Evaluating the Need for Seatbelts in Auto Rickshaws: A Comparative Analysis of Passenger Acceleration and Safety Measures in Indian Road Transport

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Background Information:
An auto rickshaw, also known as an auto, rickshaw, or tuk-tuk, is a three-wheeled motorized vehicle commonly used for transportation in many countries, particularly in India and other South Asian countries. Auto rickshaws play a vital role in urban transportation systems, especially in developing countries, by providing an affordable and efficient means of travel. Usually used for short distance travel and last mile connectivity in both urban and suburban areas. Usually having an open cabin with bench seating the question of auto rickshaw safety is an extremely imperative one. Safety belts have become a necessity in recent years in all modes of transportation including cars, buses, airplanes etc. The use of seatbelts has grown dramatically since the introduction of the 3-point seatbelt in 1959. Yet seatbelts are still not available in one of the most widely used modes of transport, autorickshaws.

Problem Statement:
Despite the extensive use of rickshaws in urban areas such as Gurugram these vehicles have no safety mechanism for passengers or drivers.
In 2018 5.9% of all road accidents in that year were attributed to auto Rickshaw related collisions (*Road Accidednts in India - 2018.cdr*, 2019). 56% of all accidents were a result of 'Head on collision', 'Hit and Run' or 'Hit from the Back'. Vehicle to vehicle collisions made up 52.2% of the cases of accident related deaths. The public perception of auto rickshaws is mainly unsafe under 2 major categories which is unsafe structure and unsafe vehicle dynamics (Priye & Manoj, 2020, #). Unsafe structure refers to the lack of stable structure, railings, coverings and lack of rear-end protection. Unsafe dynamics refers to the fear of over-turning and reckless driving by auto rickshaw drivers. A study conducted in 2017 on the awareness of maximum permissible speed limit of e-rickshaws in Burdwan Municipality indicated that 78.2% were unaware of speed limits (Goswami et al., 2018, #). Hence the need for seatbelts in auto rickshaws in pertinent as the use of auto-rickshaws and e-rickshaws in predicted to grow in the future.(insert stat backing this claim)

Method of Data Collection:
Data was collected using the Phyphox app, specifically utilizing the acceleration monitor feature, which excludes acceleration due to gravity. Acceleration data was recorded along the x, y, and z axes while the vehicles were in motion and displayed as line graphs. The acceleration monitor was used during travel in both cars and auto rickshaws on various types of roads, including highways, wide roads, and uneven roads with potholes.

The collected data was then exported to Excel sheets, where the focus was primarily on the acceleration along the x-axis. The data for cars and auto rickshaws was monitored and compared to analyze the differences in acceleration experienced by passengers in these vehicles

Objectives and Research Questions:

The objective of this research paper is to highlight and analyze the differences in linear acceleration experienced by a passenger when riding in an auto rickshaw compared to a commercial car. In 2018, there were approximately 27,400 road accidents in India involving auto rickshaws (Government of India, 2018). By analyzing the acceleration data and comparing it with that of a car, which is equipped with safety features and provides a smoother ride, I aim to emphasize the necessity of seatbelts in auto rickshaws.

Abstract:

The lack of safety features in Auto rickshaws poses a huge problem as they serve as the main ‘last mile’ or short distance transportation vehicles. The lack of basic protective features such as seat belts which are seen in more secure vehicles such as cars and buses highlights the lack of proper consideration amongst manufacturers for the necessity of seatbelts in Auto Rickshaws. This study focuses on highlighting the jerks and accelerations experienced by a passenger in an Auto rickshaw and serves to further provide perspective by comparing similar distance and route accelerations experienced by passengers in cars. The data was collected using the acceleration monitor in 3 axes available through the phone app Phyphox. Data was collected in collaboration with Rapido from an auto driver commuting chiefly in Gurugram. Over the course of 48 hours. This data was compared to data collected from various car passengers traveling in similar areas as that of the auto. The results show significantly higher jerks experienced by a passenger in an Auto rickshaw traveling the same route compared to a passenger traveling in a car. Data highlights that the change in acceleration experienced in an auto ride is also significantly higher than in a car. This research demonstrates the higher risk to human safety and health posed by an Auto rickshaw when compared to a car and hence emphasizes the necessity for seatbelts in Auto rickshaws to reduce road accident related injuries and improve the public perception of safety in autos.

Methodology:

The app used to collect the acceleration data is: Phyphox (physical phone experiments) is a free app that turns smartphones into scientific instruments using built-in sensors. It allows users to conduct experiments in physics, engineering, and related fields by measuring acceleration, sound, light, and other data. It's widely used for educational and research purposes. Using the 'acceleration without 'g' feature on the phone, data was collected from both cars as well as auto rickshaws. The "Acceleration without g" experiment in Phyphox measures linear acceleration while excluding the effect of gravity. Normally, smartphone accelerometers measure both the forces of motion and gravity, which can be challenging to separate. This experiment isolates the motion by subtracting the gravitational component. The process followed is: 1)**Data Collection**: The phone's accelerometer records the total acceleration (including gravity) in three axes (x, y, z). 2)**Gravity Removal**: The app applies an algorithm to remove the gravitational acceleration (9.81 m/s^2). This is done by identifying the gravity vector based on the phone's orientation. 3)**Linear Acceleration**: Once gravity is subtracted, the remaining values represent only the acceleration caused by movement, allowing for pure motion analysis. The Phyphox app has been utilized in many previous studies for example; to measure the moment of inertia of a hollow cylinder (Yasaroh et al., 2021, #). Additionally, it was also applied to perform collaborative experiments at the college level including measurement of the frequency of oscillation in a spring experiment (Staacks et al., 2022, #). In this paper the app has been used in 2 vehicles over the course of 7 days; i)Bajaj Re Compact 4 seater Petrol Auto Rickshaw 236.2 Cc Engine And 8 Liter Tank Capacity ii) Toyota Innova Crysta 7-8 seater 65 liter capacity petrol vehicle with 2393 cc, 147.51 bhp, and 343 Nm of torque (The Economic Times, 2019). The phone used to collect data on the car was an iphone XR IOS 16.6.1 and the phone used to collect data in the auto was a One+ 3 Android 6.0.1. The phone in the car was placed on the rear seat adjacent to the passengers' legs allowing it to experience each 'jerk' and acceleration equal to that experienced by a rear-seat passenger. In the auto the phone was placed on a holder next to the steering of the auto so the motion measured is most close to the acceleration experienced by the driver of the auto. The data collected was plotted in real-time on 3 individual graphs the x, y,z graph; the horizontal,vertical and lateral respectively. This paper will focus primarily on the horizontal and vertical acceleration graphs (i.e. the x and y graphs) The y graph denoted the acceleration experienced due the braking, and gear shifting. The z graph denotes the acceleration experienced due the road bumps, speed breakers and is a direct indicator of the effectiveness of the suspension system of the car and auto-rickshaw.

Parameters for Ride Comfort and Safety:

All modern cars including the Toyota Crysta are designed with certain common features responsible for improving ride comfort and safety. Ride comfort primarily refers to the vehicle vibrations in the range of 0.5-25 Hz which is a result of road roughness and it is transmitted to the passenger via shock absorbers, tires, suspension and seats (Wu et al., 2023, #).

