Participant n.9	−2.9	−8.8	−33.0	+79.8	−20.6	+68.8	−27.0	+7.9
Participant n.10	+6.0	−19.4	+12.6	−18.4	−15.6	+77.5	−22.4	+13.6
Participant n.11	−14.0	−4.8	−2.7	32.2	+4.0	+48.8	−28.1	−27.8
Participant n.12	−10.7	−18.7	+30.7	−14.8	−11.3	+44.3	−32.2	+24.5
Participant n.13	−13.4	+3.1	+53.3	−6.1	−3.6	+46.7	−17.9	+9.0
Participant n.14	+2.8	−10.8	+5.2	−19.5	−3.1	+23.5	−23.8	−9.0
Participant n.15	−4.3	−11.5	+13.1	+3.8	−11.8	+41.0	−18.1	−2.3
Participant n.16	+0.9	−9.4	+34.0	+2.6	−13.1	+48.2	−51.9	+57.3
Participant n.17	−31.9	+23.3	+26.4	−10.0	−17.0	+38.6	−16.8	+2.1
Participant n.18	−10.2	−17.4	+3.6	+8.1	+17.5	+42.6	−49.2	+33.5
Participant n.19	−14.1	−0.5	+5.6	−12.6	−10.0	+70.8	−38.0	+22.2

Fig. 8 shows two zooms of the main diagram (Fig. 7) in order to analyze how the items "T-junctions" and "roundabout" relate in the rule set with other items. Thanks to the interactivity guaranteed by the graphical interface, in addition to zooming, the balloons that are too far out have been moved and brought closer to ensure the display of all the rules that have "T-junctions" and "roundabout" as consequent items.

Fig. 9 shows the grouped matrix-based visualization which allows refining the understanding of the information derivable from the fig. 10 by clustering the antecedents of the rules and sorting the rules by "interestingness" in order to process a larger number of rules. The grouped rules are represented as an aggregate in a matrix visualized as a balloon plot. This plot visualizes the set of 97 rules mined earlier. The columns represent groups of antecedents (left-hand-side or LHS) and the rows show the consequent items (right-hand-side or RHS). The plot is organized such that the most interesting rules according to lift (the default measure of interestingness) are shown in the top-left corner. The balloon size represents support and the colour indicates lift. We also see below all RHS items, that the plot suppresses 1 consequent item representing rules with low lift values to create a less convoluted plot. This visualization allows you to clearly identify the groups of interest with the antecedent items (LHS groups) that set the rules for the two consequent items under discussion, i.e. "T-junctions" and "roundabout".

Table 8 shows the Association Rules having ITT (*Intersection Type T-Junction*) as a consequent result. 2-item, 3-item, and 4-item rules are set out with their Support, Confidence, and Lift values. The rules are ordered on the basis of the Confidence.

