

Research article

Quantitative assessment of the factors affecting the time and movement anticipation of young drivers

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Road user safety is an important concern in developing countries like India, which ranks fourth globally in road crashes and first in road fatalities. This paper examines the impact of human factors on highway safety, focusing on the role of cognitive processes involved in driving actions. The study examines the relationship between decision errors, particularly time and movement anticipation, along with the help of demographic factors such as gender, age, driving experience, possession of a license, vision and mobile phone use among young drivers in India. Data were collected using the Vienna Test System (VTS) and a questionnaire. The VTS measured cognitive and psychomotor abilities related to time and movement anticipation, while the questionnaire gathered information on social and driving-related factors. Results showed that decision errors about speed perception are influenced by gender, age, and driving experience. The results showed that females underestimate speed more than males do for all combined data and for all three speeds. However, females aged 18-20 tended to overestimate speed more than males in both the slow and fast cases. Further, it is observed that for the same experience level, overestimation increases from slow to fast motion. Novice drivers (drivers without a license) have maximum errors for slow motion. Vision correction (spectacles) did not significantly affect error rates. The use of mobile phones while driving was associated with increased error rates, indicating a reduction in cognitive attention required for driving tasks. These findings have implications for driver training programs, suggesting a need for tailored approaches based on demographic characteristics and driving habits.

1. Introduction

Highway safety is a crucial concern globally, particularly in developing countries that are undergoing fast urbanization and infrastructure development, such as India. Globally, India ranks fourth in road crashes and first in road fatalities (World Health Organization (WHO), 2023). According to the

Ministry of Road Transport and Highways (MoRTH) (Annual Report, 2022) report, about 0.46 million crashes occurred in 2022, of which 33.80% were fatal. According to MoRTH data (2020-2022), the number of crashes has steadily increased by 24% since 2020. As per the Highway Safety Manual (HSM, 2009) about 65% of the crashes are attributed to human factors. A similar scenario can be seen from

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the Indian dataset, showing 69% of the drivers as over-speeding or human error (Ministry of Road Transport and Highways (MoRTH), 2023). The age groups <18-25 and 25 to 35 account for 25.5% and 25.3% respectively of all fatal road accidents for the year 2022 (Annual Report, 2022).

There are numerous elements that contribute to human factors, including physiological and psychological characteristics such as vision, hearing, and reaction times (Bayat *et al.*, 2024). Driving is a complex task that involves a wide range of cognitive processes, such as perception, attention, learning, memory, decision-making, and action control. The cognitive processes are associated with human errors (Saurin *et al.*, 2004) that consist of mental abilities that deal with learning, problem-solving, remembering, decision-making and time and motion anticipation (Fisher *et al.*, 2019). Among these, anticipations (time and movement) are key in hazard perception and safety while driving, as they deal with the cognitive ability to apprehend the speed and distance of moving objects (Pelser *et al.*, 2005; Stahl *et al.*, 2016). Considering the time and movement anticipation, a driver can comprehend the speed of the vehicles with the change in the image in the eyes with respect to time, called speed perception (HSM, 2009). This is attributed to the perception in depth, which is essential for making decisions in critical situations, such as driving through curves and turns, at intersections, merging lanes, around roadside objects, in changing road conditions, and at pedestrian crossings. Perception in depth relies heavily on accurately calculating distances and spatial relationships between elements in the driver's environment. It allows drivers to measure their distance from other vehicles, pedestrians, obstacles, and side features. The ability to accurately perceive and judge the speed of one's own vehicle as well as the proximity to other cars on the road is necessary for maintaining a safe driving speed and responding to changing traffic conditions. Individual characteristics, environmental factors, and visual signals can all affect speed perception. There was a

42% rise in traffic crashes at various junction types between 2020 and 2022, particularly T-intersections, Y-junctions, and 4-arm junctions classified as merging areas as per MORTH (Ministry of Road Transport and Highways (MoRTH), 2023, 2022). On the other hand, the contribution of 2-wheelers and car drivers has consistently risen from 2020 to 2022, i.e., 38.8% to 43% for 2W, and for cars was approximately 19 percent. Hence, given the growing traffic volumes and diverse road users, understanding the linkages between human factors and highway safety is a crucial part.

While driving, drivers can make various types of errors, including decision errors, recognition errors, and performance and non-performance errors (Monyo *et al.*, 2021; Shaon *et al.*, 2025). Decision errors can involve too fast a reaction for a condition (e.g., breaking due to overestimation of speed), or the failure to acknowledge the unexpected action of the other user (e.g., other drivers' lane changing operation or pedestrian crossing roads). These decision errors are mostly due to time and movement anticipation, as cognitive functions are used for prediction and decision-making (Seyfzadehdarabad *et al.*, 2023). The time and movement anticipation is a cognitive ability rather than a personality trait (Seyfzadehdarabad *et al.*, 2023). These decision errors caused about 54% of driving errors and hence are necessary to evaluate. Also, these errors are affected by the driver's gender, age, driving experience, cognitive capabilities, and other distractions such as the use of mobile phones (Kim *et al.*, 2023; Tinella *et al.*, 2024). Using a phone while driving divides attention, significantly affecting driving safety (Rahman *et al.*, 2021; Rajesh *et al.*, 2017). This cognitive distraction caused by phone use affects driving performance and the sending and receiving of text messages, resulting in a significant decrease in speed and difficulty maintaining a stable speed and headway distance (Haigney *et al.*, 2000; Oikonomou *et al.*, 2025).

Thus, it can be concluded that human error is a major factor in most highway crashes. Hence, the study of human

cognitive abilities can help reduce potential human errors. The Schuhfried company developed the Vienna Test System (VTS), a computerized psychological assessment tool, in the 1980s (Schuhfried, 2013). VTS is a systematic, objective testing procedure with extensive criteria that is utilized for psychological diagnostics globally. The VTS is a comprehensive psychological assessment (also called a neuropsychological assessment) tool designed to evaluate cognitive abilities, personality traits, and specific competencies. For accurately measuring sensory, motor, and cognitive responses, tests designed in VTS use specialized input/output devices (earphones, response buttons on the panel and pedals). Pictures, lights, sounds, or animations controlled with precise timings can all be used as test stimuli. This flexibility marks VTS well-suited to simulate driving-related tasks (like responding to traffic signals, perceiving brief scenes, or tracking moving objects) under controlled conditions (Grundler & Strasburger, 2020). Some applications of this test battery include the recruitment of marine pilots, high-speed rail drivers and drone operators, and the assessment of athletes' skills, etc (Guo *et al.*, 2019; Johnsen *et al.*, 2023; Seyfzadehदारabad *et al.*, 2023; Wilczyńska *et al.*, 2021). In Austria and Germany, a traffic psychology assessment is required as part of the medical-psychological test for regaining a driving license after being removed due to accidents or serious traffic violations (Sommer *et al.*, 2008). Psychometric tests have long been used to predict safe driving performance in many countries worldwide. Medical-psychological tests are used to evaluate cognitive abilities (e.g., in Austria, Spain, and Hungary) and to select the most qualified applicants in transportation firms. Psychometric assessments have stayed mostly similar for decades, despite significant changes in truck and bus technology, as well as overall road safety infrastructure (Vetter *et al.*, 2018; Vujančić *et al.*, 2016).

One of the key features of VTS is the ability to assess time and movement anticipation. These abilities are essential for driving activities, including passing, estimating distance, and

responding to changing traffic. The Time and Movement Anticipation test (code-named ZBA) is the main VTS module for this. The exam assesses both spatial and temporal anticipation (i.e., “where will the object be at that time?” and “when will the object arrive?”). This closely resembles the demands of driving in the real world. For example, a driver must anticipate the speed and distance of approaching vehicles while overtaking. Likewise, maintaining a safe following distance involves estimating how long it will take the vehicle ahead of you to reach a specific location. It's stated that the ZBA test evaluates the ability to estimate the speed and direction of object movements, and that accurately assessing speeds and distances requires spatial and temporal orientation. Poor performance (significant time or position errors) indicates a lack of ability to anticipate motion, a characteristic that has been connected in studies to odd driving habits and collision involvement.

To the best of the author's knowledge, only a handful of studies have shown a relation between novice driver training and reductions in crashes and near-crashes (Epstein *et al.*, 2022; Fisher *et al.*, 2017, 2024). These training programs have focused either on hazard anticipation (Crundall *et al.*, 2012) or attention maintenance (Pradhan *et al.*, 2011). Further, Zhang *et al.* (2018) found that the training failed with careless drivers but worked with careful drivers. In a developing nation like India, there are very few studies on the time and movement anticipation of young drivers and the factors that affect them. This study will illustrate the underrepresented driving context in previous studies of greater traffic heterogeneity, along with non-lane-based traffic conditions. Developing nations like India have highly heterogeneous traffic with weak lane discipline, reflecting driver behaviour that can accept narrow gaps and still manoeuvre smoothly. For this type of driver behaviour, the time and movement assessment has not been well studied. Also, crashes involving motorised two-wheelers are increasing worldwide, and about 60-70% of these crashes are due to errors in

anticipation (Jaffard & van Elslande, 2012). Further, if the patterns and factors affecting time and movement anticipation are well known, the driver's training module can be prepared accordingly; hence, the present study examines decision errors related to time and movement anticipation among young drivers in India. The effects of gender, age, vision, driving experience, driving license possession, and mobile phone use on decision errors using VTS are studied, which can help develop driver training programs and interventions that are effective and tailored to the needs of this demographic.