Listed below are the key features of the Innova Crysta responsible for improved safety and comfort:

Seatbelts:

Seat belts are essential safety devices in cars that secure occupants during sudden stops or collisions. They reduce the risk of injury by restraining passengers, preventing impact with the vehicle's interior, and minimizing movement. Seat belts have proven highly effective in lowering fatalities and serious injuries in car accidents (Chaubey et al., 2018, #).

ABS(Anti Lock Braking System), EBD, BA:

Anti-lock Braking System (ABS) is a safety technology in vehicles designed to prevent the wheels from locking up during braking. This helps maintain traction between the tires and the road, allowing drivers to maintain steering control even in emergency braking situations. ABS automatically adjusts the brake pressure to prevent skidding, improving safety on slippery or uneven road surfaces. It is especially useful in preventing accidents by reducing the likelihood of losing control during hard braking or sudden stops, making vehicles safer and more stable in various driving conditions. (Qasem & Abdullah, 2024, #)

Electronic Brakeforce Distribution (EBD) is a system that works alongside ABS to automatically vary the braking force applied to each wheel, based on road conditions, vehicle load, and speed. It ensures optimal braking efficiency by distributing more force to wheels with greater traction, improving stability and reducing stopping distances. (Grover et al., 2018)

Brake Assist (BA) is a safety system that helps drivers apply maximum braking power during emergency stops. It detects when the driver is braking suddenly but not with full force and automatically increases brake pressure to reduce stopping distances. BA enhances overall braking performance, especially in critical situations.

Steel Constructional Material for Car Body:

The car body is mainly made up of steel due to its high strength and energy intensity. Energy intensity refers to the ability to absorb impact energy on collision. Multiple types of steels are used along with many other alloys and plastics serving particular purposes. (Hovorun et al., 2017, #)

Airbags:

Airbags are essential safety devices in vehicles designed to protect occupants during collisions. They inflate rapidly upon impact, cushioning passengers and reducing the risk of serious injuries. Common types include frontal, side, and curtain airbags, each targeting specific areas to enhance

Double-wishbone Suspension at the Front and a Four-link Suspension at the Rear:

The Double-wishbone suspension present in the front is also known as the 'double A arm' connecting the wheels to the chassis. It consists of two 'A' shaped arms with shock absorbers and coils in between responsible for reducing the vertical movement of the car while also improving car cornering. (Shrivastva et al., 2019, #)

The Four-link rear suspension provides for greater adjustability to the car depending on road roughness while also increasing traction and stability due to multiple points of contact between the wheel and the chassis.

Picture by Simiprof (talk) - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=25750309)

Figure 1: An illustration of double-wishbone suspension

The causes for lack of comfort in auto-rickshaws include:

Leaf Spring Suspension System in the Rear (Shirinzadeh et al., 2009, #):

This consists of flat strips on metal "metal leafs" with an elliptical shape placed on top of each other with a gradation in their sizes. These absorb large forces and thus reduce vertical motion of the vehicle. They are considered suitable mainly for commercial transport vehicles and trucks. The design is relatively simpler than the double wishbone suspension

used in cars, and are considered less comfortable due to interleaf friction. Leaf spring suspension has a much higher effective-ride stiffness and are more stiff compared to wishbone suspension providing a rougher ride especially over uneven roads as seen mainly in India (Tevema, 2024)

Figure 2: An example of leaf spring suspension

Picture By Jim Gill http://www.flmvpa.org/articles/armymotors_gill.htm, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2230192

Lightweight and Rigid Frame: Auto-rickshaws are designed to be lightweight for fuel efficiency and easy maneuvering in urban areas. However, this light frame can amplify vibrations and make the vehicle more susceptible to instability when encountering bumps, potholes, or when carrying heavier loads.

Single Front Wheel Steering: The single front wheel is responsible for both steering and stabilizing the vehicle, reducing its ability to grip the road during turns, particularly when carrying passengers or cargo in the back. This design makes three-wheelers more likely to skid or lose control compared to four-wheeled vehicles.

Weight Distribution While Turning: The weight of the front axle is significantly less than the weight on the rear as the passengers and battery box are placed at the rear while the front is driven by a singular wheel. Due to this while turning the vehicle is very easily liable to oversteer as the speed increases the steering angle continually decreases making it very easy for the vehicle to overturn at speeds where a car would remain stable. (Austin et al., 2015, #)

Higher center of gravity: Through experimentation it has been found that the center of gravity of a 3-wheeler auto-rickshaw is behind the neutral steering point causing oversteer. Additionally for better stability according to Patrick F, (2010), On The Golden Rule of Trike Design(Austin et al., 2015, #).The center of gravity should ideally be at a height less than half the track length (the distance between centrelines of wheels attached on the same axle). In reality the center of gravity is at a height much higher than half the track width making it unstable.

Thus, the above concepts lead one to believe that auto-rickshaw rides would show a much greater ‘roughness’ or discomfort in comparison to cars. The same has been validated in the graphs below comparing the acceleration in x,y axis between an Innova Crysta and a Bajaj RE Auto.

Acceleration Graphs and Analysis

The app Phyphox was used in both the Innova Crysta and the Bajaj RE Auto and acceleration data was collected in both along the x, y, z axis.

The device was fixed such that the y-axis of the phone was in line with the axis of the vehicle. The y axis graph indicates the acceleration recorded during forward or backward straight line motion of the vehicle thus, it provides a metric of the acceleration and de- acceleration experienced in the vehicles in the driving direction. The x-axis graph indicates the lateral acceleration of the vehicle perpendicular to the driving direction in the horizontal plane, thus it highlights the acceleration irregularity during turning. The z-axis documents the vertical acceleration and thus gives an effective measure of the 'jerks' experienced due to road conditions and suspension effectiveness. (Wang, 2020)

Assuming limits in accordance with 'Standards for passenger comfort in automated vehicles: Acceleration and jerk' (de Winkel et al., 2023, #) the upper limit for what passengers perceive comfortable for lateral acceleration is taken as 0.98 (m/s^2). The limit for passenger comfort for longitudinal acceleration is taken in accordance with 'A survey of longitudinal/linear acceleration comfort studies department of transportation' (Hoberock, 1976)Thus, for linear acceleration the upper limit for comfort is taken as 1.47 (m/s^2). Since vertical acceleration is an inherently unfavorable condition to comfort as it quantifies the 'bumpy-iness' of the ride, it has been compared between the car and auto purely based on the amplitude and magnitude of irregularity.

The assumed values of threshold acceleration have been taken from 2 individual research papers on linear and lateral passenger comfort standard, yet these values vary from those given in other literature based on the method of research, passenger demographic and subjectivity of the research thus, these values are not universally standard but for the purpose of this paper the following values have been assumed.

