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VIBRI-SAFE: Quantification of Motorcycle Rider Whole-Body Vibration Exposure Using a Low-Cost IoT Monitoring System with ISO 2631-1 Normalization

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ABSTRACT

Motorcycle riders are continuously exposed to mechanical vibrations from engines and uneven roads, which can lead to long-term musculoskeletal disorders (MSDs) affecting the spine, shoulders, and limbs. Current safety systems focus on accident prevention, while chronic vibration exposure remains largely unaddressed. This study presents VIBRI-SAFE, a low-cost vibration monitoring system using an Arduino Uno MPU6050 with multi-axis sensors to capture real-time vibration intensity and rider posture stability. Weighted Root Mean Squared (RMS), Vibration Dosage Value (VDV), and Static compression dose (Sed) for the spine were calculated and normalized to an 8-hour ISO reference period, which allowed short rides to be compared with long-term occupational thresholds. Results indicate higher vibrations in motorcycles with older suspensions and prolonged exposures, with RMS variability reflecting mechanical instability. VIBRI-SAFE shifts motorcycle safety from reactive crash protection to proactive physiological monitoring through combining IoT and ergonomic principles. Its affordability and diagnostic potential support integrating human health analytics into sustainable mobility.

1. INTRODUCTION

Motorcycle riders are routinely exposed to Whole Body Vibration (WBV) caused by engine operation and varying road conditions [1]. This exposure would contribute to musculoskeletal disorders (MSDs) among riders, which affect the spine, shoulder, and lower limbs [2], [3]. However, most motorcycle safety mechanisms primarily focus on crash prevention, while the cumulative physiological burden resulting from chronic vibration exposure remains insufficiently examined in rider ergonomics research [4].

Moreover, road-specific factors have also been identified as significant predictors of exposure, such as riding on rough and uneven road surfaces, which significantly increase whole-body vibration exposure. Review by [4] highlighted that vibration exposure is the primary ergonomic hazard faced by motorcyclists, which can cause MSDs and increase the risk of accidents. Yet, such ergonomic hazards are neglected in safety planning.

Previous ergonomic studies have demonstrated that prolonged motorcycle riding can expose the riders to vibration levels that exceed the health guidance thresholds defined in ISO 2631-1, especially in vehicles with ageing mechanical systems [5]. Both vibration magnitude and duration contribute to the ergonomic risk towards the users, but current approaches lack visible, cost-effective, and real-time monitoring solutions to assess whole body vibration exposure of the motorcyclists.

As such, the VIBRI-SAFE prototype was developed as a solution: a vibration monitoring system with an Arduino Uno microcontroller and an MPU6050 accelerometer that measures multi-axis vibration, enabling computation of health-related metrics and normalization to an 8-hour reference period to be consistent with ISO 2631-1 daily exposure standards. This method enables meaningful comparison of ride data from a shorter duration against standardized exposure thresholds.

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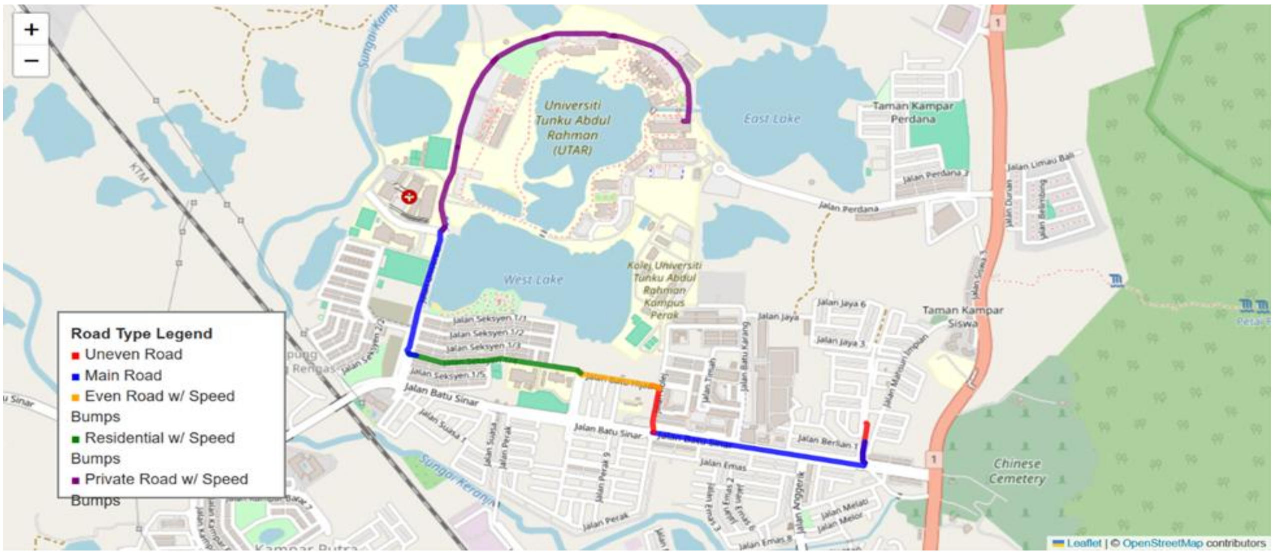