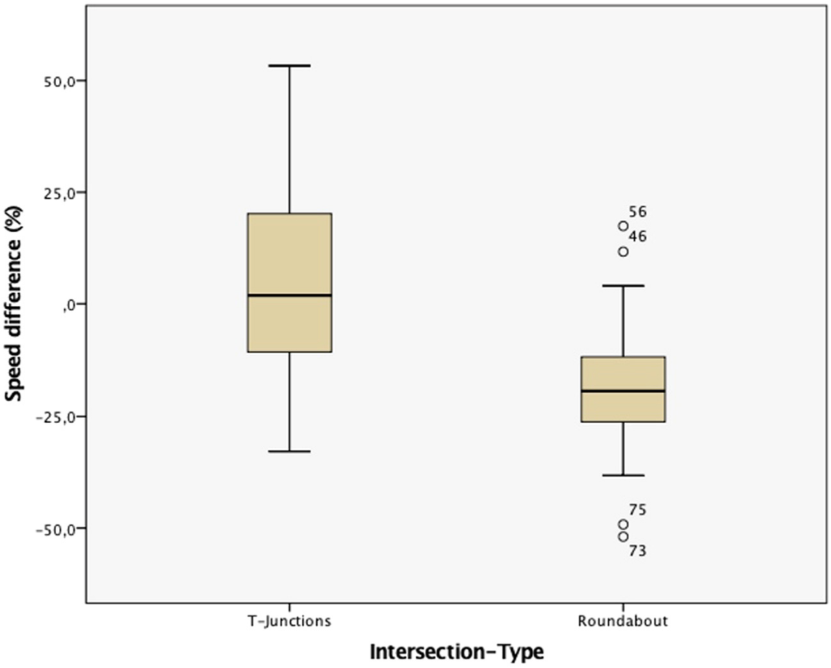
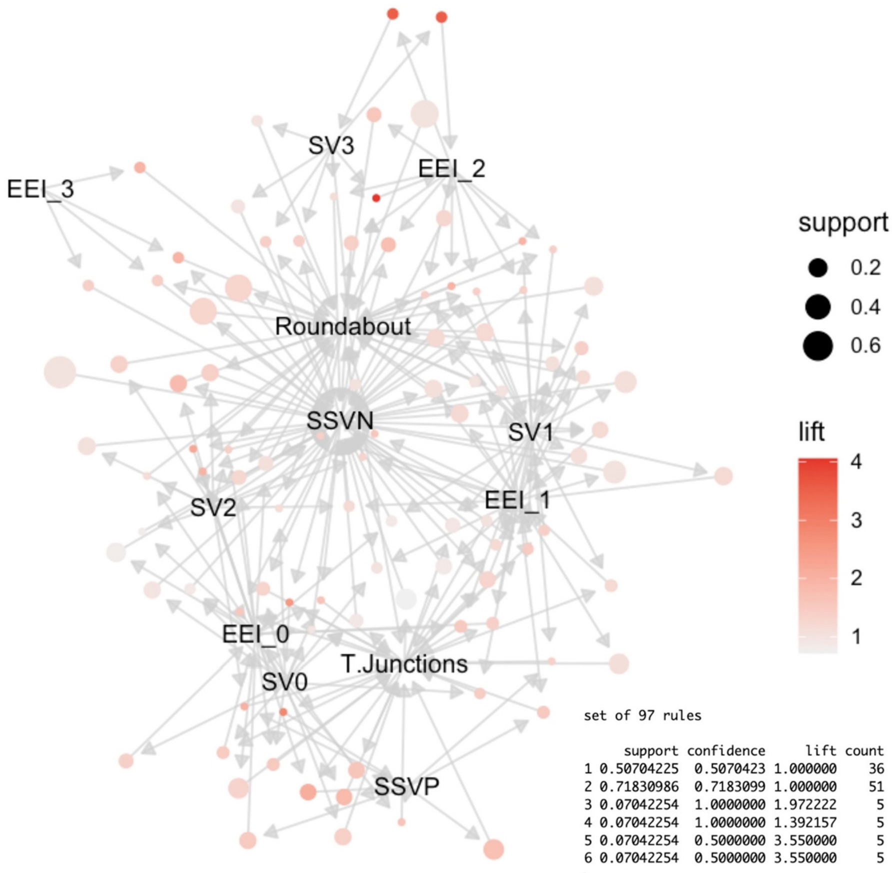


Fig. 6. Speed difference (ΔS100_0) boxplots for the two types of intersections (T-Junctions and Roundabout).



```
set of 97 rules

     support confidence     lift count
1 0.50704225  0.5070423 1.000000    36
2 0.71830986  0.7183099 1.000000    51
3 0.07042254  1.0000000 1.972222     5
4 0.07042254  1.0000000 1.392157     5
5 0.07042254  0.5000000 3.550000     5
6 0.07042254  0.5000000 3.550000     5
```

Fig. 7. Graph-based visualization with items and rules as vertices: plot shows the initial view of the complete graph. Legend: *EEI (Electrodermal Impact Index)*: EEI_0 = No Peak; EEI_1 = Between 1 and 2; EEI_2 = Between 2 and 3; EEI_3 = Between 3 and 4. *SV (Speed Variation)*: SV0 = Up to 10%; SV1 = Between 10% and 20%; SV2 = Between 20% and 30%; SV3 = Between 30% and 40%; SV4 = Between 40% and 50%; SV5 = Over 50%. *SSV (Sign of the Speed Variation)*: SSVP = Positive sign (speed increase); SSVN = Negative sign (speed reduction).

Table 9 shows the Association Rules having ITR (Intersection Type Roundabout) as a consequent result. 2-item, 3-item, and 4-item rules are set out with their Support, Confidence, and Lift values. The rules are ordered on the basis of the Confidence.

