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Does road context matter? Linking DBQ dimensions to real-world driving behaviour in urban road segments and roundabouts

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Abstract
This study investigates whether self-reported aberrant driving behaviours, measured through the Driver Behaviour Questionnaire (DBQ), are reflected in objectively observed speed behaviour under real urban driving conditions, and whether these relationships vary across road contexts. An instrumented-vehicle experiment was conducted with 45 Portuguese drivers on a controlled urban circuit in Coimbra, including repeated observations across road segments and roundabouts. Drivers were characterised according to three DBQ dimensions: infractions and aggressive driving (IAD), non-intentional errors (NIE), and lapses. Mean speed, speed variability, and acceleration/deceleration profiles were analysed using random-parameter linear regression models to account for repeated observations and inter-driver heterogeneity. Results show a consistent positive association between IAD and higher mean speed, as well as stronger acceleration and deceleration patterns across both road segments and roundabouts. In contrast, NIE is associated with lower speeds and lower acceleration/deceleration levels. Lapses show limited and inconsistent effects. Importantly, the magnitude and stability of these associations vary across road elements, with more complex environments such as roundabouts amplifying behavioural differences in speed variability and manoeuvre execution. These findings provide empirical support for the ecological validity of DBQ-based behavioural profiling while demonstrating that its expression is context-dependent. Risky driving behaviour should therefore be understood as the result of an interaction between driver disposition and infrastructure characteristics, rather than as a fixed individual characteristic.

Keywords Driver behaviour questionnaire, Instrumented vehicle, Speed variability, Urban driving behaviour, Regression analysis, Random parameters

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1 Introduction

Road safety research has increasingly shifted from describing crashes after they occur to understanding the behavioural mechanisms that precede them. This shift is especially relevant in urban environments, where the same driver is repeatedly exposed to rapidly changing demands created by tangents, roundabouts, pedestrian activity, traffic control devices, and interactions with other road users. Within this perspective, the present study is positioned in an evidence-based stream of transport safety research that seeks to explain how stable driver-related tendencies interact with road context to produce observable driving behaviour.

A long-standing framework for studying aberrant driving is the Driver Behaviour Questionnaire (DBQ), originally proposed by Reason et al., [1], who distinguished between violations, errors, and lapses. Since then, the DBQ has become one of the most widely used instruments in behavioural road safety research because it offers a theoretically grounded way to capture habitual unsafe tendencies that are not directly observable in large populations. Subsequent work has shown that the DBQ structure is reasonably stable across samples and time, although the exact factorial solution may vary according to country, sample composition, and questionnaire version [2, 3]. Importantly, a meta-analysis by de Winter and Dodou [4] demonstrated that DBQ scores significantly predict self-reported crash involvement, reinforcing the instrument's relevance for safety research.

However, the growing use of DBQ-based profiling may also point to a potential limitation: many DBQ studies tend to remain centred on self-reports, crashes, or broad behavioural outcomes aggregated over long periods [5]. As a result, they tell us relatively little about how self-reported behavioural tendencies are expressed in specific driving contexts and road elements. This limitation matters because safety-critical behaviour is not emitted in a vacuum. Drivers speed, decelerate, stabilize, or vary their control in response to road geometry, traffic complexity, and visual demands. Therefore, a central challenge is not only to identify whether a driver reports more violations, errors, or lapses, but also to determine whether these tendencies are manifested consistently when the same driver faces different roadway situations. This is in line with Van der Horst [6], who demonstrated that speed choice emerges from the interplay between cognitive classification processes, attitudinal factors, and road design characteristics.

This gap is particularly relevant for speed behaviour. Speed remains one of the most important proximal determinants of crash risk and injury severity, and speed choice reflects an interplay between personal propensity and situational affordances. Earlier work by Haglund and Åberg [7] showed that drivers display a degree of stability in speed choice under free-flow conditions, especially in homogeneous road environments. At the same time, more recent research suggests that the relationship between self-reported tendencies and actual speed behaviour is more nuanced. Helman and Reed [8], using behavioural data from an instrumented vehicle and a high-fidelity simulator, found that DBQ violations were associated with objectively measured speed, whereas errors and lapses were less consistently related to observed speed. More recently, Thomas et al., [9], using large-scale naturalistic driving data, reported that DBQ errors and violations were significantly associated with speed indicators, but their explanatory power was modest compared with situational traffic and environmental factors. Taken together, these studies suggest that DBQ dimensions are behaviourally meaningful, but that their observable expression depends strongly on context.

Road geometry is one of the most relevant contextual mechanisms shaping that expression. A systematic review by Bobermin et al., [10] concluded that road design characteristics such as curve radius, lane width, shoulder width, and alignment affect driver performance indicators, especially speed and lateral control, but also highlighted major heterogeneity in methods and measures across studies. More recent work has reinforced the point that even in urban settings, geometry does not simply constrain movement mechanically; it also influences perceived complexity, perceived safety, and chosen speed. For example, van Eggermond et al., [11] showed that continuous urban road design measures can influence preferred, safe, and actual driving speed, although the magnitude of those effects may be modest and mediated by human factors. Such findings align with the principle of Self-Explaining Roads (SER), according to which the design and layout of the road environment should automatically elicit behaviour that is appropriate for that type of road, including appropriate speed choice, without the need for enforcement or explicit instruction [12, 13].

Roundabouts are especially relevant in this regard because they impose dynamic speed adjustment, gap assessment, steering control, and visual sampling within a relatively short spatial interval. Prior empirical work has shown that roundabout crossing behaviour varies according to geometry and movement type. Silva et al., [14] reported distinct speed and trajectory patterns across consecutive multilane roundabouts, suggesting that the same driver may adapt differently depending on the specific roundabout configuration. At a broader system level, Fernandes et al., [15] showed that roundabout type and sub-segment are associated with meaningful differences in speed, acceleration, jerk, and emissions, further illustrating how localized geometric and operational features shape driver behaviour. Trullos et al., [16] proposed a probabilistic framework for detecting near-crashes in roundabouts, highlighting the safety relevance of fine-grained behavioural variation in these facilities.

At the same time, evidence from European and other transport behaviour studies suggests that speed-related behaviour is also influenced by attitudes and social norms. Yannis et al., [17] showed that drivers' self-reported speeding attitudes differ by road type and are linked to beliefs about other drivers' behaviour, prior sanctions, and demographic factors. This is an important insight because it suggests that behavioural tendencies are partly general and partly context-specific: some drivers may carry a stronger disposition toward unsafe behaviour, but whether and how that disposition emerges can still vary by road environment.