Figure 3: Indicating the orientation of the axes on the phyphox app

Auto:

Acceleration Graph Along y-axis i.e.Linear (along direction of motion) Acceleration

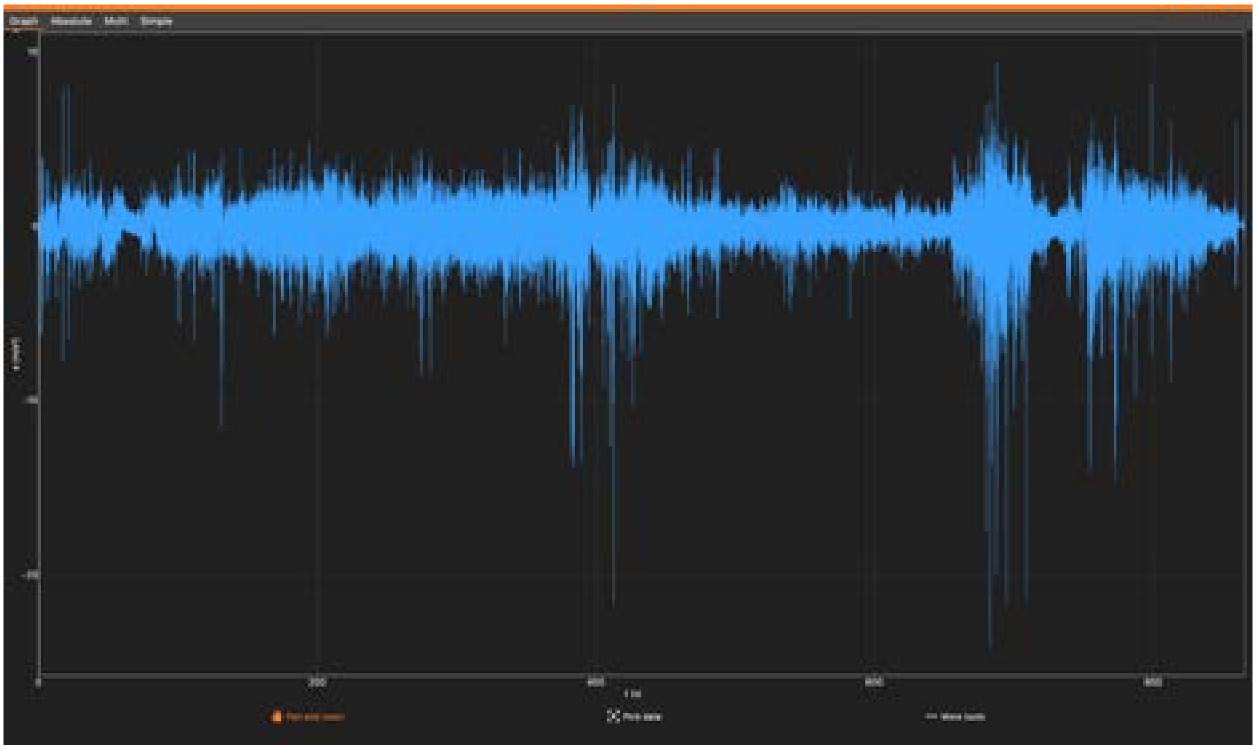


Figure 4:Graph generated by Phyphox app of y-axis acceleration in auto

Description:

The graph indicates both positive and negative peaks with majorly steep slopes between successive fluctuations. The lines appear extremely condensed thus indicating that the number of fluctuations in linear acceleration per second is extremely high thus the frequency of fluctuation (i.e acceleration change) is extremely high. The positive region of the graph highlights when the auto is speeding up (the speed is increasing); the negative region indicates when the auto is slowing down (speed is decreasing). When the acceleration is zero the auto can be assumed to be moving with a constant velocity. From the graph it is clear that the auto is almost never moving at a constant speed instead constantly alternating between accelerating and decelerating thus subjecting the passenger and driver to constantly changing conditions. From the graph it is clear that the extent of deceleration is very high with some peak values including -21.61 and -24.13 (m/s^s) additionally the slope of the lines is tending to zero indicating that the acceleration was not gradual.

	A	B
1	Time (s)	Linear Acceleration y (m/s^2)
2	0.133943986	-0.218791723
3	0.138918351	-0.208964348
4	0.143862199	-0.188729048
5	0.148806047	-0.363340616
6	0.153780412	-0.298873425
7	0.15872426	-0.27614975
8	0.163698625	-0.272613049
9	0.168642473	-0.201630831
10	0.17358632	-0.185320616
11	0.178560685	-0.219953299
12	0.183504533	-0.211373091
13	0.188448381	-0.19613719
14	0.193422746	-0.132599354
15	0.198366594	-0.036271572
16	0.203340959	0.010750294
17	0.208284807	-0.051189423
18	0.213259172	-0.12400794
19	0.218203019	-0.208243132
20	0.223146867	-0.16608119
21	0.228121232	-0.154755592
22	0.23306508	-0.16625452
23	0.238039445	-0.168845177
24	0.24301381	-0.174039841
25	0.247957658	-0.186322689
26	0.252932023	-0.242912531
27	0.257875871	-0.277551651
28	0.262819719	-0.265089512
29	0.267794084	-0.220270395
30	0.272737932	-0.145722866
31	0.277712297	-0.123540163
32	0.282656144	-0.12906909
33	0.287599992	-0.171473026
34	0.292574357	-0.22013402
35	0.297518205	-0.214392662
36	0.30249257	-0.213721991
37	0.307436418	-0.177937508
38	0.312410783	-0.166110039
39	0.317354631	-0.168521881
40	0.322298478	-0.246048212
41	0.327272844	-0.235522509
42	0.332216691	-0.23302412
43	0.337191057	-0.236248732
44	0.342134904	-0.271168947
45	0.347078752	-0.271128893
46	0.352053117	-0.280658484

The data from the above graph was then exported to Excel where the data stamp per second was recorded individually.

Figure 5: The data of acceleration on y-axis as displayed on excel

The acceleration in the y-axis was compared with the upper limit value of 1.47 m/s^s using the 'IF' function in excel. Each data was then categorized and 'comfortable' or 'uncomfortable' based on the result of the 'IF' function. The number of 'comfortable'

and 'uncomfortable' was then calculated using the 'COUNTIF' function.

	A	B	C	D	E
1	Time (s)	Linear Acceleration y (m/s^2)	comfortable	Comfortable	Uncomfortable
2	0.133943986	-0.218791723	comfortable	60903	4633
3	0.138918351	-0.208964348	comfortable		
4	0.143862199	-0.188729048	comfortable		
5	0.148806047	-0.363340616	comfortable		
6	0.153780412	-0.298873425	comfortable		
7	0.15872426	-0.27614975	comfortable		
8	0.163698625	-0.272613049	comfortable		
9	0.168642473	-0.201630831	comfortable		
10	0.17358632	-0.185320616	comfortable		
11	0.178560685	-0.219953299	comfortable		
12	0.183504533	-0.211373091	comfortable		
13	0.188448381	-0.19613719	comfortable		
14	0.193422746	-0.132599354	comfortable		
15	0.198366594	-0.036271572	comfortable		
16	0.203340959	0.010750294	comfortable		
17	0.208284807	-0.051189423	comfortable		
18	0.213259172	-0.12400794	comfortable		
19	0.218203019	-0.208243132	comfortable		
20	0.223146867	-0.16608119	comfortable		
21	0.228121232	-0.154755592	comfortable		
22	0.23306508	-0.16625452	comfortable		
23	0.238039445	-0.168845177	comfortable		
24	0.24301381	-0.174039841	comfortable		
25	0.247957658	-0.186322689	comfortable		
26	0.252932023	-0.242912531	comfortable		
27	0.257875871	-0.277551651	comfortable		
28	0.262819719	-0.265089512	comfortable		
29	0.267794084	-0.220270395	comfortable		
30	0.272737932	-0.145722866	comfortable		
31	0.277712297	-0.123540163	comfortable		
32	0.282656144	-0.12906909	comfortable		
33	0.287599992	-0.171473026	comfortable		
34	0.292574357	-0.22013402	comfortable		
35	0.297518205	-0.214392662	comfortable		
36	0.30249257	-0.213721991	comfortable		
37	0.307436418	-0.177937508	comfortable		
38	0.312410783	-0.166110039	comfortable		
39	0.317354631	-0.168521881	comfortable		
40	0.322298478	-0.246048212	comfortable		
41	0.327272844	-0.235522509	comfortable		
42	0.332216691	-0.23302412	comfortable		
43	0.337191057	-0.236248732	comfortable		
44	0.342134904	-0.271168947	comfortable		
45	0.347078752	-0.271128893	comfortable		
46	0.352053117	-0.280658484	comfortable		
47	[illegible]	[illegible]	comfortable		