4. Discussion

It is well acknowledged that roundabouts strategically modify the built environment to affect traffic speed and patterns. The comparison between accident rates of roundabouts and of standard intersections confirms the reduction of speeds, of accidents and of the severity of the accidents themselves in roundabouts [22,42,43]. Roundabouts are also known to reduce speed as they influence driving behaviour by inducing a certain level of stress. The analysis of speed and electrodermal activity allowed to estimate the human response to the stress coming from the two different types of intersection. The results of this study seem to confirm the existence of a correlation between driving behaviour and physiological parameters. Association rule analysis with

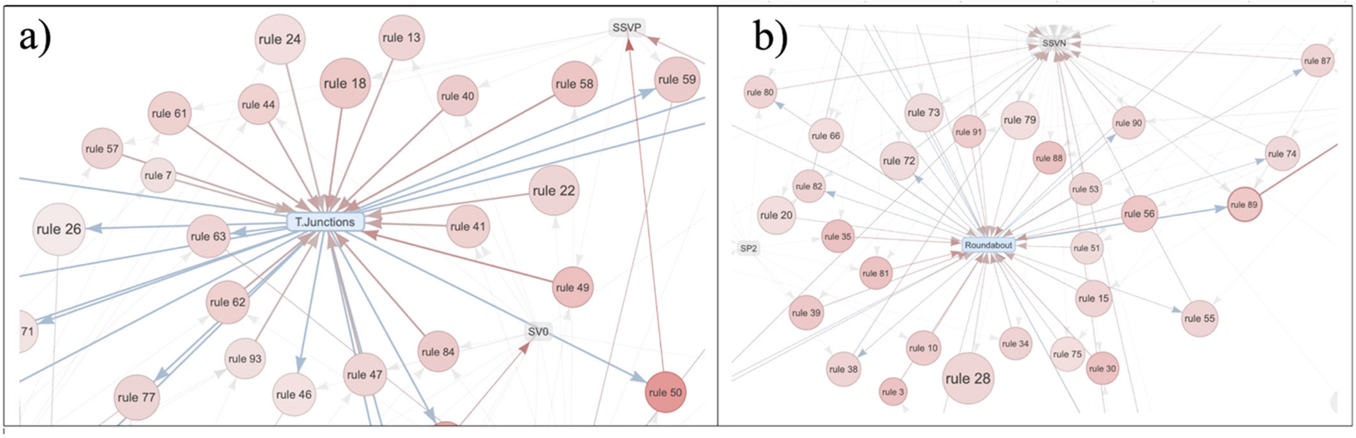


Fig. 8. Graph-based visualization: plot a) uses zooming in to show the rules that have "T-junctions" as consequent item; plot b) uses zooming in to show the rules that have "Roundabout" as consequent item.