Another reason this issue deserves attention is methodological. Simulator studies are indispensable for isolating design effects, but questions of transferability to real traffic remain relevant. Gemou et al., [18] compared simulator and on-road performance and found meaningful transferability for speed and lateral deviation measures across road contexts, supporting the value of controlled experimentation while also underscoring the need for real-world validation. Naturalistic studies, on the other hand, capture authentic behaviour but often emphasize broad trip-level exposure rather than repeated, element-specific comparisons within the same controlled route. Brazilian naturalistic evidence has illustrated how rich and heterogeneous driver adaptation can be: Bastos et al., [19] documented substantial mobile phone use during real driving, while Amancio et al., [20] showed that even when exposed to the same enforcement device, drivers exhibit distinct temporary and compensatory speed responses. These findings reinforce the idea that observable behaviour is shaped by both stable driver characteristics and situational triggers.

Despite this progress, an important research gap remains unresolved. There is still limited evidence on whether behavioural differences associated with DBQ dimensions remain consistent when the same drivers repeatedly traverse different urban road elements under comparable operating conditions. In particular, few studies have examined whether mean free-flow speed and speed variability differ systematically across road segments and roundabouts as a function of driver behavioural profile. This is not a minor question. If DBQ-related differences are stable across elements, then behavioural profiling may support parsimonious calibration of safety analyses, microsimulation, and driver-assistance logic. If, instead, the effect of behavioural profile changes materially across elements, then context-dependent models become necessary. This interpretation is consistent with human information-processing frameworks of driving [6], which view driving behaviour as the outcome of a continuous interaction between individual dispositions, intentions, and roadway characteristics. Consequently, behavioural risk should be understood as an interaction between person and infrastructure rather than as a fixed driver trait.

The present study addresses this gap using repeated observations from an instrumented-vehicle experiment conducted on an urban circuit in Coimbra, Portugal. Drivers were pre-characterized using DBQ dimensions and then observed across multiple laps, including both road segments and roundabouts. Rather than treating behaviour as a single trip-level average, the study examines whether DBQ-related behavioural differences are maintained across distinct road elements when analysing mean speed and speed standard deviation under free-flow conditions. By doing so, the paper contributes to transport safety research in three ways: first, by linking self-reported behavioural tendencies to objectively measured driving performance; second, by testing those relationships in a repeated within-driver design; and third, by focusing on element-specific urban contexts that are highly relevant for speed management and behavioural safety interventions.

Accordingly, the objective of this study is to investigate whether the behavioural differences associated with DBQ dimensions remain consistent across different urban road elements, with particular emphasis on mean speed and speed variability in road segments and roundabouts and on decelerations when approaching roundabouts and accelerations when leaving them. The underlying premise is that safer behaviour cannot be adequately understood by considering either driver disposition or road context in isolation; instead, it emerges from their interaction following the safe system approach, contributing to the knowledge of human factors, particularly how road design can be further adjusted to human capabilities [21].

2 Methods

2.1 Procedure and sample characterization

An instrumented vehicle was used to obtain behavioural data from 45 Portuguese drivers [25 women; mean age 43.33 ± 11.17; mean years of driving license 22.60 ± 9.70; mean years of regular driving 21.38 ± 9.23; 19 drivers reported at least one at-fault crash].

All drivers were selected from a larger sample who had completed a previous questionnaire covering personality, self-reported driving behaviour, and socio-demographic characteristics [22]. Participants were required to have a minimum of 10 years of driving experience and to be aged 65 years or younger, to reduce the influence of inexperience and potential confounding effects associated with ageing [23, 24]. Also, all individuals were regular drivers, who lived or worked in Coimbra city and were familiar with the specific urban environment where the experiments took place. Drivers also answered a crash history reporting the number of at-fault crashes. Only crashes that resulted in material damage and/or injuries to any of those involved were considered. Prior to participation, individuals were informed about the research objectives and eligibility criteria, and all signed an informed consent declaration.

Driver behaviour was assessed using the Portuguese translation of the short version of the Manchester Driver Behaviour Questionnaire [1, 25, 26]. This version comprises 24 items rated on a six-point Likert scale ranging from 0 to 5, with higher scores reflecting more frequent engagement in risky driving behaviours. Following the psychometric analysis of the instrument, a final three-factor structure was established, which excluded two items (1 and 24) and differed slightly from the original factorial model. The resulting factors were Infractions and Aggressive Driving (IAD; Cronbach's alpha = 0.77), Non-Intentional Errors (NIE; Cronbach's alpha = 0.73), and Lapses (Cronbach's alpha = 0.71) [27]. Overall, the scale demonstrated good construct validity and very good internal consistency, with a Cronbach's alpha of 0.84. Descriptives of DBQ and its dimensions results can be seen in Table 1. The DBQ's three factors are:

Factor 1 – Infractions and aggressive driving (IAD)– deliberate deviations from practices believed necessary to maintain safe driving. 7 items.
Factor 2 – Non-intentional errors (NIE) – to fail planned actions, which may result in dangerous outcomes. 9 items.
Factor 3 – Lapses – failures related to distractibility, which can cause embarrassment but are unlikely to have an impact on driving safety. 6 items.

Participants were instructed to drive as they normally would along a predefined 3.7 km urban circuit in the city of Coimbra, Portugal. The circuit included six roundabouts, six road segments, and 13 crosswalks (five of them signalized).

The trials were conducted over a two-month period, on working days, during daytime hours, avoiding peak traffic times, and under good weather conditions (i.e., no rain). Each driver completed 10 consecutive laps of the circuit, the first one accompanied by the researcher and the other nine alone, totalling approximately one hour of continuous driving. A repetitive circuit design was adopted for this driving experiment to reduce drivers' discomfort and unfamiliarity with the vehicle, as well as to minimise the need for sustained attention and the stress associated with following a predefined route. In contrast, a longer and continuously varying route could lead drivers to adjust their behaviour due to increased attentional demands and the stress of making navigation errors.