2. Novelty of the present study

The novelty of the present study is as follows

- Prior research into novice driver training has mostly focused on time and movement anticipation and has been carried out in developed countries. However, the present study addresses time and movement anticipation among young drivers in a developing country like India.
- The variation of the decision errors and time anticipation with respect to gender and age for the young drivers in India has not been studied in previous studies, and hence, the present study evaluated the effect of gender and age on the decision errors and time anticipation with respect to three different motions.
- Lastly, the spatial anticipation in simple and complex progression is not explored well for developing country drivers, and hence, in the present study, the spatial anticipation is studied.

3. Literature review

Travelling at high speed can increase the risk of a crash if the driver fails to account for the speed of the upcoming vehicle or its distance from the vehicle. If the driver fails to perceive these factors, stopping within the safe stopping distance will not be possible, leading to a collision with the object/vehicle. As per the

study by Pascal, driving at fast speeds can have catastrophic repercussions, since drivers may fail to foresee an incoming hazard and lose control of their car, resulting in a crash (Cœugnet *et al.*, 2013).

The study by Hunt *et al.* (2011) highlighted the significance of gap-acceptance judgments for road user safety, emphasising the need to evaluate both the distance and speed of oncoming cars. It emphasizes that people frequently depend entirely on distance when making gap estimations, ignoring the speed of the oncoming vehicle, which can lead to dangerous actions, particularly when the oncoming vehicle is driving unusually fast. Jurecki & Stańczyk (2011) subjected 30 drivers to three different tests in order to evaluate their behavior prior to a collision. The first test, a psychological exam, assessed drivers' simple and complex reaction times. In simple reaction-time tests, drivers press a key when a stimulus (a light) appears on the screen. Complex reaction time tests require drivers to press a key when a specific colour of light appears on the screen. The second test was conducted on a test track where drivers are forced to react to prevent a collision with another car at a crossroads. The third test used a simulation in which the same scenario was replicated as conducted in the second test. The analytical report indicated that reaction time values on simulators are lower than those on the track, for both simple and complex reaction times. Mańkowska *et al.* (2015) studied the effects of visual perception on reaction time, anticipatory time, and movement in basketball players. Only females were considered for the purpose of the study. They concluded that time and movement anticipation are necessary for any sports person to handle complex situations effectively, and that this ability is mostly influenced by an individual's perceptual abilities. Horváth *et al.* evaluated the effect of the six-week training programme on car racing drivers using VTS. They found that the drivers were more accurate on word-reading tests during exercise compared with rest conditions. Further, they found that car drivers' performance improved, with reduced

reaction times. No significant differences were found in time or movement anticipation with training.

[Stahl et al. \(2016\)](#) studied the effect of the in-vehicle interface on the anticipation of novice and experienced drivers. They found that novice drivers show a significant effect on time anticipation. [Wu et al. \(2017\)](#) found that gender, driving experience, driving speed, and road type affect the speed perception of drivers. They found that inexperienced drivers make more errors on wider roads than on narrow roads. Further, they concluded that females make the most estimation errors at both slow and fast speeds. [Saadat et al. \(2018\)](#) evaluated the effect of waterpipe smoking on the psychomotor performance of drivers using VTS. They found that waterpipe smoking enhanced the two-hand coordination, concentration and attention. No significant differences were observed for time and movement anticipation. Another study by [Saadat et al. \(2019\)](#), involves hospital nurses who napped later during their night shift (from 3:00 to 6:00 AM) and demonstrated poorer time-movement anticipation abilities compared to those who napped earlier (from 12:00 to 3:00 AM). Since time-movement anticipation is essential for tasks such as safe driving, hazard management, and preventing road traffic collisions, these findings suggest that nurses who nap later in their shift may be at greater risk of road traffic accidents while commuting after work. [Pelser et al. \(2005\)](#) evaluated the strategy for selecting haul truck operators using the psychomotor test of VTS. They utilized Cognitrone, Determination Test, ZBA test and two-hand coordination tests. They found the positive skewness for ZBA and the two-hand coordination test, and hence, respondents performed well on these tests.

[Mohanty & Samal \(2019\)](#) used a questionnaire-based approach to study the role of young drivers in road crashes in the city of Bhubaneswar, India. The 15-25 age group was split into four groups. The study found that individuals between the ages of 18 and 21 are more likely to have catastrophic vehicle crashes. Over-speeding of vehicles accounting for 80 kmph and above is considered a

disaster for riders. Moreover, not wearing a helmet increases the risk of a severe accident by approximately 400 times. [Monyo et al. \(2021\)](#) studied the factors influencing older driver errors. They found that gender, age, lighting conditions, location, alcohol involvement, distraction, etc., were factors affecting decision errors and recognition errors. They concluded that drivers are more likely to make decision errors (approximately 54%) than recognition errors. [Babic et al. \(2022\)](#) found that gender, road type, visibility conditions and vehicle speed affect the drivers' speed perception. [Mamcarz et al. \(2023\)](#) examined the personality traits of the young driver as a link between the reaction time and traffic perception using the VTS. Various VTS tests, including Reaction Time (RT), ZBA, and others, were administered to 60 participants. They found that gender affects the personality factors, self-control, motor time, risk avoidance and time anticipation. The results showed that females had higher self-control scores but lower time-anticipation scores. [Murphy & Voyer \(2023\)](#) studied the effects of laterality and time estimation on accident proneness, using a sample of psychology undergraduate students. They found that the participants who made the positive error (underestimating time) were more susceptible to crashes. [Wu \(2024\)](#) found that speeds were perceived as lower when the vehicle moved in the same direction as the driver. Further, the author concluded that errors were more frequent in a simple road environment than in a more complex one. [Marković et al. \(2025\)](#) concluded that there was overestimation at lower speeds and underestimation at higher speeds in the study conducted at night. On the other hand, [Papić et al. \(2020\)](#) found that pedestrians underestimated higher speeds while crossing roads.

From the above-mentioned literature, it is observed that age, driving experience, and gender have significant effects on reaction time. However, the effects of age and gender, particularly on reaction time for time and movement anticipation, have not been well studied. Hence, the present study examines

time and movement anticipation among Indian drivers. First, the distribution of time and movement anticipation deviation is studied, and then the effects of age and gender are explored for the dataset.

4. Methodology

For the present study, the computerized psychological evaluation tool VTS, is used to measure several aspects of cognitive and psychomotor abilities. It comprises a variety of standardized tests intended to evaluate multiple aspects of a person's personality, emotional intelligence, and cognitive performance. VTS is used by researchers for cognitive studies of time and movement anticipation (Seyfzadehdarabad *et al.*, 2023; Veliks *et al.*, 2023). The VTS have high reliability for time and movement anticipation tests, ranging from 0.94 to 0.99 (Schuhfried, 2013).

5. Data collection

Test units ZBA S5 and ZBA S2 module in VTS are used to evaluate time and movement anticipation for the present study. The details of the test are given below.

5.1 Time anticipation (ZBA S5)

The test window with instructions is shown in Figure 1 (a). A slow-moving green ball emerges on the screen to gauge the anticipation of time (Schrödter *et al.*, 2023; Schwegman *et al.*, 2021). The ball vanishes at an unpredictable period, and a red line then appears. The target line is shown in a red line (Figure 1 (b)). It is the respondent's responsibility to predict when the ball will cross the goal line. In order to accomplish this, the respondent presses a button when he/she thinks it is appropriate. The output is expressed as a deviation in milliseconds (ms). The deviation is the difference between the actual time the dot would cross the line and the time the participant indicated it would cross. Here, a positive deviation indicates overestimation of speed by the participants (early braking), and for the negative response,

it is indicated as the underestimation of speed (late braking) (Murphy & Voyer, 2023). If a driver overestimates the speed at which the dot travels, he/she pulling out of a driveway when cross traffic is present. A similar understanding can be seen from the study of Wan *et al.* (2015).

There are eighteen test items. These eighteen elements are further separated into three categories: medium motion, fast motion, and slow motion. There are six elements in each subcategory, and the pace of each motion is set specifically for that motion. The ball's speed is maintained in slow motion so that it crosses the target or red line in six seconds. Similarly, it takes four seconds at medium speed and two seconds at fast speed. The participant presses the button when he/she thinks it is appropriate, a dotted line along with the position of the ball from the target line is displayed only in the example phase to let the participant get an idea about his/her accuracy in predicting the speed.

5.2 Movement anticipation (ZBA S2)

The respondent is asked to locate the point at which the ball would cross the target line to estimate their anticipation of movement. Two keys are used to control the arrow on the screen. The respondent then receives feedback during the instruction phase; he/she is shown where the dot actually was when he/she hit the button and how it continued along its path. There is no such input during the test phase.

There are currently 12 items on this test. These twelve items are divided into two further categories: simple progression and complex progression. The four progressions that follow the linear motion (Figure 2 (a)) are part of the simple progression. On the other hand, for complex progression, there are eight progressions: two involves a sinusoidal wave, and six involve curvilinear shapes (Figure 2 (b)). For instance, some people might place the dot close to their car, whereas others might place it farther away.