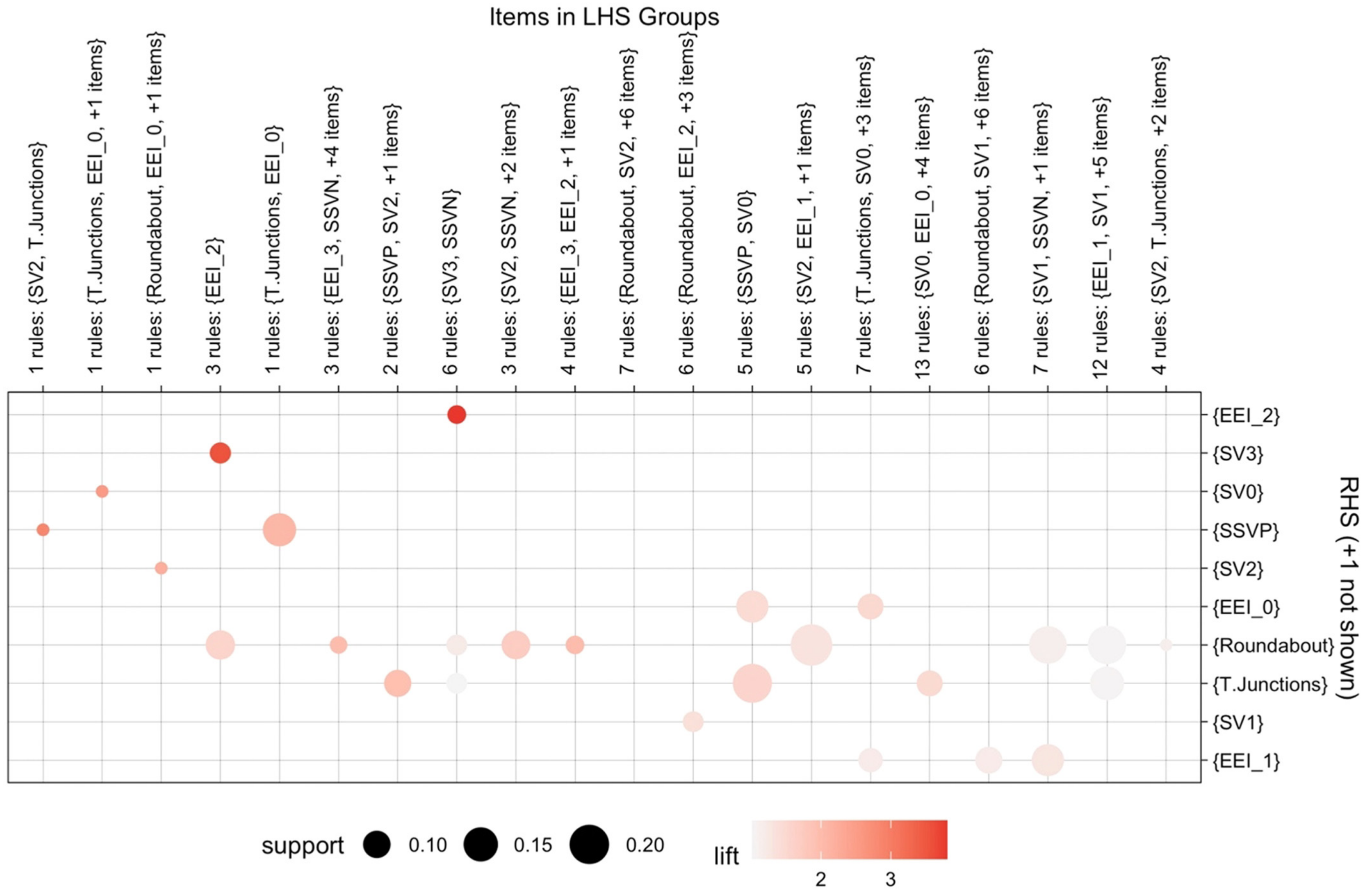


Fig. 9. Grouped matrix-based visualization with groups of antecedents in the columns and consequent items in the rows. Legend: *EEI (Electrodermal Impact Index)*: EEI_0 = No Peak; EEI_1 = Between 1 and 2; EEI_2 = Between 2 and 3; EEI_3 = Between 3 and 4. *SV (Speed Variation)*: SV0 = Up to 10%; SV1 = Between 10% and 20%; SV2 = Between 20% and 30%; SV3 = Between 30% and 40%; SV4 = Between 40% and 50%; SV5 = Over 50%. *SSV (Sign of the Speed Variation)*: SSVP = Positive sign (speed increase); SSVN = Negative sign (speed reduction).

Apriori algorithm was applied in order to obtain the rules associating the type of intersection, the number and the amplitude of SCR peaks (assessed by the Electrodermal Impact Index in aggregate form) and the variation of speed.

Particularly, the analysis of Table 2 shows that ten out of nineteen participants exhibited multiple SCR peaks during the roundabout crossing manoeuvres, while in the case of the T-junctions manoeuvres only two participants showed more than one spike. Ten out of nineteen participants show a higher amplitude of the SCR peaks during the manoeuvres on the roundabout.

Table 8
Association rules for T-Junctions.

ID Rule	Consequent	Antecedent	Support (%)	Confidence (%)	Lift
#49	ITT	SV2 and SSVP	5.600	100.000	2.029
#58	ITT	SSVP and EEI_0	14.100	90.900	1.844
#18	ITT	SSVP	23.900	85.000	1.724
#40	ITT	SV0 and SSVP	5.600	80.000	1.623
#84	ITT	SV0 and SSVN and EEI_0	5.600	80.000	1.623
#41	ITT	SV0 and EEI_0	8.500	75.000	1.521
#62	ITT	SV1 and EEI_0	8.500	75.000	1.521
#61	ITT	SSVP and EEI_1	8.500	75.000	1.521
#44	ITT	SV0 and EEI_1	7.000	71.400	1.449
#13	ITT	SV0	15.500	68.800	1.395
#57	ITT	SV1 and SSVP	5.600	66.700	1.352
#22	ITT	EEI_0	23.900	65.400	1.326
#47	ITT	SV0 and SSVN	9.900	63.600	1.291
#24	ITT	EEI_1	22.500	53.300	1.082
#7	ITT	SV3	7.000	50.000	1.014
#93	ITT	SV1 and SSVN and EEI_1	7.000	50.000	1.014

Table 9
Association rules for Roundabout.