Table 1 Descriptives of DBQ and its dimensions results

	n **(M ± SD)**
DBQ	45 (26.04 ± 11.71)
Infractions and aggressive driving	45 (10.42 ± 6.33)
Non-intentional errors	45 (5.56 ± 3.58)
Lapses	45 (10.07 ± 4.37)

A light passenger vehicle was equipped with a data logger device, DL1 MK3from Race Technologies, with a 6 g 3-axis accelerometer and a 20 Hz GPS that allows data to be referenced by time and position on the road (positional accuracy of about 3 m – circular error probability – and the speed accuracy better than 0.1 km/h). A pedal movement sensor (for the acceleration pedal) and VIDEO 4 with three cameras (one capturing the driver and two capturing the road) were also connected to the datalogger. Although the participants were aware of the presence of all equipment, as they signed a consent form, all the equipment was installed as discreetly as possible, so that the driver would not notice it, or at most, would not feel uncomfortable if they did.

2.2 Road segments and roundabouts descriptives

The configuration of the experimental road circuit is illustrated in Fig. 1. Table 2 provides a description of the road segments, including key characteristics such as segment length (between roundabouts and crosswalks), number of lanes, speed limit, and the presence or absence of a pronounced longitudinal slope. Overall, the segments are broadly comparable.

Road segments T1 and T6 were excluded from the analysis in order to control infrastructure-related effects and better isolate behavioural differences in speed choice. The straight section of segment T1 was not sufficiently long for the purposes of the experiment. Moreover, because the experimental trial both commenced and concluded approximately at the midpoint of this segment, drivers frequently decelerated while attempting to identify the location of the accompanying researcher. Road segment T6 was also excluded due to its short length combined with pronounced positive and negative gradients, which could affect the interpretation of the results. This approach is consistent with previous research indicating that roadway geometry and gradient can significantly influence speed choice and should therefore be controlled or accounted for when the aim is to isolate behavioural differences [19, 28].

Table 3 describes the roundabouts in terms of internal diameter, number of lanes, lane width, and number of entries/exits. As in the case of the road segments, the roundabouts present similar features as the circuit is not so long (less than 4 km) in a road classified as urban, in the Municipal Master Plan of Coimbra.

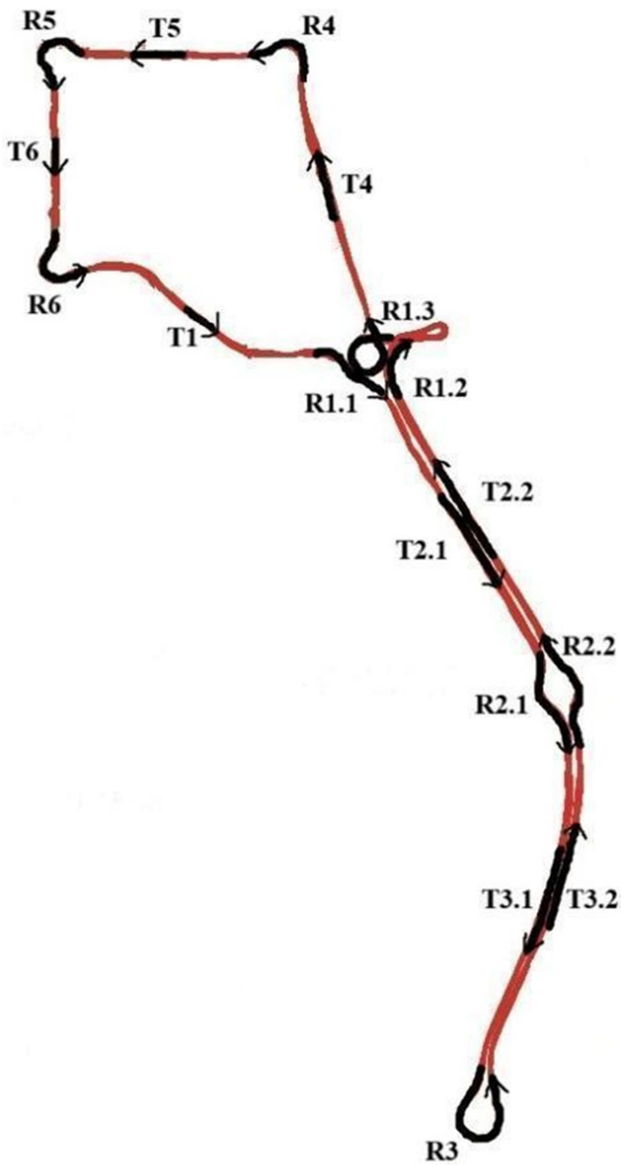

Fig. 1 Road circuit with road segments and roundabout movements identification

Table 3 Roundabouts descriptives

Roundabout	Number of lanes	Internal diameter (m)	Lane width (m)	Number of entries/exits
R1 (crossed three times per lap)	2	36	4.90	4
R2 (crossed two times per lap)	2	36	4.3	4
R3	2	40	4.4	4
R4	2	36	4.9	4
R5	3	36	4.2	4
R6	3	28	3.5	4

Four different types of movements were collected:

- Going around a half circle and leaving the roundabout in the second exit- movements R2.1 and R2.2
- Going around three-quarters circle, leaving the roundabout at the third exit- movements R4, R5 and R6
- Going around all circles, leaving the roundabout at the fourth exit- movement R3
- Going around a circle and a quarter movement R1.3

2.3 Variables collected and statistical analysis

Each driver completed 10 laps of the circuit. However, the first lap (accompanied by the researcher) and the second lap (the first completed independently) were excluded from the analysis, as they were assumed to serve as familiarisation with both the circuit and the vehicle.

Instantaneous speed data were collected using GPS and a data logger at 20 Hz. Pedal pressure data were recorded at the same frequency. By combining video observations with graphical analyses of speed and pedal inputs—generated using Race Technology Analysis software—speed-related variables were derived. For each road segment and roundabout, mean speed and standard deviation were calculated separately for each lap.

The mean speed variable for a road segment was defined as the mean speed between the end of acceleration after leaving a roundabout or crosswalk, and the beginning of deceleration when approaching the next roundabout or crosswalk. Only free-flowing speed conditions were considered in this analysis. Reviewing the

Table 2 Road segments descriptives

Road segments	Number of lanes	Length between roundabouts (m)	Length between crosswalks (m)	Lane width (m)	Pronounced longitudinal slope (yes-1, no-0)	Speed limit (km/h)
T2.1	2	396	256	3.25	0	50
T3.1	2	470	276	3.25	1 (+9% in the last quarter of the segment)	50
T3.2	2	470	276	3.25	1 (-9% in the first quarter of the segment)	50
T2.2	2	396	256	3.25	0	50 and 40 (158 m before entering roundabout)
T4	2	304	228	3.25	0	50
T5	2	210	109	3	0	50

Road segments 2.1. and 2.2 correspond to the two directions of the same road (same with 3.1 and 3.2) video recordings captured by the three cameras positioned to monitor the road, speed data were included in the database only when no other vehicles were observed ahead and in the immediate vicinity. The mean speed of each driver was computed per round across the six road segments. The standard deviation within each segment was also calculated to better characterize the consistency of speed.