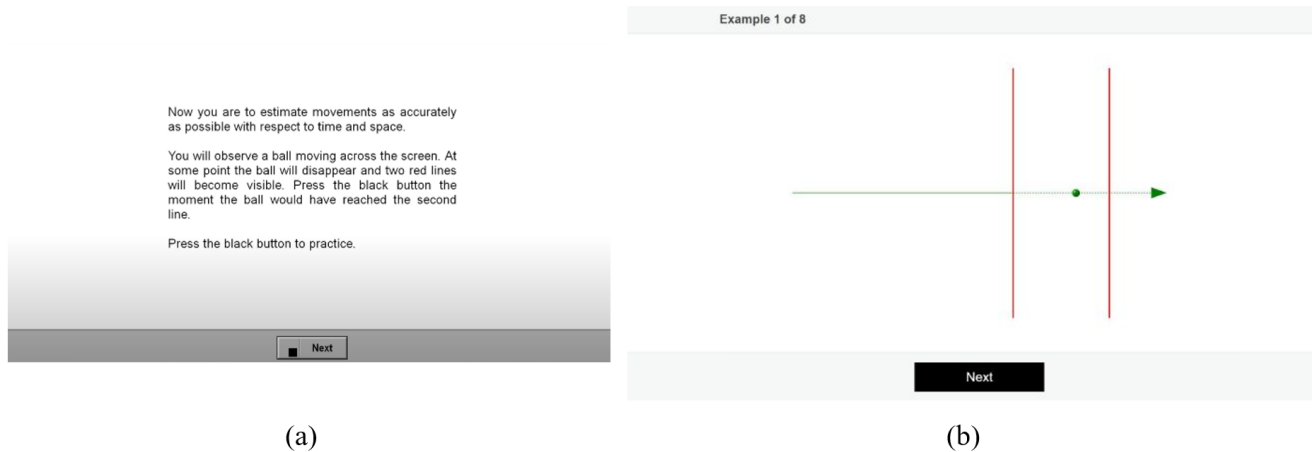


Figure 1. Interface of time anticipation (ZBA S5) test: (a) test instruction; (b) test showing the linear path

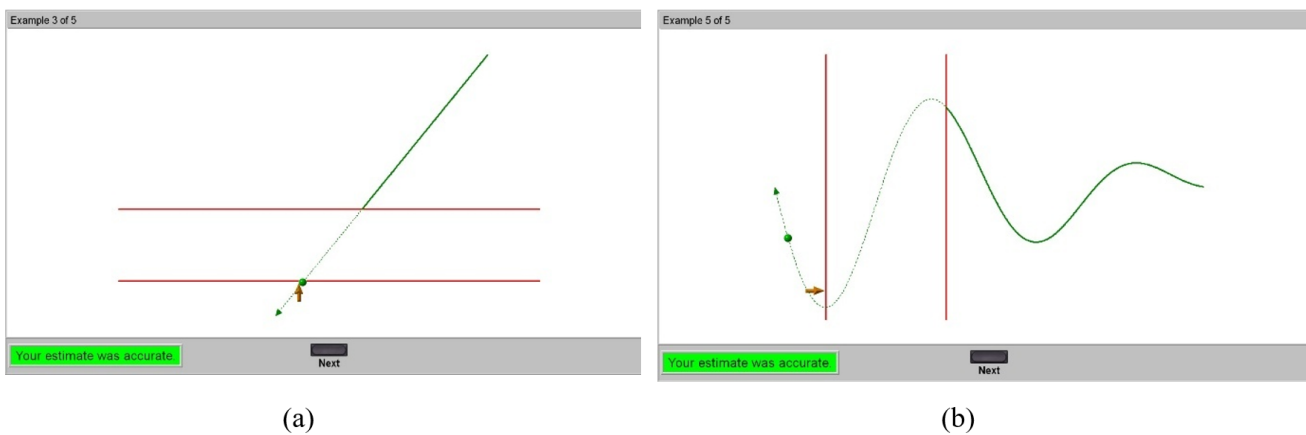


Figure 2. Interface of movement anticipation (ZBA S2) test: (a) simple progression; (b) complex progression

Along with this, a questionnaire was prepared to assess the socioeconomic and other aspects related to the driving of the respondents. The data, such as age, gender, experience (years), present eyesight condition, highest education level, etc., were collected. The parameters mentioned in the questionnaire are shown in Table S1. Most of the participants were driving two-wheelers, and very few were driving a two-wheeler and a car. Hence, vehicle class-wise analysis is not presented.

For the present study, seventy-seven participants (52 male, 25 female) volunteered for the VTS and questionnaire dataset. While this ratio does not meet the ideal distribution of equal proportions, it is consistent with

the gender ratios used in several similar studies (Chouhan *et al.*, 2025; Jeihani *et al.*, 2017; Pawar *et al.*, 2020). The age range is 19-30, with an average age of 23.02 ± 2.57 years and a driving experience of 4.15 ± 3.12 years. The participants were recruited from the university on a voluntary basis, had normal vision, and had no neurological history. Written consent was obtained from them. Each participant completed the test in a quiet room with adequate lighting. The total test time for each participant was 30 minutes, including ZBA S5, ZBA S2 (practice session and final test) and questionnaire survey. The data was handled by the research team, only with the password-protected files.

6. Data analysis

After obtaining the data, the deviation in reaction time (hereafter, called deviation time) is studied for both time and movement anticipation. The conflict and simulation analysis need the distribution of deviation times as an input (Astarita & Giofr , 2019), and hence an attempt is made to find the best-fitted distribution for the deviation time.

To fit the distribution of the speed perception test data, first, the family of distributions is prepared by studying the literature, and it includes Log-Normal, Normal, Weibull, Generalized Extreme Value (GEV) and Log-Logistic distributions as given in Equations (1) to (5).

Normal:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \quad (1)$$

where μ – mean, σ – standard deviation

Log-normal:

$$f(x) = \frac{\exp\left(-\frac{1}{2}\left(\frac{\ln x - \mu}{\sigma}\right)^2\right)}{x\sigma\sqrt{2\pi}} \quad (2)$$

where σ – shape parameter ($\sigma > 0$), μ – location parameter.

Weibull:

$$f(x) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & x \geq 0 \\ 0 & x < 0 \end{cases} \quad (3)$$

where k – shape parameter, λ – scale parameter.

Generalized Extreme Value (GEV):

$$f(x) = \begin{cases} \frac{1}{\sigma} \exp\left(-\left(1 + k\left(\frac{x-\mu}{\sigma}\right)\right)^{-\frac{1}{k}}\right) & k \neq 0 \\ \frac{1}{\sigma} \exp\left(-\left(\frac{x-\mu}{\sigma}\right)\right) & k = 0 \\ -\exp\left(-\left(\frac{x-\mu}{\sigma}\right)\right) & \end{cases} \quad (4)$$

where σ – shape parameter ($\sigma > 0$), μ – location parameter, k – shape parameter.

Log-logistic:

$$f(x) = \frac{\left(\frac{\beta}{\alpha}\right) \left(\frac{x}{\alpha}\right)^{(\beta-1)}}{\left(1 + \left(\frac{x}{\alpha}\right)\right)^{\beta^2}} \quad (5)$$

where α – scale parameter, β – shape parameter.

The Kolmogorov-Smirnov (KS) non-parametric test is applied to evaluate the goodness of fit (Bari *et al.*, 2021a; Dong *et al.*, 2015). The KS value checks the difference between the cumulative frequency distribution (CDF) curve (Bari *et al.*, 2022; Navandar *et al.*, 2021). In the present study, a 90% confidence interval is considered. 90% confidence level is considered, as the p-values were marginally higher than 0.05 for all distributions. The null and alternate hypotheses for the present study are as follows.

H_0 : the deviation time follows the specified distribution.

H_1 : the deviation time does not follow the specified distribution.

The best-fitting distribution is the one with the minimum KS value. Then, the effects of age and gender on the deviation are critically examined.

6.1 Best fitted distribution

The results of the KS tests for participants' responses to overestimation of speed (i.e., positive deviation time for time anticipation) are shown in Table 1.