ID Rule	Consequent	Antecedent	Support (%)	Confidence (%)	Lift
#30	ITR	SSVN and EEI_3	7.000	100.000	1.972
#3	ITR	EEI_3	7.000	100.000	1.972
#35	ITR	SV1 and EEI_3	5.600	100.000	1.972
#81	ITR	SV1 and SSVN and EEI_2	5.600	100.000	1.972
#88	ITR	SV2 and SSVN and EEI_0	5.600	100.000	1.972
#56	ITR	SV2 and SSVN	15.500	91.700	1.808
#39	ITR	SSVN and EEI_2	11.300	88.900	1.753
#10	ITR	EEI_2	11.300	80.000	1.578
#91	ITR	SV2 and SSVN and EEI_1	5.600	80.000	1.578
#34	ITR	SV3 and SSVN	7.000	71.400	1.409
#15	ITR	SV2	15.500	68.800	1.356
#53	ITR	SV2 and EEI_1	5.600	66.700	1.315
#28	ITR	SSVN	46.500	64.700	1.276
#73	ITR	SV1 and SSVN	16.900	60.000	1.183
#51	ITR	SV2 and EEI_0	5.600	57.100	1.127
#79	ITR	SSVN and EEI_1	16.900	54.500	1.076
#20	ITR	SV1	19.700	53.800	1.062
#66	ITR	SV1 and EEI_1	9.900	53.800	1.062
#75	ITR	SSVN and EEI_0	11.300	53.300	1.052

Four participants had the same number of peaks during the manoeuvres on the roundabout and during the manoeuvres on the T-junctions. One participant (participant 5) did not show any peak at all. Only one participant had more SCR peaks during the manoeuvres on the T-junctions rather than during the manoeuvres on the roundabout (participant 11). The number of SCR peaks as well as the amplitude of the peaks are overall higher for the manoeuvres on the roundabout (number of peaks: 58 for roundabout, 29 for T-junctions; medium amplitude of peaks: 1132 for the manoeuvres on the roundabout, 1083 for the manoeuvres on the T-junctions. Over 80% of the SCR peaks occurred in approaching the intersections, i.e. between 100 m before the intersection centre and the intersection centre. 24 peaks out of 29 occurred in approaching the T-junctions and 47 peaks out of 58 occurred approaching the roundabout. These results can be interpreted for increased anxiousness (higher emotional response) with respect to baseline [44], with more impact in the roundabout.

The analysis of Table 5 shows that the drivers' behaviour in terms of speed variation when approaching the intersections (ΔS_{100_0}) is really different for T-junctions and roundabouts. 4 drivers out of 19 increase their speed approaching the T-Junction T1. 16 drivers significantly increase their speed approaching the T-Junction T2. Drivers' increases of speed when approaching intersection T2 could be due to the fact that they are exiting a roundabout and they are entering onto the straight road on MUEAVI. Anyway, the presence of the T-junction T2 does not induce drivers to reduce their speed. As for the roundabout, only 3 drivers increase their speed approaching the roundabout during manoeuvre 3 and all drivers significantly reduce their speed approaching the roundabout during manoeuvre 4. These results confirm the well-known vocation of the roundabouts as traffic calming measures. By contrast, the T-junctions analysed shows modest reductions in the approach speed and, at the same time, dangerous increases in the approach speed. As for the speed variations ΔS_{0_100}, it can be seen that all 19 drivers significantly increase their speed leaving the roundabout during manoeuvre 3 and almost all drivers increase their speed leaving the roundabout during manoeuvre 4 (only 3 drivers decrease their speed). For the two T-Junctions several drivers decrease their speed leaving the intersection, with speed variations higher than 15%. This is probably due to the road geometry which, immediately after both T-junctions, has curvilinear sections that induce users to slow down.