Regarding the mean speed at the roundabout, the value was calculated between the entry and exit points. Situations when the driver's speed was influenced by other road users were excluded from this analysis (e.g. when other vehicles were observed driving ahead in the roundabout). The standard deviation of speed inside the roundabout was also computed. For each driver, these variables were computed per round, across the eight roundabout crossings. Deceleration prior to entering the roundabout and acceleration when exiting it were also computed for certain roundabout movements, in locations where visibility conditions were good and the road gradient was not significant. Jerk events were also computed, nevertheless they showed to be extremely rare, resulting in insufficient data for meaningful analysis.

2.4 Data analysis

In the experiment, each driver drove eight rounds for each road element – six segments and six roundabouts; thus, we have repeated measurements of the same variable under different conditions on the same subjects. The nature of the driving performance measures, which are speed mean and standard deviation, acceleration and deceleration (all continuous variables), as well as the data structure, suggested a linear regression approach. The model accounts for driver behaviour (DBQ dimensions) and driver characteristics (age, sex, crash history). To ensure that no high correlation exists between the DBQ dimensions and driver characteristics, in particular with crash history, the correlation matrix was computed, showing that the correlations were all less than 0.5. Since the participants drove eight rounds, which may have induced a learning effect or other effects, a dummy variable was added to capture this effect. Finally, based on the research hypothesis that each road element may elicit different driving performance depending on the driver behaviour measured by DBQ dimensions, a separate regression model was applied for each road element. In total, 14 models were estimated for mean speed, 14 models for standard deviation speed, five models for deceleration and five models for acceleration. As human behaviour is complex, individual variation (e.g., differences between drivers of the same age or same DBQ dimension) can be found; therefore, a random parameters linear regression model with heterogeneity in the means (also named mixed-linear regression model) was considered to account for variability as follows:

$$\begin{aligned} Y_{ir} = \alpha_{ir} + \beta_{ki} DBQ_{ki} + \beta_{AGEi} AGE_i \\ + \beta_{SEXi} SEX_i + \beta_{ACCIDi} ACCID_i \\ + \beta_{ROUNDri} ROUND_r + \varepsilon_{ir} \end{aligned} \tag{1}$$

And

$$\alpha_{ir} = \alpha + \mu_{ir}\,;\ \beta_i = \beta + \mu_i$$

Where Y_{ir} represents the driving parameters, which are mean speed, standard deviation (SD) speed, maximum acceleration or maximum deceleration, of each participant ($i = 1, 2, \ldots 45$) in each round ($r = 1, \ldots 8$); α_{ir} is the constant term, DBQ is a continuous variable representing the three dimensions of the DBQ ($k = 1,2$ and 3), AGE is the age of the participant as a continuous variable, SEX is a binary variable in which 0 is female and 1 is male, ACCID is binary variable in which 0 represents no history of crash and 1 a history of at least one crash, and ROUND corresponds to the round sequence. The estimated parameters β_i show the effect of each variable on the dependent variable (mean speed, SD speed, maximum acceleration, or maximum deceleration). ε_{ir} is the disturbance term assumed to be independently and identically normally distributed with a mean of zero and a constant variance of σ^2. All estimated parameters, except that of the ROUND variable, were estimated as random parameters. Therefore, α_{ir} and β_i are estimated parameters with the random components, u_{ir} and u_i, respectively, which were assumed to be normally distributed with a mean of zero and a variance of σ_{μ}^{2}, convey the stochastic nature of the random parameters for each driver characteristic, capturing individual variability. The model parameters were estimated by the maximum simulated likelihood method with 2000 Halton draws using NLOGIT 5 [39].

A random parameter is used when the standard deviation of the parameter density is statistically significant. If its estimated standard deviation is not statistically different from 0, the parameter is fixed across the individuals. In this case, no relevant variability exists in the DBQ dimension or characteristic represented by the respective variable. Note that this random-parameter formulation is equivalent to a random effects model if only the constant term is a random parameter [29]. Alternatively, if the random component u_{ir} or u_i is statistically significant, there is individual variability in that DBQ dimension or driver characteristic.

3 Results

3.1 Descriptive analysis

Figure 2 presents boxplots calculated for each dependent variable - mean free speed in road segments,