From Table 1, it can be seen that, for all cases, the KS value is lower for the GEV distribution; hence, it is taken as the best-fitting distribution for studying deviation times, even in the tails. Along with the KS statistics, the p-value is also significant, and hence the distribution is accepted under the null hypothesis (as indicated by the bold values in Table 1). Similarly, analyses were carried out for underestimation and overall deviation time, and it was found that the GEV was the best-fitting distribution in most of the cases. The GEV distribution is a three-parameter distribution with a shape parameter that explicitly models tail behaviour, accommodating skewness (Bari *et al.*, 2022). Also, previous studies showed that reaction time distributions are positively

Table 1. KS values for the overestimation of speed

Category	Normal	Log-normal	Weibull	GEV	Log-logistic	Best-fitted distribution
SLOW-Combined Participants	0.0842	0.1152	0.0544	0.0456	0.1168	GEV
MEDIUM-Combined Participants	0.0737	0.1364	0.0639	0.0383	0.0814	GEV
FAST-Combined Participants	0.0539	0.1383	0.0567	0.0430	0.1096	GEV
SLOW-Male	0.0856	0.1265	0.0726	0.0422	0.1253	GEV
MED-Male	0.0571	0.1364	0.0757	0.0350	0.1402	GEV
FAST-Male	0.0703	0.1437	0.0830	0.0586	0.1454	GEV
SLOW-Female	0.0853	0.1493	0.1157	0.0613	0.1539	GEV
MED-Female	0.1182	0.1828	0.1270	0.0715	0.1905	GEV
FAST-Female	0.0769	0.1631	0.1038	0.0678	0.1669	GEV

Bold values show that the null hypothesis (H_0) is accepted.

skewed (Asadamraji *et al.*, 2026; Rakhshan *et al.*, 2014; Yoshida & Yokoyama, 2026), with a heavy right tail, which are difficult to capture by symmetrical distributions such as the normal distribution. To strengthen the findings, the Quantile-Quantile (Q-Q) plot has been used to visualise the tail fit for the distributions considered (Navandar *et al.*, 2021) (Figure 3). The GEV data show points near the 45° line, indicating a better fit. Hence, the GEV distribution is retained as the best-fitting distribution.

Table 2 shows the parameters of the GEV distribution (μ , σ and κ) for all different combinations for the overestimation of speed. It can be seen that the μ for each set varies, with a maximum for the slow as compared to the medium and fast reactions for the combined dataset. This means the average of the slow-combined is higher than the others. Considering the gender effect on the μ of three categories, which are slow, medium and fast motion, the females show a higher value than the males. This means females are overestimating the speed more than males.

Though the mean for medium and fast motion for all combined data is higher than slow motion, they showed lower standard deviation (σ) values. These showed that as vehicle speed increased, participants tended to estimate speed more accurately with less variability. Considering gender, the female participants show greater variability in the dataset with larger μ and σ values. The shape parameter (κ) for all combinations for the overestimation of speed comes out to be negative. These indicate higher values (Bari

et al., 2022), thus implying that participants pressed the button too quickly; hence, there are fewer data points near the line.

6.2 Time anticipation (ZBA S5) test results

The participant's deviation times are studied across five categories: gender, age, driving experience (years), license availability, and vision for overestimation and underestimation of speed. As seen from the distribution fit analysis, the deviation time follows a GEV distribution; hence, nonparametric tests are used to determine whether there are significant differences between the groups. The Mann-Whitney two-sample test is a significant test for two variables (Chauhan *et al.*, 2021; Ibrahim *et al.*, 2021). Further, for the driving experience, the Kruskal-Wallis test has been used (Bari *et al.*, 2021b; Yelds & Burris, 2000). Both tests are evaluated at a 95% confidence interval.

6.2.1 Variation of deviation time in accordance with gender

The data for the male and female participants were separated into two categories: participants' response deviations in time from the mean position (target line) only in cases of overestimation, or positive deviation and participants' response deviations from the mean position (target line) only in cases of underestimation, or negative deviation. Table 3 shows the percentage of participants who responded to the three cases: slow motion, medium motion and fast motion,

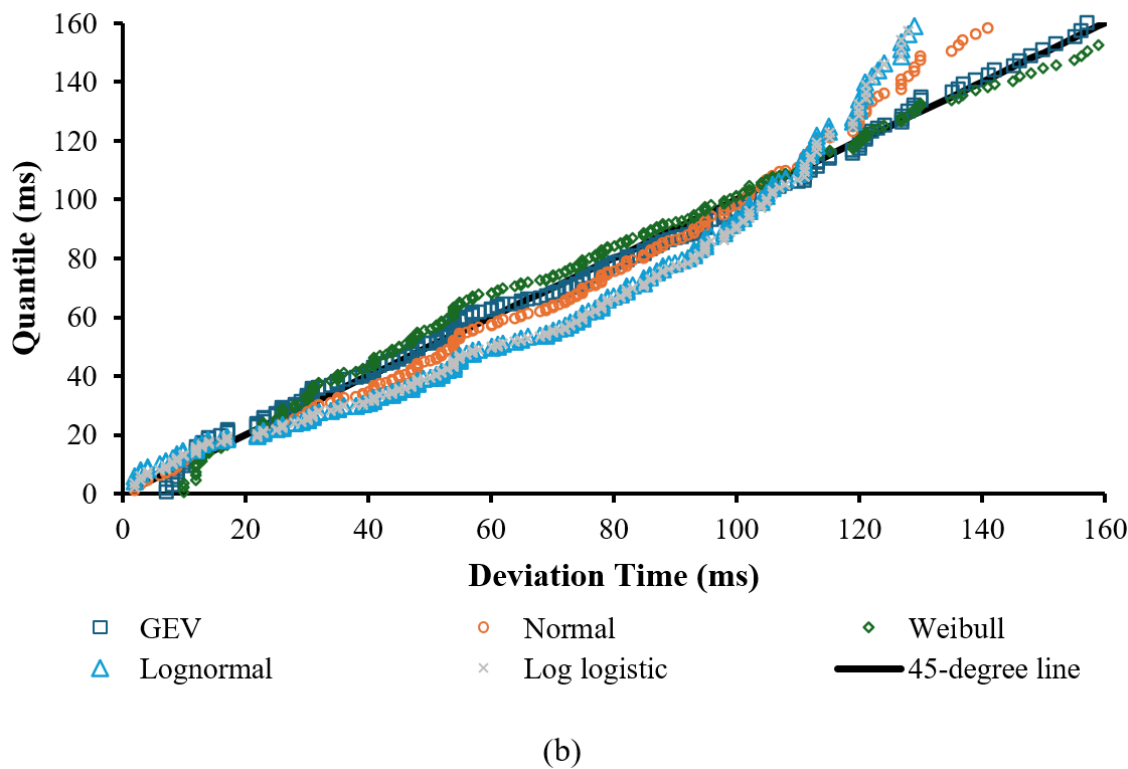
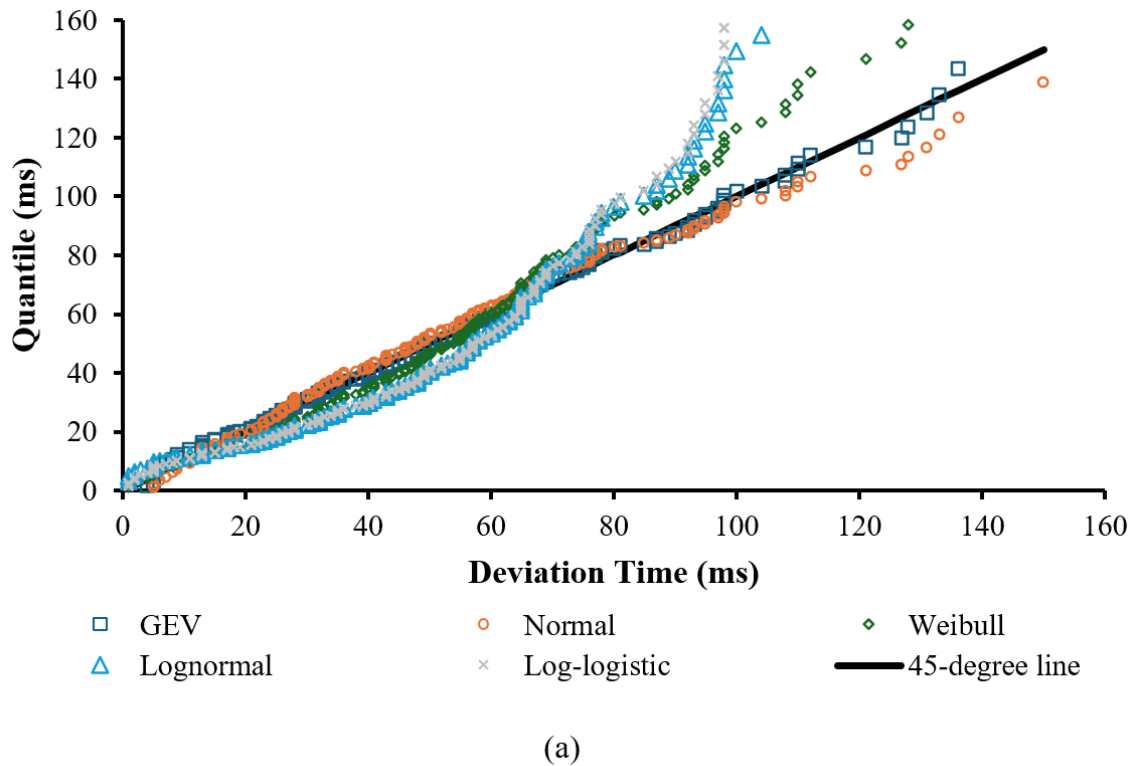


Figure 3. Quantile-Quantile (Q-Q) plot: (a) medium – male, b) Slow – combined participants

which caused positive (overestimation) and negative deviation (underestimation). It can be seen from Table 3 that, compared with males, female respondents tend to