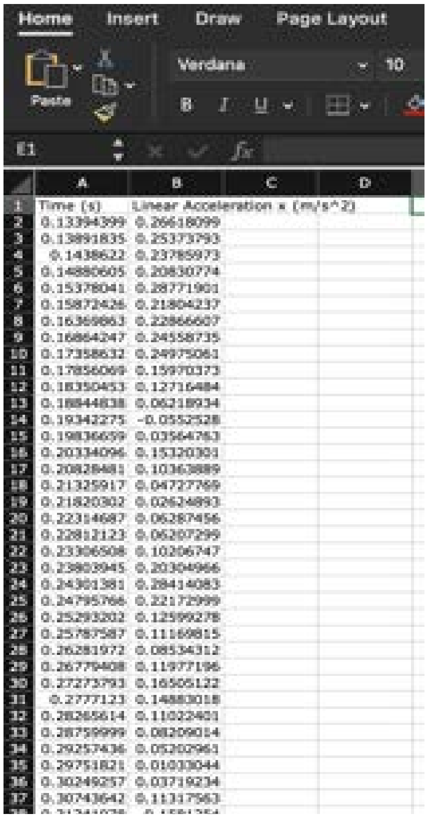
Figure 6:The data of acceleration on y-axis as displayed on excel, after applying the 'IF' and 'COUNTIF' formula

Acceleration Graph Along x-axis i.e.Lateral (turning) Acceleration

Figure 7:Graph generated by Phyphox app of x-axis acceleration in auto

Description:

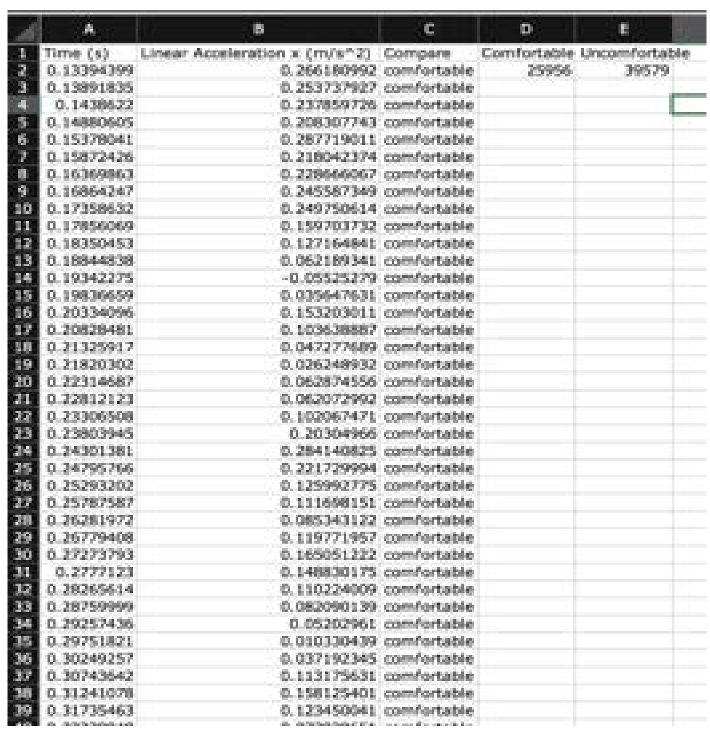
The graph indicates the acceleration experienced during lateral motion, thus it highlights the fluctuations in speed during over-takes, lane changing and turning motion of the auto. The positive region of the graph indicates acceleration while the negative part indicates deceleration. The lines appear extremely condensed thus indicating that the number of fluctuations in lateral acceleration per second is extremely high thus the frequency of fluctuation (i.e acceleration change) is extremely high.The slopes of each peak line tends to zero thus the change in acceleration is not gradual or smooth be extremely sudden or abrupt. The graph indicates momentary extremes in acceleration which can be attributed to extremely sudden movement of the vehicle resulting in changes in its lateral acceleration i.e. swerving or jerk-motion. Peak values including 13.05 and 20.13 (m/s^2)



	A	B	C	D
1	Time (s)	Linear Acceleration x (m/s^2)		
2	0.13394399	0.26618099		
3	0.13891835	0.25373793		
4	0.1438622	0.23785973		
5	0.14880605	0.20830774		
6	0.15378041	0.28771901		
7	0.15872426	0.21804237		
8	0.16369863	0.22866607		
9	0.16864247	0.24558735		
10	0.17358632	0.24975061		
11	0.17856069	0.15970373		
12	0.18350453	0.12716484		
13	0.18844838	0.06218934		
14	0.19342275	-0.0552528		
15	0.19836659	0.03564763		
16	0.20334096	0.15320301		
17	0.20828481	0.10363889		
18	0.21325917	0.04727769		
19	0.21820302	0.02624893		
20	0.22314687	0.06287456		
21	0.22812123	0.06207299		
22	0.23306508	0.10206747		
23	0.23803945	0.20304966		
24	0.24301381	0.28414083		
25	0.24795766	0.22172999		
26	0.25293202	0.12599278		
27	0.25787587	0.11169815		
28	0.26281972	0.08534312		
29	0.26779408	0.11977196		
30	0.27273793	0.16505122		
31	0.2777123	0.14883018		
32	0.28265614	0.11022401		
33	0.28759999	0.08209014		
34	0.29257436	0.05202961		
35	0.29751821	0.01033044		
36	0.30249257	0.03719234		
37	0.30743642	0.11317563		

The data from the above graph was then exported to Excel where the data stamp per second was recorded individually.

Figure 8: The data of acceleration on x-axis as displayed on excel



	A	B	C	D	E
1	Time (s)	Linear Acceleration x (m/s^2)	Compare	Comfortable	Uncomfortable
2	0.13394399	0.2661180992	comfortable	25956	39579
3	0.13891835	0.253737927	comfortable		
4	0.1438622	0.237859726	comfortable		
5	0.14880605	0.208307743	comfortable		
6	0.15378041	0.287719011	comfortable		
7	0.15872426	0.218042374	comfortable		
8	0.16369863	0.228666067	comfortable		
9	0.16864247	0.245587349	comfortable		
10	0.17358632	0.249750614	comfortable		
11	0.17856069	0.159703732	comfortable		
12	0.18350453	0.127164841	comfortable		
13	0.18844838	0.062189341	comfortable		
14	0.19342275	-0.05525279	comfortable		
15	0.19836659	0.035647631	comfortable		
16	0.20334096	0.153203011	comfortable		
17	0.20828481	0.103638887	comfortable		
18	0.21325917	0.047277689	comfortable		
19	0.21820302	0.026248932	comfortable		
20	0.22314687	0.062874556	comfortable		
21	0.22812123	0.062072992	comfortable		
22	0.23306508	0.102067471	comfortable		
23	0.23803945	0.20304966	comfortable		
24	0.24301381	0.284140825	comfortable		
25	0.24795766	0.221729994	comfortable		
26	0.25293202	0.125992775	comfortable		
27	0.25787587	0.111698151	comfortable		
28	0.26281972	0.085343122	comfortable		
29	0.26779408	0.119771957	comfortable		
30	0.27273793	0.165051222	comfortable		
31	0.2777123	0.148830175	comfortable		
32	0.28265614	0.110224009	comfortable		
33	0.28759999	0.0820901139	comfortable		
34	0.29257436	0.05202961	comfortable		
35	0.29751821	0.010330439	comfortable		
36	0.30249257	0.037192345	comfortable		
37	0.30743642	0.113175631	comfortable		
38	0.31241078	0.158125401	comfortable		
39	0.31735463	0.123450041	comfortable		