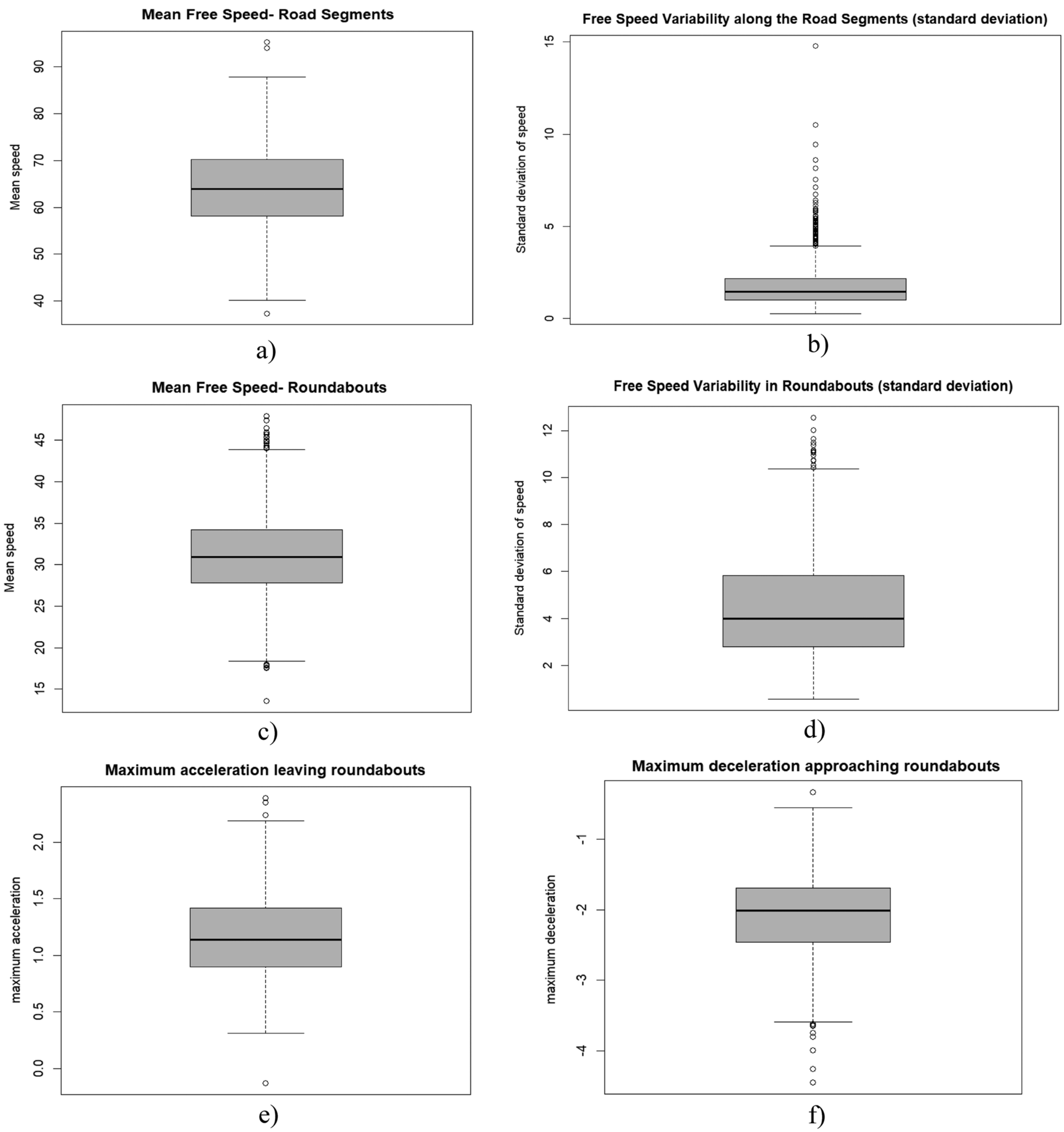

Fig. 2 Boxplots of (**a**) Mean speed in road segments; (**b**) Standard variation of speed in road segments; (**c**) Mean speed in roundabouts; (**d**) Standard deviation of speed in roundabouts; (**e**) Maximum deceleration when approaching roundabouts; (**f**) Maximum acceleration when leaving roundabouts. (generated using RStudio, version 2025.09.2 Build 418) [40, 41]

mean free speed in roundabouts, standard deviation of speed in road segments, standard deviation of speed in roundabouts, maximum deceleration when approaching roundabouts and maximum acceleration when leaving them- for all road segments and all roundabouts, all drivers and all laps. Table 4 presents the mean scores (and standard deviations) of each dependent variable for each road element and roundabout movement. The differing number of observations is due to the free-flow criteria, which led to the exclusion of some observations.

An analysis of the mean speed adopted by each driver throughout the experiment shows that 18% of drivers adopted mean speed equal to or greater than 70 km/h,

Table 4 Mean speed, standard deviation of speed, maximum acceleration and maximum deceleration descriptive statistics

Road Element / Roundabout movement	Mean Speed			Standard Deviation of Speed			Maximum Acceleration			Maximum Deceleration		
	n	mean	standard deviation	*n*	mean	standard deviation	*n*	mean	standard deviation	*n*	mean	standard deviation
T2.1	217	63.75	7.34	217	1.75	1.21						
T3.1	286	70.81	7.19	286	2.6	1.54						
T3.2	251	68.49	8.00	251	1.86	1.03						
T2.2	172	64.38	7.64	172	1.75	1.09						
T4	293	61.77	6.84	293	1.58	0.74						
T5	247	55.67	6.54	247	0.93	0.55						
R1.1	312	30.84	6.28	312	5.68	2.26	132	0.98	0.35	-	-	-
R2.1	307	31.89	3.8	307	3.4	1.73	250	1.21	0.28	202	-2.02	0.51
R3	341	34.99	3.28	341	0.12	0.05	-	-	-	-	-	-
R2.2	303	32.58	4.74	303	4.45	2.42	197	1.14	0.35	228	-2.05	0.55
R1.2	-	-	-	-	-	-	-	-	-	119	-1.97	0.5
R1.2	322	29.35	2.48	322	5.05	1.79	279	1.26	0.35	-	-	-
R4	320	31.88	3.8	320	3.69	1.96	275	1.13	0.35	242	-1.96	0.58
R5	296	28.99	3.24	296	5	2.32	-	-	-	244	-2.33	0.63
R6	259	26.44	2.82	259	4.23	1.92	-	-	-	-	-	-

and only 2% (drove at an mean speed of 50 km/h or lower (which is the limit speed in these roads).

3.2 Models' results

A total of 38 models were run: 14 models for mean speed in road segments and roundabouts, 14 models for the standard deviation of speed along road segments and within roundabouts, five models for maximum deceleration when approaching roundabouts, and five models for maximum acceleration when leaving roundabouts. Although all independent variables (IAD, NIE, lapses, sex, age, and crash history) were included in the model specifications, only statistically significant results are presented for clarity.

As described in Sect. 2.4, rounds were also included as dummy variables. With the exception of certain roundabout movements (R2.2 and R3) and road segment T2.1, no significant influence of this variable was observed on mean speed. Regarding the standard deviation of speed, statistically significant effects were identified only for movements within roundabouts R2.1 and R6. In the models for maximum acceleration and deceleration, although some rounds showed statistically significant effects, these were inconsistent across models and no clear pattern emerged. For this reason, and due to space constraints, these results are not presented in this manuscript.

Finally, it should be noted that results significant at the 10% level are reported alongside those meeting the conventional 5% and 1% thresholds. This decision reflects the constraints imposed by the sample size of 45 drivers, which limits statistical power. Effects significant at the 10% level are retained for transparency and to avoid discarding substantively meaningful patterns that are theoretically consistent with the broader findings.