Table 2. Parameters of the GEV distribution for the overestimation of speed

Parameters	Mean (ms)	Standard deviation (ms)	k	σ	μ
Slow – combined	73.78	47.59	-0.077	40.805	54.023
Medium – combined	54.60	33.31	-0.084	28.929	40.135
Fast – combined	49.09	24.92	-0.294	25.484	40.288
Slow – male	69.84	44.92	-0.077	38.377	51.597
Slow – female	84.76	53.18	-0.134	48.57	62.507
Medium – male	51.79	31.06	-0.103	27.303	38.849
Medium – female	62.16	37.95	-0.090	33.507	45.590
Fast – male	48.59	24.58	-0.281	24.697	40.251
Fast – female	50.47	25.94	-0.297	25.676	42.803

Table 3. Percentage variation of responses with respect to age

Parameter	Slow – male	Slow – female	Medium – male	Medium – female	Fast – male	Fast – female
All combined						
Positive deviation [overestimation] (%)	66.31	55.83	69.86	60.83	89.29	76.27
Negative deviation [underestimation] (%)	33.69	44.17	30.14	39.17	10.71	23.73
Gender wise variation of responses for the age group 18-20						
Positive deviation [overestimation] (%)	66.66	75.76	87.87	40.00	53.33	80.00
Negative deviation [underestimation] (%)	33.34	24.24	12.13	60.00	46.67	20.00
Gender wise variation of responses for the age group 21-30						
Positive deviation [overestimation] (%)	66.21	68.05	89.72	61.11	63.33	75.00
Negative deviation [underestimation] (%)	33.79	31.95	10.28	38.89	36.67	25.00

underestimate the speed in all three cases (the highest percentage of underestimation compared with males). In general, the faster vehicle speeds are overestimated and thus misjudged considering all combined data. When comparing the same scenario, e.g., Fast Case, the result shows that males (89.29%) are overestimating more than female subjects (76.27%) (Wan *et al.*, 2015). This means that females have a slightly lower time-anticipation ability than males. A similar result was observed by Mamcarz *et al.* (2023) in a study carried out with an average age of 25.9 years. On the contrary, Papić *et al.* (2020) for the pedestrian study showed that males are underestimating speeds more than females. Marković *et al.* (2025) found that participants overestimated speeds for the lower range (< 30km/hr) and underestimated speeds for the higher range of speeds (> 50km/hr). Considering the gender-wise variation with age, the results are the same as those observed for the combined one. In the 18-20 age group, females overestimate the lowest for medium-speed values (40.00%) and the maximum for higher-speed values (80.00%). Table 3 shows that females in

the 18 to 20 age group overestimate speed more than males do for both slow and fast motion. Overall (considering responses from both male and female participants), for the slow case, more than 60% of the total test subjects are overestimating the speed prediction. For the medium speed scenario, the female subjects underestimate the speed prediction comparatively by a larger margin than the male respondents. Figure 4 shows the variation in median deviation values across three cases by gender.

From Figure 4 (a) and Figure 4 (b), it can be seen that there is a significant difference in both Positive and Negative deviation times for slow-motion cases between male and female participants. Similarly, for the medium motion case, the same results are observed (Figure 4 (a) and Figure 4 (b)). For the fast motion case, not much significant variation is observed in accordance with gender. The Mann-Whitney test was performed to check whether statistically significant differences between various cases exist or not. The results are shown in Table 4 at a 95% confidence level. The *p-value* for slow motion (positive deviation *p-value* 0.049, negative deviation *p-*

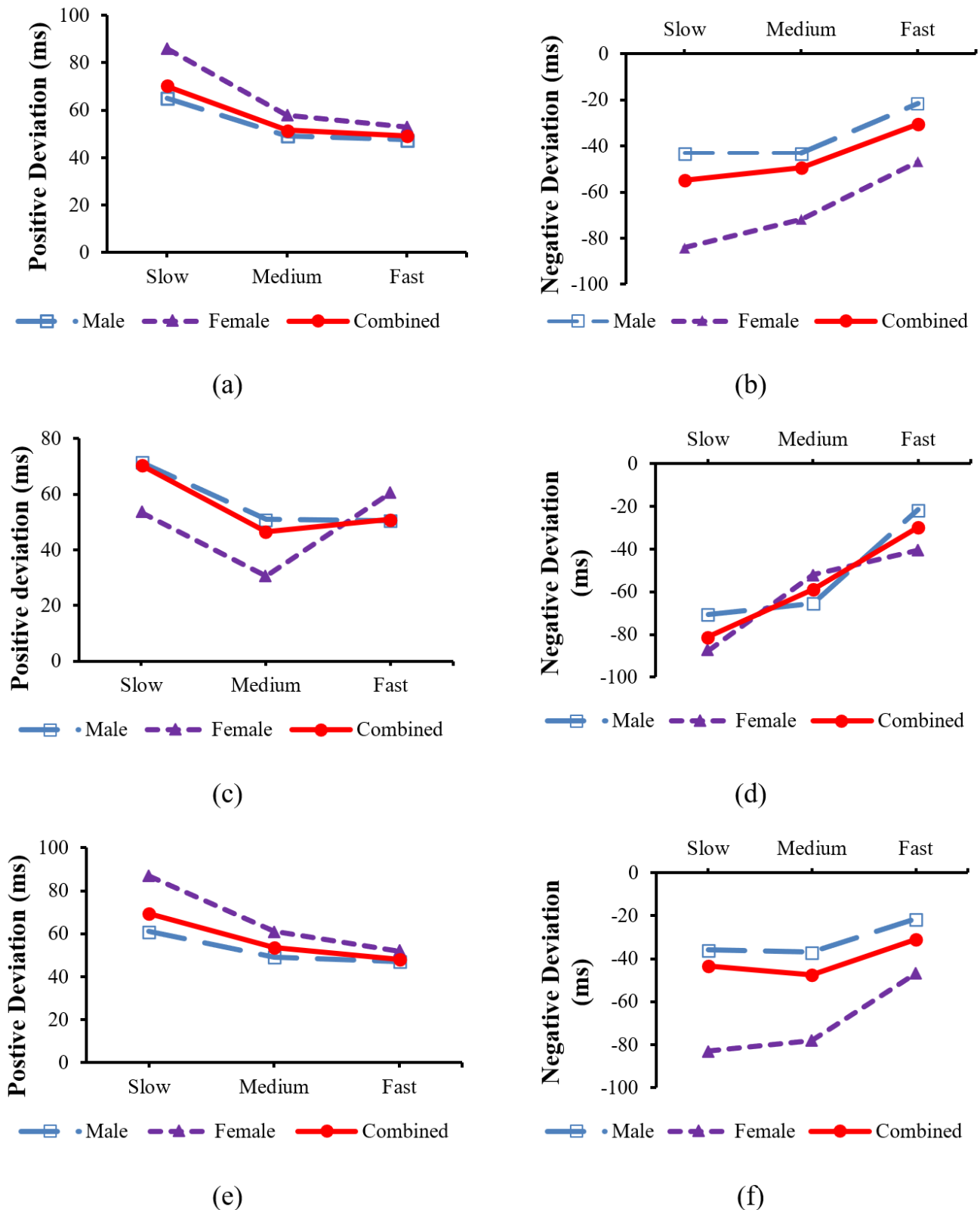


Figure 4. Gender wise variation of median values: (a) positive deviation – all combined (b) negative deviation – all combined (c) positive deviation – age 18-20 (d) negative deviation – age 18-20 (e) positive deviation – age 21-30 (f) negative deviation – age 21-30

Table 4. Results of the Mann-Whitney test for positive and negative deviation times in accordance with gender for all three motions

Particular	Slow – male	Slow – female	Medium– male	Medium– female	Fast – male	Fast – female
All Combined						
Positive deviation time		0.049		0.066		0.213
Negative deviation time		0.010		0.010		0.085
Age group 18-20						
Positive deviation time		0.043		0.048		0.061
Negative deviation time		0.098		0.128		0.145
Age group 21-30						
Positive deviation time		0.038		0.004		0.551
Negative deviation time		0.005		<0.001		0.091

Bold values show significant values at a 0.05 level of significance.

Cell value shows p-value

value 0.010) and medium (underestimation) (negative deviation *p*-value 0.010) is less than 0.05, which indicates that male and female participants' responses differ significantly from one another for overestimation as well as underestimation of speed. On the other hand, for the medium (overestimation) (*p*-value 0.066) and fast case (positive deviation *p*-value 0.213 and negative deviation *p*-value 0.085), no significant difference is observed between males and females. These results confirmed that on highways with higher speed limits, such as National Highways and Expressways, the speed estimation by any respondent will be the same regardless of gender. In slow cases, such as urban or village roads, there is a significant difference in deviation times, and hence the variation in responses can be seen between males and females. For both age groups for fast case, there is no significant difference observed (*p*-value >0.05).

6.2.2 Variation of deviation time in accordance with age and gender

To study the effect of age, the age data is separated into two distinct categories: first the individuals between the ages of 18-20 and second, those between the ages of 21-30. As seen from the literature, the response varies between youngsters, too, and hence, in the present study, age is divided into two groups (Mohanty & Samal, 2019). For these distinct groups, the variation in positive and negative deviations across the three cases of slow, medium, and fast motion is studied.

Table 5 shows the mean, median, standard deviation, kurtosis, skewness, minimum, maximum, and count for both overestimation and underestimation cases in the age group 18-20 years, by gender.