The Association Rules having ITT (*Intersection Type T-Junction*) as a consequent result (Table 8) shows that the strongest association is expressed by rule #49 ($L = 2.029$, $C = 100\%$ and $S = 5.6\%$), which associates *Intersection Type T-Junction* (ITT) with the speed increase between 20% and 30%.

The strongest associations in which at least one item associated with EEI appears are all those containing EEI_0 (absence of SCR peaks and consequently EEI = 0). These are rules #58, #84, #41 and #62, thus showing that T-junctions have a negligible effect on driving stress.

The low propensity of T-junctions to induce significant changes in driver electrodermal activity is confirmed primarily by rule #58, which defines a very strong association ($L = 1.844$; $C = 90.9\%$; $S = 14.1\%$) between *Intersection Type T-junction* (ITT) and “EEI = 0” and “Speed increase.”

Rule #18 is a very strong rule ($L = 1.724$ and $C = 85\%$) and also features very high Support (23.9%). Considering that this is a 2-Items rule involving the “Positive sign” of speed variation, it is confirmed that drivers do not significantly reduce speed while approaching T-Junctions.

Rules #40 and #84 are of equal strength ($L = 1.623$; $C = 80\%$; $S = 5.6\%$) and show that *T-Junctions*, when they cause small changes in speed, do so with similar frequency both in the direction of a decrease and in the sense of an increase in speed. In particular, rule # 84 shows that small decreases in speed are often not associated with any SCR peak (EEI = 0).

The association rules that have ITR (*Intersection Type Roundabout*) as a result (Table 9) show that the strongest associations are expressed by rules #30 and #3 ($L = 1.972$, $C = 100\%$ and $S = 7\%$), which associate Intersection Type Roundabout (ITR) with speed reduction and with EEI_3 (EEI between 3 and 4), i.e. the maximum state in terms of electrodermal activity.

Of particular interest are rules #35 and #81 ($L = 1.972$, $C = 100\%$ and $S = 5.6\%$), #39 ($L = 1.753$, $C = 88.9\%$ and $S = 11.3\%$) and #10 ($L = 1.578$, $C = 80\%$ and $S = 11.3\%$). These are very robust rules showing that the driving condition associated with a speed reduction between 10% and 20% is strongly correlated with high electrodermal activity (EEI between 2 and 3). The driving activity associated with significant stress when approaching the roundabout (EEI_2) is therefore reflected in moderate speed reductions that are still considered appropriate by drivers to enter the roundabout safely. On the other hand, rule #88, which has the same strength as rules #35 and #81, and rule #91 ($L = 1.578$, $C = 80\%$ and $S = 5.6\%$) show that the most significant reductions in speed, i.e. reductions between 20% and 30%, are associated with the condition of absence of peaks SCR (strong association) and with the condition of EEI between 1 and 2 (medium association).This is probably representative of the fact that a more cautious driving behaviour when approaching the roundabout, i.e., characterized by high speed reductions already from a certain distance from the roundabout, prepares drivers more naturally to encounter the roundabout without any particular stress when executing the entry manoeuvre.

Rule #56 ($L = 1.808$, $C = 91.7\%$ and $S = 15.5\%$) and rule #34 ($L = 1.409$, $C = 71.4\%$ and $S = 7\%$) show clear correlations between driver behaviour when entering the roundabout with both speed reductions between 20% and 30% (strong association) and speed reduction between 30% and 40% (medium association).

Ultimately, the rules identified for roundabouts confirm the role of roundabouts in influencing the approach speeds of drivers to the extent that they lead to speed reductions between 10% and 40%. There is also a close correlation between the maximum electrodermal activity (EDA) detected and the reduction in approach speed up to 20%.

A limitation to the presented study is the sample size. The sample size (19 participants) is relatively small. Moreover, the frame of drivers aged between 28 and 50 years with more of 3 years of licensed driving experience, could not guarantee the generalizability of the results. The sample of intersections is limited too. While there are no reasons to believe that the observed intersections are atypical in any way, the generalizability of the results cannot be guaranteed. The aim was to select intersections without atypical design features. However, it is possible that minor design features have influenced the results. Human factors, which are broadly recognized as the main cause in determining road accidents, can be further examined by means of other indicators of the drivers' stress level. Physiological signals are indeed a useful metric for providing feedback about a driver's state. In this paper the authors analysed only drivers' electrodermal activity to evaluate their physiological and behavioural responses to different intersections. The results of this study should be regarded as indicative of central issues worth studying further in relation to physiological parameters and behavioural responses to different at grade intersections. Further studies may focus on overcoming the above-mentioned limitations. The sample size of participants could be increased and more intersections could be observed in order to make the results more generalizable. Moreover, further studies may deepen the correlations between different at grade intersections and other physiological parameters, such as blood volume pulse, heart rate and heart rate variability, which were measured during the same experiment on which this study is based.