3.2.1 Mean speed models

In the mean free-flow speed models (Table 5), the DBQ dimensions IAD and NIE are statistically significant across all road segments and most roundabout movements. IAD is positively associated with speed, whereas NIE shows a negative relationship. The lapses dimension is statistically significant in only a few cases (three road segments and two roundabouts), with consistently negative effects.

Age is significant across all road segments and in three roundabout movements, although the coefficients are very small. Younger drivers tend to drive faster. The sex variable is significant in only four models, again with small effect sizes, with female drivers associated with slightly higher speeds. Crash history shows a positive and statistically significant association with mean speed across all road segments and two roundabouts, although the corresponding coefficients are small.

Table 5 Mean speed models result for each road segment and each roundabout movement

Road Segment / Roundabout movement	Mean Speed Models						
	Constant term	IAD	NIE	Lapses	Sex [1]	Age	Crash history
T2.1	68.19***	12.82***	-10.14***		-1.81**	-0.14***	2.66**
	SD = 4.74***						
T3.1	79.30***	16.62***	-15.60***		-1.74**	-0.19***	2.80***
	SD = 3.30***						
T2.2	79.79***	11.87***	-13.41***	-5.97*		-0.28***	2.62**
	SD = 2.88***						
T3.2	83.82***	16.17***	-16.98***	-6.79**	-2.28**	-0.29***	3.33***
	SD = 1.24***						
T4	69.33***	15.17***	-14.04***	-4.00**		-0.19***	3.04***
	SD = 2.53***		SD = 2.39***				
T5	65.97***	10.54***	-10.67***			-0.20***	1.84**
R1.1	30.26***						1.34*
R2.1	31.25***	4.37***	-3.85***				-0.68**
	SD = 2.22***	SD = 2.90***	SD = 1.45***				
R3	36.36***	6.05***	-4.73***	-1.25**		-0.04***	
	SD = 2.26***		SD = 1.37***				
R2.2	32.16***	5.32***	-4.34***		– 0.67**		
	SD = 3.43***	SD = 4.17***					
R1.3	29.68***	3.21***	-2.06***			-0.02*	
		SD = 2.33***	SD = 0.92***				
R4	34.89***	5.35***	-5.45***	-2.44**		-0.06***	0.77**
	SD = 1.42***	SD = 2.27***	SD = 2.35***	SD = 0.56*			
R5	30.00***	3.28***	-4.57***				
			SD = 1.98***				
R6	26.88***	3.05***					
	SD = 0.89***	SD = 0.75*					

[1] (Female = 1, Male = 2)

***, **, * ==> Significance at 1%, 5%, 10% level

With regard to the random parameter results, most variables exhibit fixed effects. Statistically significant variability is observed only in the constant term for most road segments (with the exception of T5) and for the NIE variable in road segment T4. However, the probability of the coefficient taking an alternative sign is negligible, suggesting that the effect remains consistent across individuals.

The coefficients estimated for the roundabout models are generally smaller than those obtained for the road segment models. The IAD dimension shows a statistically significant ability to explain mean free-flow speed across all roundabouts, with a positive association. NIE and lapses display negative relationships with mean speed, although the latter is statistically significant in only two roundabouts. Age, sex, and crash history exhibit significant predictive effects in only a limited number of roundabouts, and the associated coefficients are small.

Some degree of behavioural heterogeneity is observed in roundabouts. The IAD variable presents significant standard deviations in movements R2.1, R2.2, R1.3, R4, and R6. The highest heterogeneity is observed for movement R2.2, for which the probability of the coefficient taking an alternative sign is approximately 10%. The NIE variable also exhibits significant standard deviations in movements R2.1, R3, R1.3, R4, and R5; however, the probability of the coefficient taking an alternative sign remains below 2%. As for lapses, the standard deviation is significant only in movement R4, with a negligible effect.

3.2.2 Standard deviation speed models

No statistically significant results were obtained for the models of speed standard deviation in road segments, except for the constant term. This suggests that the DBQ dimensions are not associated with differences in driving behaviour as measured by this speed-related indicator (Table 6). With regard to the standard deviation of speed within roundabouts, statistically significant results were obtained for the IAD variable in roundabouts' movements R1.3, R4, R5 and R6, showing a positive influence of this behaviour on the variability of speed. NIE shows a negative influence on speed variability within roundabouts R1.3, R4, and R5. As for Lapses, it only showed statistically significant results in two roundabouts' movements, and with opposite signals. Sex presented a statistically significant influence on the variation of speed in

Table 6 Standard deviation of speed models results for each roundabout movement

Roundabout movement	Standard Deviation of Speed Models						
	Constant term	IAD	NIE	Lapses	Sex [1]	Age	Crash history
R1.1							
R2.1	**4.48*****					-0.02*	0.47**
	SD = 0 0.59***						
R3							
R2.2							
R1.3	4.85***	**1.74*****	**-1.02****		0.70***		
		SD = 1.11***	**SD = 1.05*****				
R4	**3.31*****	1.03*	-1.39**	1.37**			
	SD = 0.69***						
R5	**5.67*****	1.62**		-1.60**			
	SD = 1.06***						
R6	**3.62*****	1.81***	-1.65***		0.52**		
	SD = 0.52***						

[1] (Female = 1, Male = 2)

***, **, * ==> Significance at 1%, 5%, 10% level

Table 7 Maximum deceleration models for each roundabout approach movement

Roundabout movement	Deceleration Models						
	Constant term	IAD	NIE	Lapses	Sex [1]	Age	Crash history
R2.1	**-2.06*****	-0.65***					
	SD = 0.16***						
R2.2	**-2.60*****	**-0.69*****		0.70***	0.14**	0.01***	-0.28**
	SD = 0.29***	**SD = 0.52*****					
R1.2	**-2.39*****	-0.70***		0.45*	0.21**		
	SD = 0.12***						
R4	**-2.01*****	-0.65***	0.42***			0.01***	-0.35***
	SD = 0.45***						
R5	**-2.88*****	-0.54***		0.53***		0.01**	
	SD = 0.31***						

[1] (Female = 1, Male = 2)

***, **, * ==> Significance at 1%, 5%, 10% level

R1.3 and R6, although with lower coefficient values As for age and crash history, statistically significant effects were observed in only one roundabout, again with exceedingly small coefficients.

In terms of heterogeneity in each variable result, statistical significance of the standard deviation speed was obtained in IAD and NIE variables, for only the roundabout movement R1.3. The probability of the coefficient taking an alternative sign is 6% for IAD and 17% for NIE. The constant term presents statistically significant standard deviation in four roundabouts, but with a negligible effect.