The acceleration in the x-axis was compared with the upper limit value of 0.98 m/s^s using the ‘IF’ function in excel. Each data was then categorized as ‘comfortable’ or ‘uncomfortable’ based on the result of the ‘IF’ function. The number of ‘comfortable’ and ‘uncomfortable’ was then calculated using the ‘COUNTIF’ function.

Figure 9: The data of acceleration on x-axis as displayed on excel, after applying the ‘IF’ and ‘COUNTIF’ formula

Acceleration Graph Along z-axis i.e.Vertical (upward-downward) Acceleration

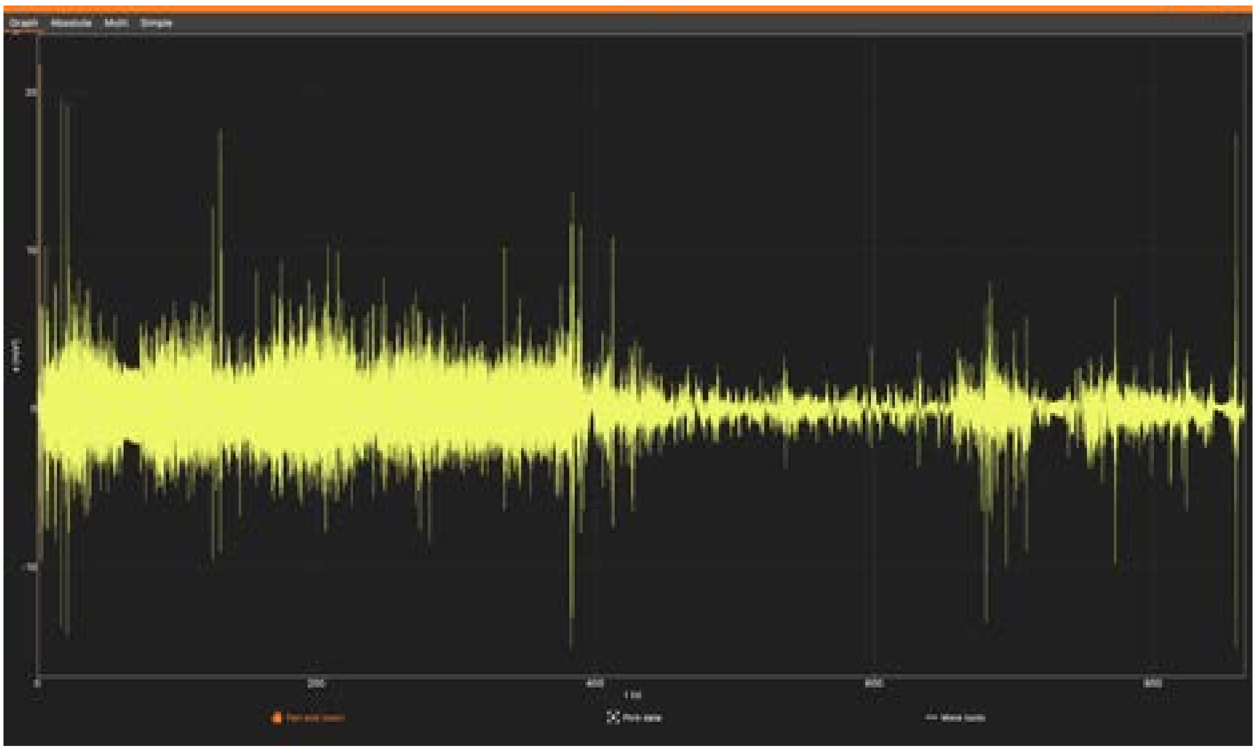


Figure 10:Graph generated by Phyphox app of z-axis acceleration in auto

Description:

The acceleration along the z-axis indicates the acceleration experienced due to change in velocity during an up-down motion similar to that experienced by a passenger when traveling over a speedbump through a pot-hole or on uneven road. Thus, the major spikes in the graph can be correlated to road ‘roughness’. The density of the lines uptill the 400s mark in the graph clearly indicates that the rate of change of vertical acceleration with time is extremely high, thus the passenger experience can be assumed to be ‘bumpy’.

The data from the above graph was then exported to Excel where the data stamp per second was recorded individually.

Using the maximum, minimum, average and standard deviation functions in excel the following values from the data were collected and displayed to be compared with the corresponding data from the car.

Figure 11: The data of acceleration on z-axis as displayed on excel, after applying the given functions

	A	B	C	D	E	F
1	Time (s)	Linear Acceleration z (m/s^2)	MAX	MIN	AVERAGE	STD DEV
2	0.13394399	0.11342144	21.791275	-14.379048	-0.0895124	1.75163814
3	0.13891835	0.107807159				
4	0.1438622	0.097019196				
5	0.14880605	0.271364212				
6	0.15378041	0.284996033				
7	0.15872426	0.184844971				
8	0.16369863	0.096964836				
9	0.16864247	0.053311348				
10	0.17358632	0.11728096				
11	0.17856069	0.241724014				
12	0.18350453	0.360194206				
13	0.18844838	0.408085823				
14	0.19342275	0.357117653				
15	0.19836659	0.301018715				
16	0.20334096	0.344874382				
17	0.20828481	0.439822197				
18	0.21325917	0.519379616				
19	0.21820302	0.61690712				
20	0.22314687	0.540411949				
21	0.22812123	0.377810478				
22	0.23306508	0.142439842				
23	0.23803945	0.027339935				
24	0.24301381	0.013372421				
25	0.24795766	0.04920578				
26	0.25293202	0.107894898				
27	0.25787587	0.144371033				
28	0.26281972	0.088689804				
29	0.26779408	-0.029405594				
30	0.27273793	-0.117226601				
31	0.2777123	-0.180140495				
32	0.28265614	-0.082303047				

Car:

The car was then driven over the same route as the auto while the Phyphox app was used to record acceleration data.