Another limitation of this study is that the priority rule for the T-junctions and for the roundabout are different. Participants had indeed the right of way while crossing the T-junctions. However, the authors deliberately chose to compare these two different situations, as the final aim of the paper was to compare how drivers perform the same manoeuvre (i.e. crossing manoeuvre) in two different types of intersection (i.e. T-junctions and roundabouts). It is true that the priority rules are different, but this is implicitly part of the type of intersection. The point is that a driver has always to yield when crossing a roundabout and has often the right of way when crossing a T-junction because this is what the type of intersection provide. In other words, the final aim of the study was to evaluate how the type of intersection affects driver behaviour, and the priority rule can be considered “part of the intersection”.

Moreover, it has to be pointed out that in this study the authors did not use a Motion Artifact removal procedure. Both analysed parameters, i.e. EDA and speed variations, are clearly influenced by the different approach of the drivers, which includes the physical movements while driving, such as turning the wheel or moving the feet to operate the brake and accelerator pedals. When entering roundabout, you have to slow down and to turn the wheel. These two actions are not expected in T-junction when you are going straight ahead. These differences of body movements may lead to differences in EDA responses. In this study, therefore, the authors deliberately chose not to use a Motion Artifact removal procedure because the final aim was to understand the overall influence (i.e., including all factors affecting actions taken while driving) that each of the two types of road intersections considered had on the driving behaviour.

5. Conclusions

The aim of this study was to increase knowledge about drivers' physiological responses when approaching T-junctions and roundabouts. The developed analysis allowed to evaluate if and how the two types of at grade intersection affects drivers' responses in terms of physiological signals and speed variations. Speed and electrodermal activity were collected continuously during a driving study which took place on a test environment including 3 at grade intersections (1 roundabout and 2 T-junctions).

The main results of this study are the following:

1) the rules obtained for the manoeuvres on T-junctions define a very strong association with the absence of SCR peaks (EEI = 0) and the speed increase. Therefore, these rules highlight how T-junctions induce negligible variations in electrodermal activity and are often associated with a significant speed increase (which was estimated to be between 20% and 30%). It is therefore evident that speed reduction is not at all a prerogative of T-junctions.
2) the rules obtained for the manoeuvres on the roundabout define a very strong association with the condition of maximum electrodermal activity (EEI between 3 and 4; i.e. lot of peaks with high amplitude) and speed reduction (up to a maximum decrease of 20%). It is therefore evident that the roundabout strongly affects drivers' behaviour, inducing significant electrodermal activity and speed reductions (mainly between 20% and 40%).

The analysis conducted in the present study using the Association Rule with Apriori algorithm showed that the stress level induced by roundabouts is significantly higher than that one induced by T-junctions. The quantification of the associations between speed variations and electrodermal activity enabled to better understand how roundabouts and T-junctions affect in a different way driving behaviour and to confirm that, compared to T-junctions, roundabouts induce greater attention in road users and in particular during the crossing manoeuvre.

The results of this study also show how the search for correlations between physiological parameters and driving behaviour can be extended to other aspects of road safety. Behavioural responses of drivers in terms of speed reduction due to traffic calming measures or other elements in urban environments (e.g., reduced radius curves, entrance and exit sections of highway ramps), can be assessed and better understood through measurements of electrodermal activity and other physiological parameters. If established correlations between physiological parameters and behavioural responses are found, design decisions can be optimized, e.g., by monitoring physiological parameters of participants driving on different scenarios simulated on driving simulators. Thus, the verification of the safety level of a road infrastructure might be done by applying a double channel of investigation, i.e. the analysis of the driving behaviour (variation of speed, execution of trajectories, choice of safety distances, etc.) and the analysis of the physiological response resulting from the perception of the infrastructure scenario.

Declaration of Competing Interest

None.

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