Fig. 1. Route used for the test ride with varying road conditions.

Following that, this study aims to quantify vibration exposure using VIBRI-SAFE prototype in a test ride and demonstrate how a low-cost IoT solution can deliver ergonomic feedback to reduce long-term musculoskeletal risks of the users. A preliminary version of this manuscript was presented virtually at the IGIIDEATION 2026.

VIBRI-SAFE is designed as a low-cost and motorcycle-mounted solution that measures multi-axis vibration directly. This is different from existing vibration monitoring systems for motorcycles, whereby they typically rely on rider-worn accelerometers and smart devices with limited analysis against ISO recommended thresholds [1] or smartphone-based accelerometer solutions for general structural and pavement vibration monitoring [6], [7], that are not focused on measuring whole-body vibration for riders. VIBRI-SAFE also avoids discomfort associated with wearable devices to riders by placing the sensing unit beneath the seat to capture the transmission of vibration more representative of whole body vibration exposure. This combination of affordability and portability differentiates VIBRI-SAFE from existing approaches and enhances its applicability for daily commuter and occupational riding scenarios.

2. METHODOLOGY

2.1 Materials and Resources

This study utilized both hardware and software as resources to measure and analyze motorcycle vibrations. The hardware resources consisted of an Arduino Uno Microcontroller for data processing, an MPU6050 accelerometer for measuring tri-axis acceleration, an SD card logger for storing accelerometer data in a CSV file, and a power bank as the power supply. The assembly was mounted securely under the motorcycle seat to ensure consistent measurements during the test ride.

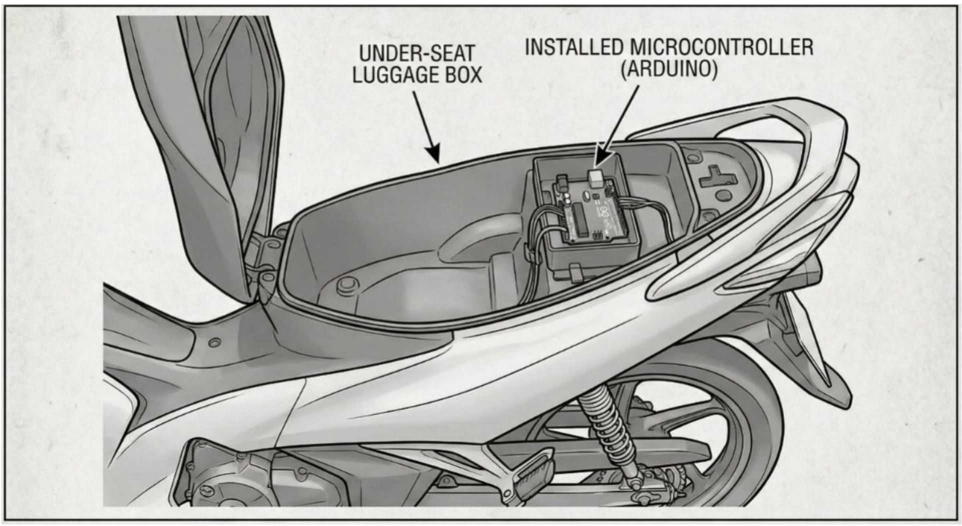

Fig. 2. Illustration of hardware assembly mounting on motorcycle.

A moderately old moped was used for testing as it reflects the typical motorcycle conditions used by the Malaysian

Motorcyclists [8]. Python 3.9 with pandas, numpy, and matplotlib libraries was used to calculate weighted Root Mean Square (RMS), Vibration Dose Value (VDV), and Static Compression Dose (Sed) metrics.

The resources used in the project were aimed at being low cost, open source and available to ensure reproducibility in a commercial setting.

2.2 Data Collection

This study employed quantitative measurements of motor-induced vibrations using a microcontroller-based system. The testing was conducted in Kampar, Perak, Malaysia, where most of the road users are university students. The route from Taman Mahsuri Impian to Universiti Tunku Abdul Rahman (UTAR) via Westlake Homes was selected, as it represents a typical daily commuting route for students and provides natural variability in road conditions (Figure 1).