It can be seen that for slow and median motion, the median deviation times of males are greater than those of females for the overestimation case (e.g., Medium-Male: 51.00 ms, Medium-Female: 30.50 ms). On the contrary, for fast motion, the male deviation times are lower than those of females for both underestimation and overestimation. Considering the standard deviation, females show greater variability in deviation times across all three motions than males for overestimation (e.g., Slow-Male: 36.96 ms and Slow-Female: 75.21 ms). It can be said that, though males are underestimating speed more in slow (median values for male and female: 71.50ms and 53.50ms) and medium motion (median values for male and female: 51.00ms and 30.50ms) (urban road/village road) conditions, they are underestimating less on highways (median values for male and female: 50.50ms and 60.50ms) (fast case). On the other hand, in the underestimation case, the female shows higher median values for the low- and fast-motion cases.

From Figure 4 (c), it is observed that there is a significant difference between the deviation times (ms) of young male and female participants (age group 18-20) for the slow and medium motion of the test (Table 4). As the *p*-value for the overestimation case with slow

Table 5. Descriptive statistics of deviation time (ms) by gender for drivers aged 18–20 years

	Slow – male	Slow – female	Medium– male	Medium– female	Fast – male	Fast – female
Positive deviation time [Overestimation]						
Mean	66.16	79.92	54.18	43.69	49.84	51.42
Median	71.50	53.50	51.00	30.50	50.50	60.50
Standard Deviation	36.96	75.21	31.77	34.36	21.62	29.89
Kurtosis	-0.61	1.19	-0.63	0.62	-0.42	-1.29
Skewness	-0.05	1.25	0.34	1.29	0.07	-0.2
Minimum	0	8	1	10	5	0
Maximum	146	254	131	116	96	98
Count	52	36	68	19	42	38
Negative deviation time [Underestimation]						
Mean	-98.18	-82.89	-99.5	-69.86	-46.63	-66.83
Median	-70.50	-87.50	-65.50	-52.00	-21.50	-40.50
Standard Deviation	85.14	45.75	90.31	59.91	66.27	81.8
Kurtosis	-0.48	-0.79	-0.07	0.34	6.42	3.27
Skewness	-0.7	0.42	-1.16	-1.04	-2.47	-1.78
Minimum	-290	-158	-270	-205	-205	-222
Maximum	-1	-4	-10	-5	-7	-5
Count	26	12	10	29	36	10

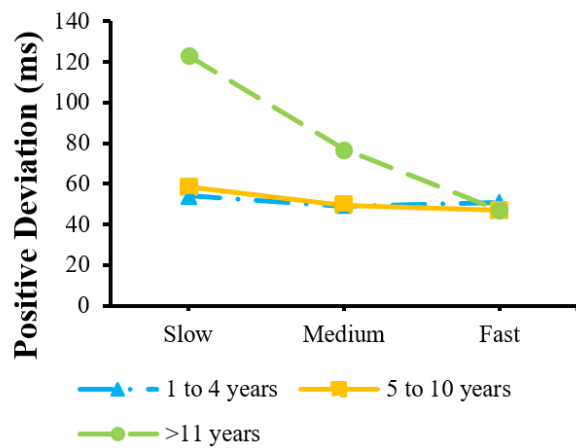
and medium motion is smaller than 0.05, it can be concluded that there is a significant difference in the deviation times (Table 4 and Figure 4 (c)). Also, for fast motion, no significant difference is observed for both over- and underestimation cases and for slow- and medium motion of under estimation (Figure 4 (c) and Figure 4 (d)). The results are supported by the Mann-Whitney test, too, with a *p-value* greater than 0.05 (Table 4).

A similar analysis has been carried out for the age group 21-30, and the descriptive statistics are shown in Table S2. Figure 4 (e) and 4 (f) show the variation in accordance with gender for the age group 21-30 for all three cases and two categories of deviations. It can be seen that, in both overestimation and underestimation, the median deviation times for females are greater than those for males. From Table 4, it can be observed that in the slow- and medium-speed cases, there is a significant difference in speed prediction results between male and female subjects in both under- and overestimation (Figure 4 (e) and 4 (f)). However, for fast motion, no significant difference was observed in either test (Table 4 and Figs. 4(e) and 4(f)).

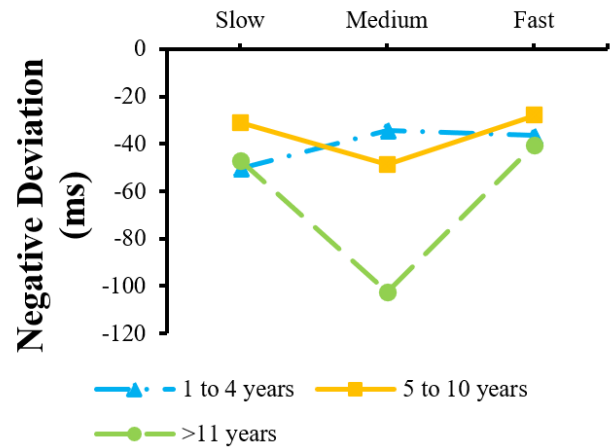
6.2.3 Variation of deviation time with respect to the driving experience on an aggregate level

Table S3 presents descriptive statistics for deviation times by driving experience in years. The driving experience is divided into classes of four by using the interval formula according to the data obtained (Kadiyali, 2008). It can be seen that with an increase in the experience level, the deviation times for the overestimation case decrease from slow motion to fast motion (Figure 5 (a)). Similar findings are obtained by Marković *et al.* (2025). On the other hand, for a particular motion, e.g., slow, the deviation time in the overestimation case increases with experience level (Figure 5 (a)).

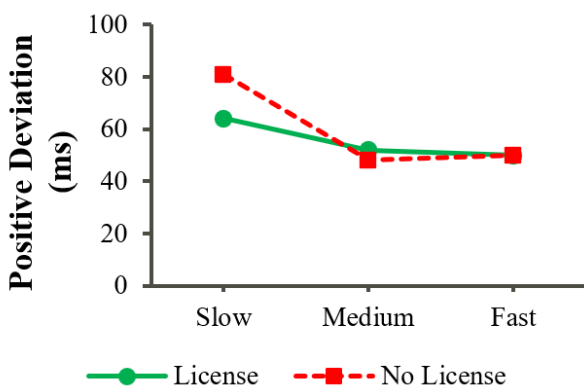
Considering the underestimation case, the trends in deviation times for 5 to 10 years and > 11 years are similar: first, lower median deviation times for slow motion, then higher for medium motion, and then again lower for fast motion (Figure 5 (b)). For the experience between 1 and 4 years, the median reaction time increases for medium motion, and then it increases again for fast motion (Figure 5 (b)). From Table S4, for the same experience level, the overestimation increases from slow motion to fast motion. Participants with more



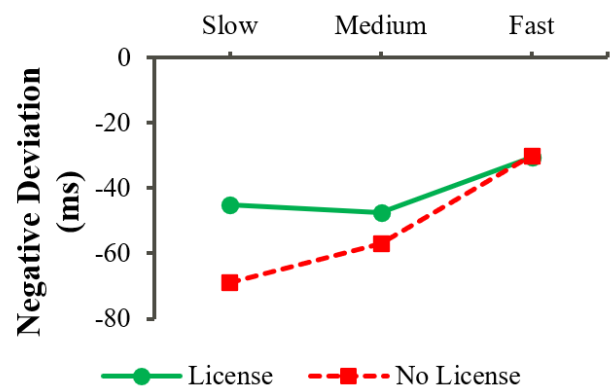
(a)



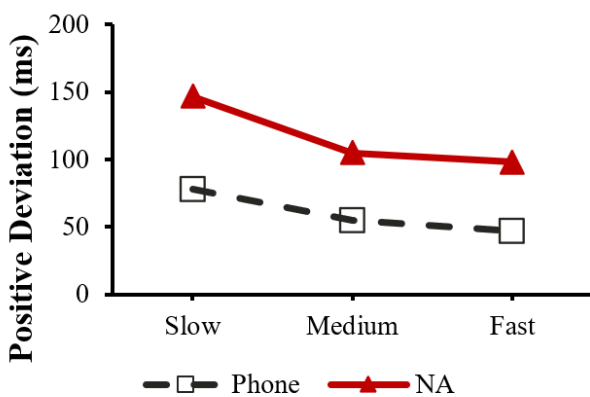
(b)



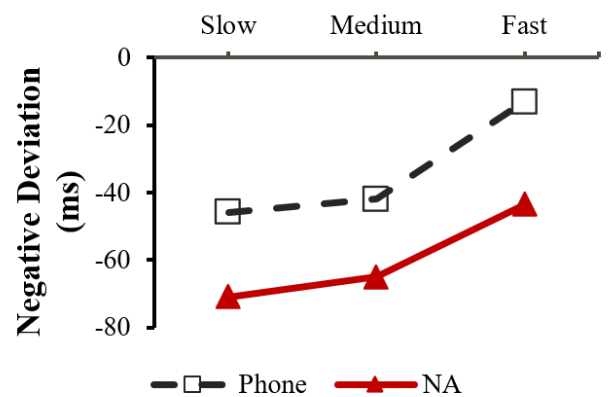
(c)



(d)



(e)



(f)

Figure 5. Variation in deviation times: a) positive according to driving experience, b) negative according to driving experience, c) positive according to license possession, d) negative according to license possession, e) positive according to phone user, f) negative according to phone user

than 11 years of driving experience tend to underestimate speeds.