3.2.3 Deceleration and acceleration models

IAD exhibits the strongest associations (Table 7), with statistically significant predictive power for higher deceleration rates when approaching all roundabouts considered in this analysis, although the effect sizes is relatively small (i.e., less than 1). Within these models, Lapses dimension shows statistically significant effects in R2.2, R1.2, and R5, whereas the NIE variable is statistically significant only in R4. Drivers with higher scores in these two behavioural dimensions tend to exhibit lower deceleration rates. In roundabouts R2.2 and R1.2, female drivers exhibit higher deceleration rates. With respect to age, older drivers tend to exhibit lower deceleration rates in roundabouts R2.2, R4, and R5. However, the corresponding coefficients are close to zero. Drivers with a crash history exhibit higher deceleration rates in roundabouts R2.2 and R4. Regarding the random parameters, statistically significant results were only obtained for IAD in roundabout R2.2, with a probability of a different effect on deceleration of 10%. The constant term presents statistically significant standard deviation in all roundabouts, although the magnitude of this effect is negligible.

IAD exhibits a statistically significant positive association with acceleration when exiting all analysed roundabouts (Table 8). NIE shows a statistically significant negative association with acceleration in roundabouts R2.2, R1.3, and R4, while Lapses is statistically significant

Table 8 Maximum acceleration models for each roundabout exit movement

Roundabout movement	Acceleration Models						
	Constant term	IAD	NIE	Lapses	Sex [1]	Age	Crash history
R1.1	1.01***	**0.79*** SD = 0.30*****		-0.26*	0.14**		
R2.1	**1.28*** SD = 0.08*****	**0.41*** SD = 0.13*****		-0.23**			
R2.2	**1.57*** SD = 0.20*****	0.39***	-0.34***	-0.46***		-0.004**	
R1.3	**1.56*** SD = 0.18*****	**0.43*** SD = 0.22*****	-0.47***	-0.38***		-0.004***	0.23***
R4	**1.47*** SD = 0.16*****	0.45***	-0.66***		0 0.10***	-0.01***	

[1] (Female = 1, Male = 2)

***, **, * ==> Significance at 1%, 5%, 10% level

in R1.1, R2.1, R2.2, and R1.3. Male drivers exhibit higher acceleration levels in R1.1 and R4. With regard to age, younger drivers tend to exhibit higher acceleration levels in roundabouts R2.2, R1.3, and R4. However, the corresponding coefficients are very close to zero. Crash history is statistically significant only in R1.3, with a positive coefficient. Regarding random parameters, statistically significance of standard deviation was obtained for IAD, in roundabouts R1.1, R2.1, and R1.3, however, the probability of the coefficient taking an alternative sign is negligible, suggesting that the effect remains consistent across individuals. The constant term presents statistically significant standard deviation across all roundabouts, except for R1.1, but also with a negligible effect.

4 Discussion

The present findings provide evidence that self-reported aberrant driving tendencies are reflected in objectively measured behaviour in a real urban context. In particular, the consistent positive association between infractions/aggressive driving and mean speed, together with the negative association observed for non-intentional errors, suggests that DBQ dimensions capture not only broad attitudinal dispositions but also behavioural tendencies that remain observable under repeated on-road conditions. This pattern is aligned with recent validation work showing that DBQ violations and errors are significantly associated with real-world speed indicators, although with modest explanatory power once situational factors are considered [9]. These results reinforce the validity of this tool to analyse the driving behaviour, even though the DBQ version used included only four speed-related items. Additionally, it should be noted that the sample did not present very high scores in the three DBQ dimensions, with no driver showing extreme behaviour. Nevertheless, associations between DBQ dimensions and driving parameters were obtained. In this sense, the present study extends previous literature by showing that these associations remain detectable even when the route is short, repeated, and relatively homogeneous, and with DBQ scores relatively low, thus reinforcing the ecological validity of DBQ-based behavioural profiling. It is also worth noting that the present findings contribute to a broader body of evidence suggesting that the critiques levelled at DBQ research - particularly those concerning the inflation of associations due to common method variance when self-reported behaviours predict self-reported crashes [30] - do not appear to undermine the instrument's utility when objective behavioural criteria are used. The consistent associations observed here between DBQ dimensions and instrumentally recorded speed indicators, alongside comparable findings by Helman and Reed [8] and Thomas et al., [9], suggest that the DBQ retains meaningful predictive value beyond the realm of self-report, and that common method variance is unlikely to account for the pattern of results obtained in studies using objective behavioural measures.

When analysing the results of the mean speed models for road segments, the strongest association between IAD and mean speed is observed in segments T3.1 and T3.2. These segments are characterised by greater length, with approximately one quarter of their extent presenting a gradient, features that may help explain the higher speeds adopted by drivers with higher IAD scores [31, 32]. For the NIE and Lapses variables, the higher correlations are also observed in these road segments.

The analysis of the mean speed models in roundabouts shows that the correlation between the IAD variable and vehicle speed becomes stronger as the inscribed circle diameter increases. These findings are consistent with previous studies, which indicate that inscribed circle diameter influences speed [14] and that larger roundabouts allow higher vehicle speeds due to reduced geometric constraints and larger vehicle trajectory [33]. However, this relationship is not observed in the case of the NIE variable.

The variable NIE presents, in all models, a negative correlation with speed. This pattern may also reflect a form of behavioural adaptation rather than a simple reduction in overall risk. Previous research has suggested that drivers engaged in secondary tasks often adopt compensatory strategies, most notably by selecting lower speeds or timing engagement to less demanding situations. In simulator research, distracted drivers have been shown to reduce speed as a self-regulatory response, particularly when safety attitudes are stronger [34]. Naturalistic evidence is more cautious but points in the same direction, with small speed adjustments observed during demanding secondary tasks such as texting [35]. This interpretation is also consistent with Brazilian naturalistic findings showing lower selected speeds during mobile phone use and with evidence that drivers may shorten or modulate phone engagement as a risk-management strategy [19, 36]. Accordingly, the negative association observed here for NIE may indicate a less assertive operational style, without implying that these drivers are necessarily safer overall.