Acceleration Graph Along y-axis i.e.Linear (along direction of motion) Acceleration

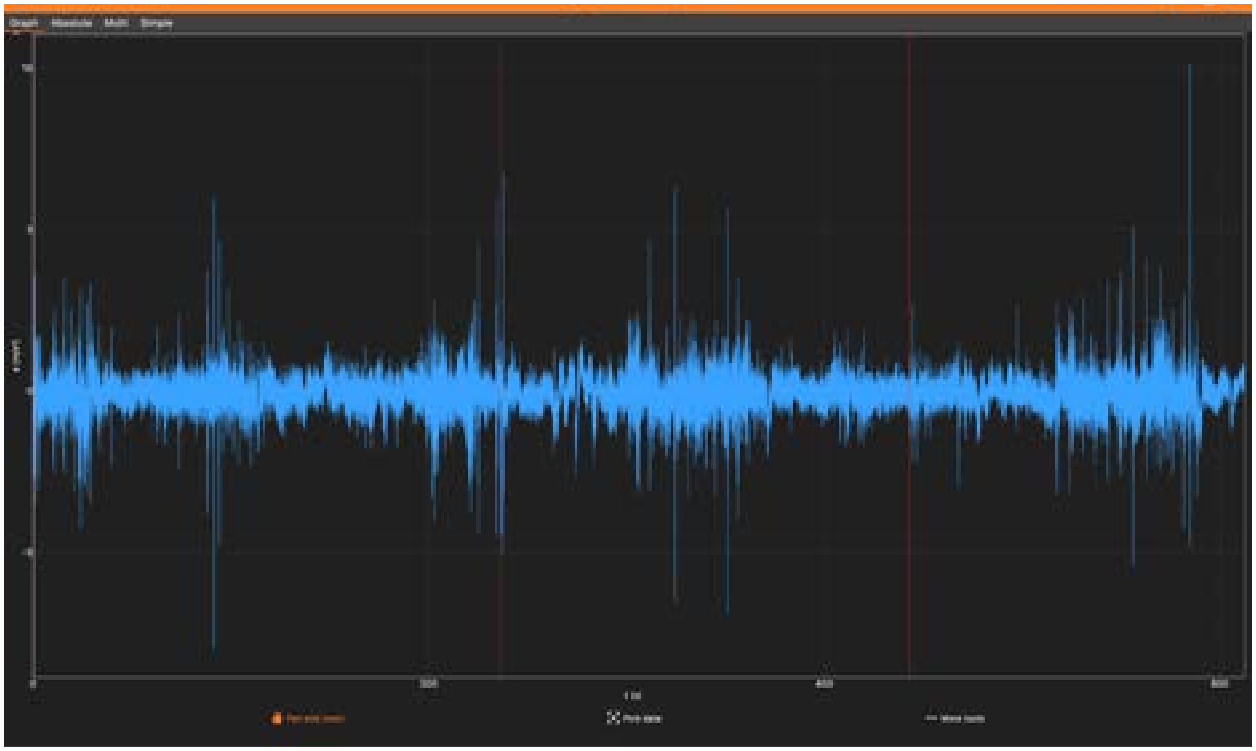


Figure 12: Graph generated by Phyphox app of y-axis acceleration in car

Description:

The graph indicates the acceleration experienced during lateral motion, thus it highlights the fluctuations in speed during over-takes, lane changing and turning motion of the car. The positive region of the graph indicates acceleration while the negative part indicates deceleration. The lines appear condensed but less so than the same displayed for the auto rickshaw. The general range of the graph on the acceleration axis is significantly lesser than that of the auto rickshaw graph with most readings between 5 to -5 m/s^2 in contrast to the range of 10 to -10 on the auto-rickshaw graph. This indicates that the magnitude of linear acceleration fluctuation in the car is significantly lesser than the auto rickshaw. The acceleration experienced by the passenger due to braking, gear change and slowing down and speeding up is thus significantly lesser in the car than in the auto.The graph indicates momentary extremes in acceleration which can be attributed to extremely sudden movement of the vehicle resulting in changes in its lateral acceleration i.e. swerving or jerk-motion. Peak values including 6.73 and 10.14 (m/s^2)

The data from the above graph was then exported to Excel where the data stamp per second was recorded individually.

The acceleration in the y-axis was compared with the upper limit value of 1.47 m/s^s using the 'IF' function in excel. Each data was then categorized and 'comfortable' or 'uncomfortable' based on the result of the 'IF' function. The number of 'comfortable' and 'uncomfortable' was then calculated using the 'COUNTIF' function.

	A	B	C	D	E	F
1	Time (s)	Linear Acceleration y (m/s^2)	comfortable	comfortable	uncomfortable	
2	0.00349562	0.183090355	comfortable	60008	834	
3	0.01356362	-0.06314759	comfortable			
4	0.02363162	-0.20772029	comfortable			
5	0.03369963	-0.275238381	comfortable			
6	0.04376763	-0.31536753	comfortable			
7	0.05383563	-0.248682959	comfortable			
8	0.06390363	-0.096388426	comfortable			
9	0.07397163	0.030329215	comfortable			
10	0.08403963	0.081757523	comfortable			
11	0.09410763	0.145782196	comfortable			
12	0.10417463	0.24097896	comfortable			
13	0.11424263	0.443932014	comfortable			
14	0.12431063	0.572692381	comfortable			
15	0.13437863	0.724877863	comfortable			
16	0.14444663	0.804497644	comfortable			
17	0.15451463	0.88350873	comfortable			
18	0.16458263	1.021056	comfortable			
19	0.17465063	1.252798113	comfortable			
20	0.18471863	1.502136545	comfortable			
21	0.19478663	1.68597359	comfortable			
22	0.20485463	1.697953658	comfortable			
23	0.21492263	1.823450693	comfortable			
24	0.22499063	2.018941531	comfortable			
25	0.23505863	2.033299661	comfortable			
26	0.24512663	1.890499253	comfortable			
27	0.25519463	1.74149261	comfortable			
28	0.26526263	1.685204973	comfortable			
29	0.27533063	1.59148814	comfortable			
30	0.28539863	1.382120105	comfortable			
31	0.29546663	1.122591146	comfortable			
32	0.30553463	0.893427947	comfortable			
33	0.31560263	0.679525981	comfortable			
34	0.32567063	0.377025249	comfortable			
35	0.33573863	0.077760659	comfortable			
36	0.34580663	-0.27583392	comfortable			
37	0.35587463	-0.85208287	comfortable			
38	0.36594263	-1.198603487	comfortable			
39	[illegible]	[illegible]	[illegible]			

Figure 13: The data of acceleration on y-axis as displayed on excel, after applying the 'IF' and 'COUNTIF' formula