Kruskal-Wallis test results at the 0.05 level of significance are shown in Table 6. From Table 6, it can be seen that, for the overestimation case, significant differences are observed in deviation times for the driving age groups 1 to 4 (p -value = 0.004) and >11 (p -value = 0.034), and 5 to 10 (p -value = 0.045) and >11 (p -value = 0.041), for both slow and medium motion (red part of Table 6). In the fast case, no significant difference was observed in either over- or underestimation for any motion (p -value > 0.05) (except 1 to 4 and > 11 for underestimation).

6.2.4 Variation of deviation time with respect to the driving license on an aggregate level

Table S5 presents descriptive statistics for individuals with and without a driving license. It can be seen that those without a driving license have more deviation times for the slow and medium motion case, but for the fast case, it is the same as that of a licensed driver (Figure 5). Thus, it can be said that the participants without a driving license are more likely to make errors on rural and urban roads than on the highways.

From Table S4, it can be seen that those with a license overestimate the speeds, while those who do not have a license underestimate the speeds for the slow and medium cases. For the fast motion case, both are overestimating the speed. Further, the significant difference can be seen for slow-motion estimation of speed (p -values 0.049 and 0.037 for positive and negative deviation, respectively) (Table 7). For medium and fast cases, no significant difference is observed (p -value > 0.05).

6.2.5 Variation of deviation time with respect to the use of mobile phones on an aggregate level

Now, the responses of participants using a phone while driving are compared with those of participants who do not use a phone while driving. Table S6 presents the descriptive

statistics for the deviation time by mobile phone. Figure 5 compares between phone users and non-users, assuming that “phone” denotes participants who use phones while driving and “NA” denotes participants who do not use phones while driving. From Figure 5, it is observed that there is a significant difference between phone users and non-users for all three motions, both in positive and negative deviations. The results of the Mann-Whitney test for the positive deviation case stated that there is no significant difference between the phone users and non-users (p -value > 0.05) (Table 7). For negative deviation, the slow (p -value = 0.007) and fast (p -value < 0.001) motions showed significant differences in responses between phones users and non-users. However, the medium motion did not show a significant difference. Along with these, the effects of hearing and vision are also checked, but no significant results are found and are therefore not shown in the analysis section.

6.3 Movement anticipation (ZBA S2) test results

ZBA S2 test in VTS comprises the simple and complex progressions. The simple progression test involves linear motion of a ball that mimics the real-world field conditions, such as driving on a straight path. The results resonate with the anticipation of a hazard during straight vehicle movement, such as when stopping at mid-blocks on the highway. On the other hand, the complex progression represents the scenario in which the driver must deal with multiple factors simultaneously, such as the speed and direction (e.g., lane change, merging, diverging) of a vehicle/pedestrian. The sinusoidal nature or the curvilinear motion of the ball in the test illustrates the non-compliant behaviour of pedestrians and vehicles on the road. It is evident from the literature that Indian traffic behaviour is non-lane-based and heterogeneous, the test results will represent the actual scenario for Indian traffic. In this test, along with the deviation in speed, the details of the variation in accuracy of predicting the location are also obtained. As

Table 6. Results of the Mann-Whitney test for positive and negative deviation times in accordance with driving experience for all three motions

Particulars	Group	State	1 to 4	5 to 10	>11	State
Slow	1 to 4	Positive deviation time [overestimation]	-	0.433	0.433	Negative deviation time [underestimation]
	5 to 10		0.175	-	0.433	
	>11		0.004	0.034	-	
Medium	1 to 4	Positive deviation time [overestimation]	-	0.152	0.025	Negative deviation time [underestimation]
	5 to 10		0.226	-	0.031	
	>11		0.045	0.041	-	
Fast	1 to 4	Positive deviation time [overestimation]	-	0.806	0.806	Negative deviation time [underestimation]
	5 to 10		0.768	-	0.806	
	>11		0.768	0.768	-	

Bold values show significant values at a 0.05 level of significance.

Table 7. Results of the Mann-Whitney test for positive and negative deviation times in accordance with the presence of a license and phone user

Particular	Slow – no license	Slow – license	Medium – no license	Medium – license	Fast – no license	Fast – license
Positive deviation time		0.049		0.348		0.439
Negative deviation time		0.037		0.089		0.530
Particular	Slow – phone user	Slow – non-phone user	Medium – phone user	Medium – non-phone user	Fast – phone user	Fast – non-phone user
Positive deviation time		0.298		0.089		0.381
Negative deviation time		0.007		0.143		<0.001

Bold values show significant values at a 0.05 level of significance.

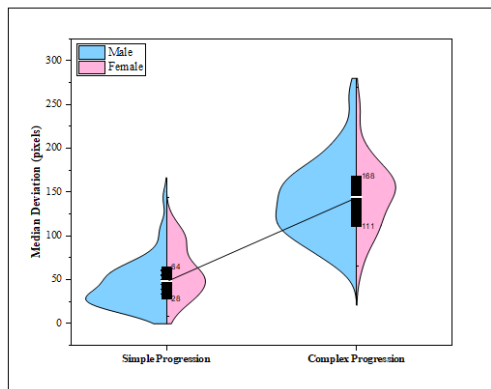
the results of deviation in speed are the same as those of ZBA S5, test S2 results of deviation in pixels (spatial error) are discussed with respect to gender, vision, phone user, driving experience and driving license possession for both simple and complex progression (Figure 6).

Table 8 Illustrates the median values of the participants' estimation results, which are compared across three categories: gender, vision, and phone user. The data demonstrate a 266.88% shift in simple progression compared with complex progression among males. In the case of females, the two test progressions changed by 182.77%. It states that the error in direction estimation increases as the motion condition becomes more complex. In terms of gender, whereas males experience a greater percentage change in progression, females tend to make more errors when predicting direction, implying that their accuracy in perceiving the position

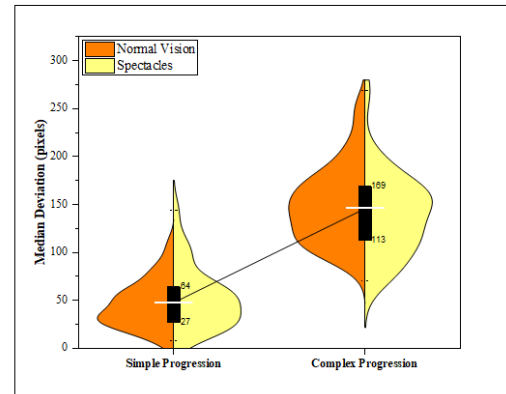
of a vehicle/object in motion is lower than that of males.

The above results were sustained among respondents with normal vision and spectacles, too, i.e., complex progression has more median deviation than simple progression. However, the effect of complex progression on normal vision drivers (percentage change = 261.72%) is more than that of the drivers with spectacles (percentage change = 183.67%). But the error deviation is greater for individuals with spectacles.

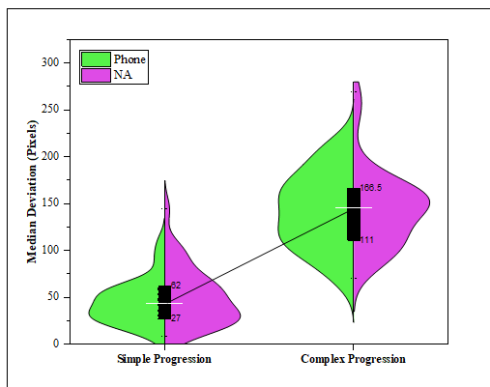
Similarly, the results reveal that using a phone reduces the accuracy of estimating the distance to an object, suggesting it increases the risk of a crash. Using mobile phones while driving reduces the driver's attention and increases the danger of a crash (Catalina Ortega et al., 2021). Further, the median for those without a driving license (52 pixels) is higher than that for those with a license (40



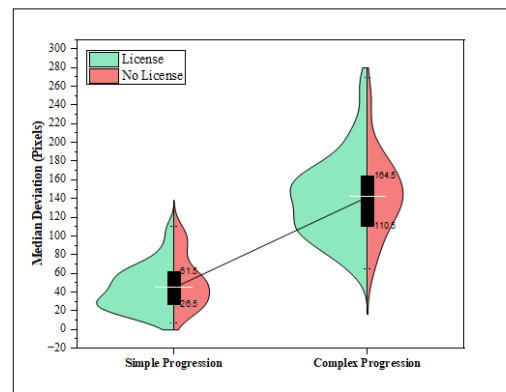
(a)



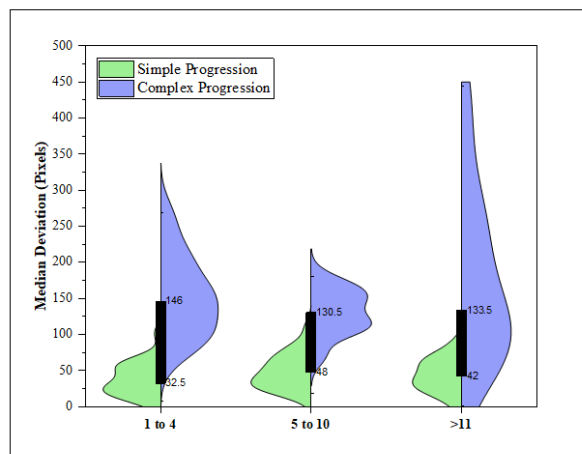
(b)