At the same time, the results suggest that these behavioural tendencies are not strongly expressed across different road elements. Although IAD was positively associated with speed in both road segments and roundabouts, the coefficients were generally smaller in roundabouts, and speed variability effects emerged almost exclusively within roundabouts. This suggests that the road environment does not merely constrain speed mechanically but modulates how driver disposition is translated into behaviour. Roundabouts impose a denser set of operational demands, including approach speed adjustment, yield assessment, steering control, and path negotiation over a short distance, which may attenuate absolute speed differences while amplifying behavioural differences in speed stability and manoeuvre execution. This interpretation is consistent with work showing that roundabout crossings vary substantially according to geometry and movement type, and with evidence that roundabout sub-segments are associated with distinct patterns of speed, acceleration, jerk, and operational volatility [15, 16]. One possible interpretation of the concentration of variability-related associations in roundabouts is that these environments amplify the expression of individual behavioural tendencies due to their higher perceptual and control demands.

Another important result is that heterogeneity was observed more often in roundabouts than in road segments, whereas the random constant was statistically significant in most models, although with a very small effect size. Substantively, this suggests two complementary processes. First, drivers appear to maintain different "baseline" operating styles even under the same experimental conditions, which is compatible with previous evidence that speed choice has a relatively stable individual component under free-flow conditions [7]. Second, the appearance of heterogeneity in IAD and NIE effects mainly in roundabouts indicates that context-sensitive infrastructure may amplify inter-driver differences that remain latent in simpler elements. This interpretation is also compatible with the broader literature showing that transfer from experimental settings to the real world is strongest for core performance indicators such as speed, but that real-world contextual demands still shape how these indicators vary across situations [18]. In practical terms, the findings suggest that behavioural risk should not be interpreted as a fixed driver trait alone; rather, it should be understood as the product of stable dispositions interacting with the local task structure of the roadway. This perspective is consistent with the underlying notion of Self-Explaining Roads, according to which good road design should naturally and intuitively encourage safe traffic behaviour [13, 21, 37].

The weaker coefficients values observed in the acceleration and deceleration models also deserve attention. Compared with mean speed and speed variability, these variables describe short-duration control actions that are likely to depend more strongly on immediate visibility, gap acceptance, local alignment, and momentary interactions with the infrastructure. For that reason, it is plausible that DBQ dimensions explain speed behaviour within a given infrastructure context, as consistently demonstrated across road segments and roundabout movements in the present study, more robustly than they explain brief manoeuvre-specific responses such as maximum acceleration and deceleration at roundabout entries and exits, which are more strongly governed by local context and visibility conditions.

This interpretation is consistent with recent large-scale evidence showing that self-reported behavioural dimensions are statistically significant yet still secondary to situational determinants in explaining observed speed behaviour [9]. It is also coherent with naturalistic evidence showing that measured behaviour in real world is highly sensitive to contextual triggers and local road conditions, even when the same driver is repeatedly exposed to a similar environment [20, 28].

Age and sex were found to be statistically significant predictors in only a few regression models, with correlation coefficients that were very small compared to those of the other variables. On the other hand, crash history showed statistically significant results in the mean speed models in road segments. Drivers who have been responsible for at least one road crash, tended to drive faster.

Overall, the main contribution of the present study may be less in predicting isolated control actions and more in demonstrating that behavioural self-reports retain explanatory value for element-specific operational behaviour in real world. This conclusion should nevertheless be interpreted with caution given the modest sample size, spatial extent of the circuit, the limited temporal scope, which did not allow for the capture of behavioural variations over time and the use of an instrumented experimental vehicle rather than each participant's own car. These features strengthen internal control, but they may also limit the generalisability of the estimated effect magnitudes.

5 Conclusions

This study showed that the DBQ dimensions IAD and NIE are meaningfully associated with objectively measured driving speed, and that these associations remain visible across repeated observations of the same drivers in real world. Infractions and aggressive driving were consistently related to higher speeds, accelerations and decelerations, whereas non-intentional errors tended to be associated with lower speeds and lower accelerations and decelerations (although with weaker effects), providing evidence of the ecological validity of the DBQ. At the same time, the findings demonstrated that road context plays an important role, as behavioural patterns differ between road segments and roundabouts.

Overall, the results support the view that risky driving behaviour and, consequently, safety outcomes, are best understood as an interaction between driver disposition and infrastructure context, rather than as a purely stable individual characteristic, consistent with the human factors approach to road system design [21]. This interpretation is further supported by longitudinal evidence from Roman et al., [38], who tracked DBQ trajectories in over 1,000 novice drivers across their first three years of licensure. Their findings revealed that self-reported violations increased over time across all driver subgroups - including those at lower behavioural risk - at precisely the period when crash involvement is known to decline most steeply with accumulated experience. This dissociation between rising DBQ violation scores and falling crash risk illustrates that the relationship between self-reported aberrant behaviour and safety outcomes is not fixed, and that contextual factors - such as driving experience, perceptual adaptation, and exposure - fundamentally shape how behavioural dispositions translate into real-world risk. Taken together with the present findings on road element context, this evidence reinforces the view that neither DBQ scores nor crash outcomes should be interpreted in isolation from the broader situational and developmental conditions in which driving behaviour unfolds.

From an applied perspective, these findings suggest that behavioural profiling may be useful, as an evidence-based tool, for safety analysis and intervention design while emphasizing the need for context-sensitive approaches, particularly in geometrically demanding urban elements such as roundabouts. Identified profiles can be integrated into traffic simulation models to better represent the diversity of driving behaviours and traffic dynamics. Additionally, they may also enhance driver training by adapting it to different learner profiles. Furthermore, in vehicle technology development, they can support the personalisation of driver assistance systems, warnings, in-vehicle interfaces, and distraction or fatigue detection systems.

Abbreviations

DBQ	Driver Behaviour Questionnaire
IAD	Infractions and Aggressive Driving
NIE	Non-intentional Errors

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Author contributions

Joana Félix Dourado: concept, design of the experimental study, data collection and data processing, methodology, formal analysis, writing- original draft; writing- review & editing. Sara Ferreira: concept, methodology, formal analysis, writing- original draft; writing- review, supervision. Eduardo César Amancio: formal analysis, writing- original draft; writing- review. Ana Bastos Silva: concept and methodology, supervision. Álvaro da Maia Seco: concept and methodology, supervision. Tatiana Maria Cecy Gadda: writing- review, supervision.

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Data availability

Data are available from the corresponding author upon reasonable request.

Declarations

Competing interests

The authors declare no competing interests.

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