Acceleration Graph Along x-axis i.e.Lateral (turning) Acceleration

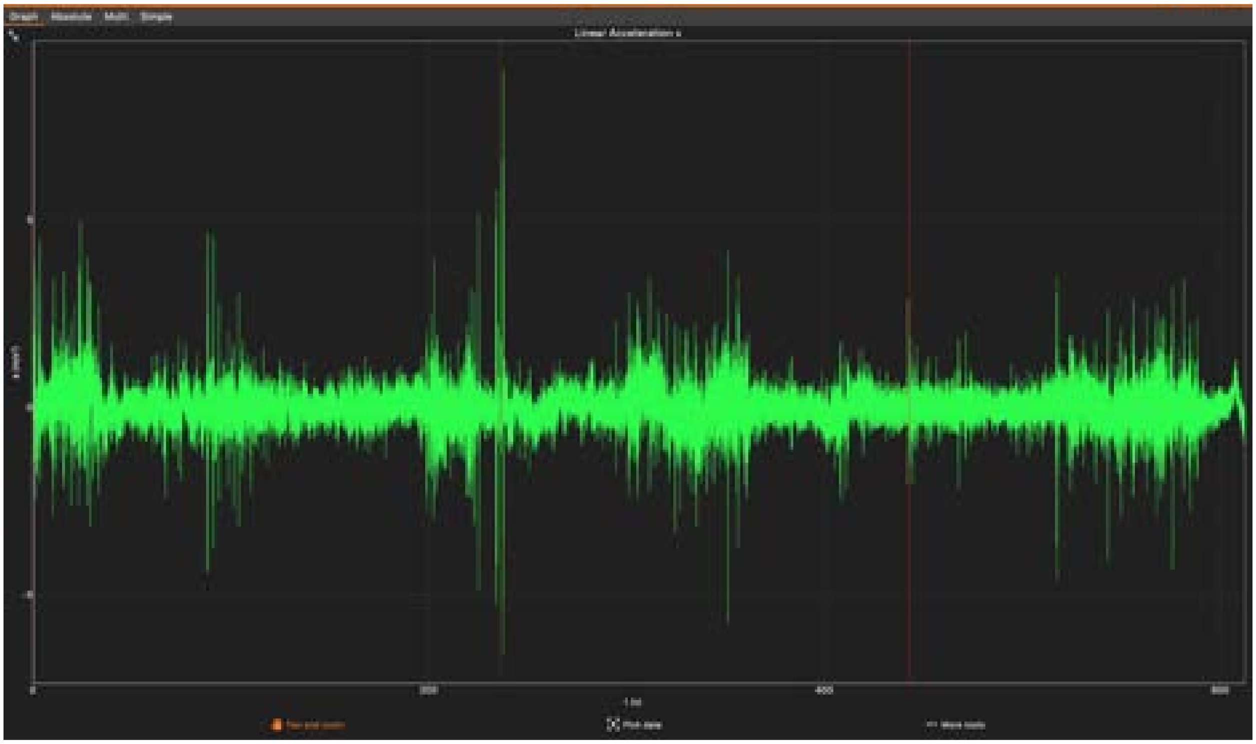


Figure 14: Graph generated by Phyphox app of x-axis acceleration in car

Description:

The graph indicates the acceleration experienced during lateral motion, thus it highlights the fluctuations in speed during over-takes, lane changing and turning motion of the car. The positive region of the graph indicates acceleration while the negative part indicates deceleration. The lines appear condensed yet less so than the auto rickshaw graph indicating a rate of change of acceleration with time which is less than that for auto rickshaws. Additionally the data lies primarily in the range from 5 to -5 (m/s^2) while the data for the auto had been majorly between 20 and -20 (m/s^2) Thus, it is clear that the extent of acceleration experienced while turning, changing lanes or generally in lateral motion in the car is lesser. Peak values including 8.9 and -5.7 (m/s^2)

The data from the above graph was then exported to Excel where the data stamp per second was recorded individually.

The acceleration in the x-axis was compared with the upper limit value of 0.98 m/s^s using the ‘IF’ function in excel. Each data was then categorized and ‘comfortable’ or ‘uncomfortable’ based on the result of the ‘IF’ function. The number of ‘comfortable’

and ‘uncomfortable’ was then calculated using the ‘COUNTIF’ function.

Figure 15: The data of acceleration on x-axis as displayed on excel, after applying the ‘IF’ and ‘COUNTIF’ formula

	A	B	C	D	E	F
1	Time (s)	Linear Acceleration x (m/s^2)	Compared	Comfortable	Uncomfortable	
2	0.00349562	0.619820647	comfortable	57679	3162	
3	0.01356362	0.618528558	comfortable			
4	0.02363162	0.477545757	comfortable			
5	0.03369963	0.383989137	comfortable			
6	0.04376763	0.463525157	comfortable			
7	0.05383563	0.584600528	comfortable			
8	0.06390363	0.820488463	comfortable			
9	0.07397163	0.81084889	comfortable			
10	0.08403963	0.611661003	comfortable			
11	0.09410763	0.604751203	comfortable			
12	0.10417463	0.72576357	comfortable			
13	0.11424263	0.782772753	comfortable			
14	0.12431063	0.768724086	comfortable			
15	0.13437863	0.644213769	comfortable			
16	0.14444663	0.500223452	comfortable			
17	0.15451463	0.38404337	comfortable			
18	0.16458263	0.323607134	comfortable			
19	0.17465063	0.243035279	comfortable			
20	0.18471863	0.134875458	comfortable			
21	0.19478663	0.062421293	comfortable			
22	0.20485463	0.135255746	comfortable			
23	0.21492263	0.17786448	comfortable			
24	0.22499063	0.292429268	comfortable			
25	0.23505863	0.425971926	comfortable			
26	0.24512663	0.520298405	comfortable			
27	0.25519463	0.472743219	comfortable			
28	0.26526263	0.403647403	comfortable			
29	0.27533063	0.306789811	comfortable			
30	0.28539863	0.322339238	comfortable			
31	0.29546663	0.372847268	comfortable			
32	0.30553463	0.460957206	comfortable			
33	0.31560263	0.627033041	comfortable			
34	0.32567063	0.655032579	comfortable			
35	0.33573863	0.62064218	comfortable			
36	0.34580663	0.631022158	comfortable			
37	0.35587463	0.447515481	comfortable			
38	0.36594263	0.550656418	comfortable			
39	0.37601063	0.941869424	comfortable			
40	0.38607863	1.216957897	uncomfortable			

Acceleration Graph Along z-axis i.e.Vertical (upward-downward) Acceleration

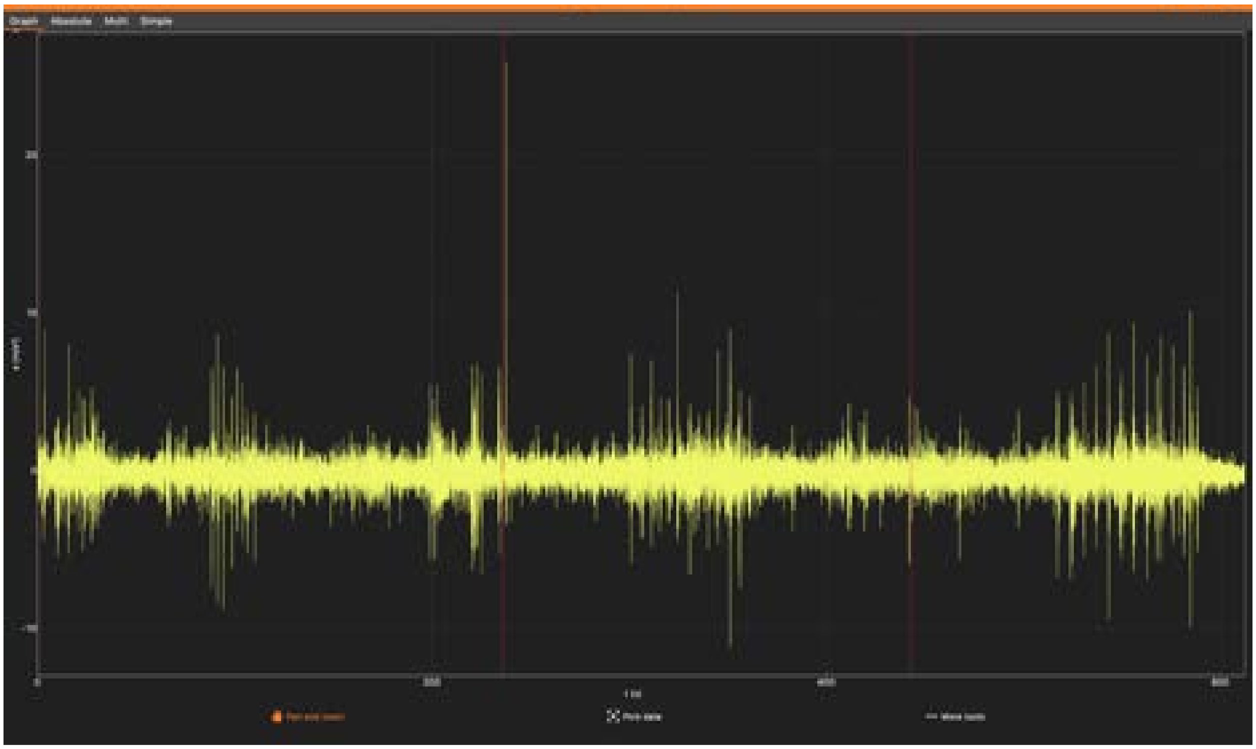


Figure 16: Graph generated by Phyphox app of z-axis acceleration in car

Description:

The acceleration along the z-axis indicates the acceleration experienced due to change in velocity during an up-down motion similar to that experienced by a passenger when traveling over a speedbump or through a pot-hole or on uneven road. Thus, the major spikes in the graph can be correlated to road 'roughness'. Unlike the auto graph the acceleration here remains relatively constant throughout the ride with no major regions where the graph spikes higher. Additionally the majority of the readings lie between 3 to -3 (m/s^2) while in contrast the readings in the auto-rickshaw graph lie majorly between 5 and -5 (m/s^2). Peak values include 11.22 and 10.03 (m/s^2)

The data from the above graph was then exported to Excel where the data stamp per second was recorded individually.

Using the maximum, minimum, average and standard deviation functions in excel the following values from the data were collected and

	A	B	C	D	E	F	G
1	Time (s)	Linear Acceleration z (m/s^2)	MAX	MIN	AVERAGE	STANDARD	DEVIATION
2	0.00349562	0.164648822	13.0575085	-11.182574	-0.2106611	0.94005622	
3	0.01356362	0.0045706677					
4	0.02363162	-0.193210716					
5	0.03369963	0.193430572					
6	0.04376763	0.664394556					
7	0.05383563	0.608385247					
8	0.06390363	-0.003835773					
9	0.07397163	-0.538017515					
10	0.08403963	-0.344581681					
11	0.09410763	-0.171820432					
12	0.10417463	-0.207258652					
13	0.11424263	-0.152432819					
14	0.12431063	-0.321886298					
15	0.13437863	-0.231558511					
16	0.14444663	0.106935049					
17	0.15451463	0.490891296					
18	0.16458263	0.718245658					
19	0.17465063	0.554400829					
20	0.18471863	0.235325872					
21	0.19478663	-0.073852673					
22	0.20485463	-0.349334298					
23	0.21492263	-0.905909706					
24	0.22499063	-1.127370075					
25	0.23505863	-0.774442663					

displayed to be compared with the corresponding data from the auto.

Figure 17: The data of acceleration on z-axis as displayed on excel, after applying the given functions

Analysis

		Uncomfortable	Comfortable
Auto	Linear/Longitudinal Acceleration	4633	60903
Car		834	60008
Auto	Lateral Acceleration	39579	25956
Car		3162	57679

The above table indicates the number of times the acceleration along x-axis(lateral) and along y-axis(linear) exceeded the threshold limits as defined in the paper. The data when exported to Excel sheets recorded each individual acceleration value for each 0.01 second and using the 'IF' function each value was compared to the threshold limits. When the value was greater than the threshold it was labeled uncomfortable and when the value was less than threshold it was labeled comfortable.

From the data above we can clearly calculate what percentage of the total readings for both auto and car come as uncomfortable.

Auto linear acceleration:

Total readings: 65,536 readings (categorized as 'comfortable'/'uncomfortable')

Readings categorized as uncomfortable: 4633÷65536=0.07069

Percentage value of 'uncomfortable': 0.07069 × 100= 7.069%

Car linear acceleration:

Total readings: 60,842 readings (categorized as 'comfortable'/'uncomfortable')

Readings categorized as uncomfortable: 834÷60842= 0.01370

Percentage value of ‘uncomfortable’: 0.01370 × 100= 1.370%

Auto lateral acceleration:

Total readings: 65,535 readings (categorized as ‘comfortable’/’uncomfortable’)

Readings categorized as uncomfortable: 39579 ÷65535=0.60393

Percentage value of ‘uncomfortable’: 0.60393 × 100=60.393%

Car lateral acceleration:

Total readings: 60,841 readings (categorized as ‘comfortable’/’uncomfortable’)

Readings categorized as uncomfortable: 3162÷60841= 0.051971

Percentage value of ‘uncomfortable’: 0.051971× 100= 5.197%

Auto vertical acceleration:

Maximum value of acceleration: 21.79 m/s^2

Minimum value of acceleration (maximum deceleration): -14.37 m/s^2

Car vertical acceleration:

Maximum value of acceleration: 13.057 m/s^2

Minimum value of acceleration (maximum deceleration) : -11.18 m/s^2

Conclusion

The percentage of linear acceleration in a 3-wheeler auto-rickshaw that can be categorized as uncomfortable for a passenger is 7.069% which is significantly higher than that of cars which is 1.370%. Cars with a more comfortable suspension system, ABS and various other safety and comfort features show a significantly more positive trend in terms of comfort and safety. This helps emphasize the necessity of more safety and protective measures in auto rickshaws as one of the most popular last mile vehicles in India. The level of passenger discomfort in an auto-rickshaw is significantly greater than a car yet cars contain seatbelts for the purpose of securing passengers to their seats to provide greater comfort and safety, while auto-rickshaws with a lower comfort rate still have no seatbelt option for passengers.

The percentage of discomfort experienced by a passenger during lateral motion in an auto rickshaw (60.393%) is significantly higher than that in a car(5.197%), which further proves the necessity for seatbelts in auto-rickshaws to make them more safe and comfortable for passengers. Due to the lack of doors in auto rickshaws a fear of falling out significantly contributes to the public perception of autos as ‘less safe’ this is further backed by the data above that clearly shows that the acceleration experienced by a passenger during tuning motions in autos is very high. Thus the motion of turning in an autos already severely displaces the passenger; the lack of seatbelts further aggravates the possibility of falling out.

The maximum vertical acceleration experienced in the car in this study is 13.057 m/s^2 While on the same route the maximum vertical acceleration in an auto rickshaw is 21.79 m/s^2 Vertical acceleration is a direct result of road ‘roughness’ as it records the upward and downward motion of the vehicle on the road. Thus, the vertical acceleration is also dampened based on the comfort of the suspension used. Since the suspension used in auto-rickshaws is less comfortable than that used in cars it is clear that the ‘bumpy-ness’ experienced in autos is greater. To help passengers feel more secure and reduce their displacement of the auto bench a seatbelt would be the ideal solution.

Therefore my research demonstrates that auto rickshaws experience significantly irregular accelerations compared to cars, which have robust suspensions and better protection. Given these jerky movements, passengers are more prone to sudden impacts, increasing the likelihood of injuries in abrupt stops or collisions. Seatbelts could mitigate these risks, providing essential restraint to reduce passenger injuries and improve comfort. Implementing seatbelts in auto rickshaws would enhance overall passenger safety, aligning with evolving public safety standards.

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