(c)



(d)



(e)

Figure 6. Variation of deviation of the median (spatial error) for phone user (a), gender (b), effect of vision (c), effect of mobile phone, (d) license possession, and (e) driving experience

Table 8. Percentage change over progression for gender, vision, mobile phone usage, possession of license and driving experience

Sr. No.	Particulars		Median values of progression (pixels)		% change (simple to complex progression)	p-value
			Simple progression	Complex progression		
1	Gender	Male	38.00	139.00	266.88%	<0.001*
		Female	52.00	148.00	182.77%	<0.001*
2	Effect of vision	Normal vision	41.00	147.00	261.72%	<0.001*
		Spectacles	49.00	139.00	183.67%	<0.001*
3	Effect of mobile phone	Phone user	47.00	145.00	208.51%	<0.001*
		Non-user	41.00	143.00	253.08%	<0.001*
4	Driving license	License	40.00	142.00	258.86%	<0.001*
		No license	52.00	147.00	181.73%	<0.001*
5	Driving experience	1 to 4	33.00	146.00	349.23%	<0.001**
		5 to 10	48.00	131.00	171.88%	<0.001**
		>11	42.00	134.00	217.86%	<0.001**

*for the Man-Whitney Test

**for Kruskal-Wallis Test

pixels). Lastly, the maximum error occurs for younger drivers (349.23%).

Further, as carried out for time anticipation, the statistical significance test has been carried out for movement anticipation too. From Table 8, the p-values are < 0.001 for all the cases, showing that there is a significant difference between the simple and complex values for all the cases.

7. Discussion

The present study examines time anticipation (speed perception) and movement anticipation (deviation errors) using VTS. Younger participants are considered for the study, and the effects of age, gender, driving experience, license possession, vision, and mobile phone use are studied. In the study, the positive deviation, i.e., the participant presses the button before the ball crosses the line, is termed as overestimation of speed. On the other hand, the negative deviation is termed as underestimation of speed. The data on deviation time is found to follow the GEV distribution (Table 1). The shape factor was negative in all cases, indicating larger values farther from the line (Table 2).

The analysis of deviation time by gender revealed that females underestimate speed more than males do, considering all combined

data and all three motions. This means that females have a slightly lower time-anticipation ability than males when observed as a combined group (without age variation). Similar findings are reported by Wu *et al.* (2017). The same results were obtained in a study by Wedagama & Dissanayake (2009), where female motorists and motorcyclists were more prone to fatal accidents than males. Considering age-wise variations, females in the 18 to 20 group overestimate more than males for slow and fast motion (Table 3). The statistical analysis showed that for slow and medium motion, there is a significant difference in gender-wise deviation times, but not for fast motion (expressways, NHs) (Table 4). For slow cases, such as urban or village roads, there is a significant difference in deviation times, and hence the variation in responses can be seen between males and females. Similar findings are reported in the study by Wu (2024), where higher errors are observed in low-complexity areas, such as suburban sections, while lower errors are observed in high-complexity areas, such as urban roads. On the other hand, Barat & Das (2025) found that as the speed of the two-wheeler increases, the speed estimation errors increase. Babic *et al.* (2022) found that the speed estimation is higher on rural roads. Also, they concluded that female respondents are more accurate in speed perception, which

contradicts the present study and studies by [Wu et al. \(2017\)](#) and [Hussain et al. \(2019a\)](#). Also, [Garach et al. \(2022\)](#) found that females perceived higher speeds better than males. [Marković et al. \(2025\)](#) found that female participants made more errors than male participants at lower speeds. Also, they found that participants had lower accuracy in speed perception on rural roads.

Considering the standard deviation, females show greater variability in deviation times across all three motions than males. It can be said that, though males underestimate speeds more in slow and medium motion (urban road/village road) conditions, they are underestimating speeds less on highways (fast case). On the other hand, in the underestimation case, the female shows higher median values for the low- and fast-motion cases. Similar results are observed by [Larue et al. \(2018\)](#). They concluded that for slower-moving trains, the speed perception errors were lower. Also, they found that the speeds were underestimated by upto 44% and thus concluded that people can't appreciate that the trains can move faster. On the other hand, the present results are in contradiction with the results obtained by [Marković et al. \(2025\)](#). They found that the males are underestimating the speeds. These gender differences in speed perception are significant for lower-speed motion. Similar to this, [Marković et al. \(2025\)](#) and [Papić et al. \(2020\)](#) showed that males are underestimating speeds more than females as pedestrians.

In the 18-20 age group, a significant difference between genders is observed only for the overestimation of slow and medium motion. It can be seen that for all other cases of underestimation and fast overestimation, there is no significant difference in speed perception (Table 4). It means that the younger and novice drivers are exhibiting more or less the same behavior. Overall, female drivers tend to overestimate the speed of moving objects in space, both for slow and fast motion (Table 3). On the other hand, for the 21-30-year age group, significant differences are observed for slow and medium motion in both over- and underestimation cases.

It can be seen that with an increase in the experience level, the deviation times in the overestimation case decrease from slow motion to fast motion (Figure 4 (a)). Similar findings are obtained by [Marković et al. \(2025\)](#) and [Papić et al. \(2020\)](#). Further, at the same experience level, the overestimation increases from slow motion to fast motion. The present findings contradict those with [Wu et al. \(2017\)](#). They found that, with increased speed, the percentage of underestimation increases among those without driving experience. For those with driving experience, underestimation is observed only at higher speeds. The Kruskal-Wallis results showed a significant difference for the overestimation case, with deviation times in the driving age groups 1 to 4 and >11, and 5 to 10 and >11, for both slow and medium motion (red part of Table 6). For fast motion, no significant difference was observed.

Further, those who don't have a driving license show a significant difference in speed estimation for the slow motion (Table 7). The effect of the phone is seen for the underestimation case (Table 7). The observations are based on the VTS and questionnaire survey; hence, the authors acknowledge that there may be a difference in the actual variation in deviation time due to the phone case. Helmut [Schrom-Feiertag et al. \(2019\)](#) found that pedestrians underestimate speeds in the virtual environment as compared to the field. [Hussain et al. \(2019b\)](#) found that simulator and field speeds vary, but the tendency and distribution remain the same.

The present study's findings suggest that the policy may consider including the time and movement anticipation test in the driving license test. Those with good speed perception can judge the speed of other vehicles and pedestrians also control their own speed. Specific speed perception programmes can also be justified for the target population (like young drivers). These implications are exploratory in nature and should be interpreted with caution until replicated in larger samples.

8. Conclusions

The present study was carried out to evaluate the factors that affect the time and movement anticipation of young drivers. The data from the ZBA S5 test in which participants who overestimated the speed follow a GEV distribution. Data analysis revealed that the positive error deviation for male participants was greater than for female participants, indicating speed overestimation. Among the 18-20 age group, female participants overestimated speed to a greater extent than male participants. With increased driving experience, the tendency to underestimate speed increases. Further, novice drivers make more errors at slower speeds. Similarly, no significant difference in error deviation was found between participants with normal vision and those with spectacles. Phone users made more errors in deviation time than non-users when estimating speed in slow motion. The results remained the same for ZBA S2 across simple and complex test progressions and cumulative tests, indicating that using a phone decreases the cognitive attention required for driving, thereby increasing crash probability, as per the literature.

The authors acknowledge that results may vary with more samples. Further, in the present study, univariate analysis was carried out across different factors as suggested in previous studies (Kerautret *et al.*, 2023; Liu *et al.*, 2021; Wu *et al.*, 2017; Wu, 2024). In future studies with larger data samples, multivariate analysis, including interaction effects, can be conducted. In the future, the same methodology can be applied to different driver types (e.g., bus drivers, truck drivers) and to different travel frequencies. Also, the effect of anger and aggression can be checked (Nergiz, 2025). Furthermore, these tests can be useful for reaction-time modelling. Real-time accident analysis can be performed using the parameters from the anticipation results.

CRediT contribution

Hrishikesh Deshpande: Data curation, Software, Visualization, Writing – original draft, Writing – review & editing. **Chintaman Bari:** Conceptualization, Data curation, Funding acquisition, Software, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Ashish Dhamaniya:** Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interests

The authors report no competing interests.

Declaration of generative AI use

During the preparation of this work the authors used Grammarly in order to have grammar checking. The output was reviewed and revised by the authors who take full responsibility for the content of the publication.

Prior dissemination declaration

This manuscript presents original work that has not been previously published or disseminated in any form.

Ethics statement

The current study, conducted with human participants, was reviewed and approved by the Internal Research Committee (IRG) of the Mahindra University, Hyderabad, in accordance with the funding and data collection (IRP/2024/3). It was advised to take informed consent from participants during data collection, and it was followed strictly. Participants provided their written informed consent to participate in this study.

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Data availability statement

Data sharing is not applicable, as no datasets were generated or analysed for this study.

Code availability statement

Code sharing is not applicable, as no custom code or scripts were developed or used for this study.

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