2.3 Sensor Calibration, Filtering, and Measurement Reliability

The MPU6050 accelerometer was calibrated using a static offset calibration procedure and a bias correction procedure. Firstly, the sensor was placed on a stable, vibration free surface, and the raw acceleration readings of the three axes were recorded. The expected values at this stage should ideally measure 0 m/s^2 along the horizontal axes and 9.81 m/s^2 along the gravitational axis, and any deviations from these expected values were identified and recorded as errors. Subsequently, these errors were adjusted in all the recorded measurements after data collection. Furthermore, a low-pass digital filter was applied to the collected data from the sensors during post-processing in Python to identify and attenuate high-frequency noise components. Moreover, the measured vibration magnitudes and trends were compared with exposure ranges and patterns reported in motorcycle and vehicle vibration studies that used ISO 2631-1 methods. This is to confirm that the behaviour of the acceleration data collected is consistent with field WBV assessments to ensure consistency of the present study with the existing studies.

2.4 Data Collection and Analysis

The hardware assembly was mounted in the luggage area under the seat of the moped to capture accelerations of three axes during the test ride (Figure 2). The raw acceleration data was recorded at 100Hz and saved in a .csv file for future analysis. Then, the file was used in Python 3.9 to calculate the following key metrics. These metrics describe vibration magnitude, shock severity, and potential spinal loading respectively, and are standard measures used in occupational vibration assessment [9], [10]. The following metrics were calculated using the data collected.

1) Weighted Root Mean Square (RMS)

The RMS quantifies the effective continuous vibration level experienced during the ride. It is the principal metric recommended in ISO 2631-1 for evaluating discomfort and health risk from steady vibration.

Formula in discrete form:

$$a_{rms} = \sqrt{\frac{\sum(a_i^2 \cdot \Delta t)}{\sum \Delta t}} \tag{1}$$

Where:

a_i = i-th acceleration sample

t = sampling interval (s)

a_{rms}= root mean square acceleration

ISO 2631 recommends extrapolating RMS to an 8-hour daily exposure:

$$a_{rms,8} = a_{rms}\sqrt{\frac{T}{T_8}} \tag{2}$$

Where:

T = measured ride duration (s)

T_8 = 28,000s

[9]

2) Vibration Dosage Value (VDV)

VDV accounts for low-frequency vibration and shocks that make it more sensitive than RMS to sudden bumps, potholes, or harsh road conditions [11].

Formula in discrete form:

$$VDV = \left(\sum(|a_i|^4 \cdot \Delta t)\right)^{1/4} \tag{3}$$

Where:

a_i = i-th acceleration sample

t = sampling interval (s)

VDV = Vibration Dose Value

Normalized to 8 hours using:

$$VDV_8 = VDV\left(\frac{T_8}{T}\right)^{\frac{1}{4}} \tag{4}$$

Where:

T = measured ride duration (s)

T_8 = 28,000s

[9], [10]

3) Static Compression Dose (S_{ed})

S_{ed} estimates the daily compressive load on the lumbar spine (L4/L5) caused by vertical WBV. The metric is based on the German biodynamic model and later ISO standards for spinal dose-response prediction [12], [13].

RMS Vertical Acceleration:

$$S_e = \sqrt{\frac{1}{T}\int_0^T a_z(t)^2 dt} \tag{5}$$

Where:

a_z = Vertical acceleration

ISO requires that shorter exposure durations be normalized to a standard 8-hour workday:

$$S_{ed} = S_e\left(\frac{T_8}{T}\right)^{\frac{1}{6}} \tag{6}$$

This 1/6-power relationship captures the non-linear sensitivity of spinal tissue to cumulative cyclic loading [14]. It also reflects the biomechanical response of spinal tissue to repeated cyclic loading. In terms of the physiological aspects of intervertebral discs of the human spine, it exhibits viscoelastic and fatigue like behaviour, which causes damage accumulation on vertebral discs to not be linearly proportional to exposure to external stressors. Instead, it follows a sub-linear power law, which indicates that longer exposure to external pressures on vertebral discs increases risk of injury at a diminishing rate. As such, the 1/6 exponent has been derived from studies on spinal loading [11], [13], to capture the cumulative biological effect of vibration induced compressive stress on motorcyclists over time. It also allows Sed to represent the progressive mechanical fatigue of lumbar tissues while providing a biologically meaningful indicator of long term musculoskeletal risk.

Sed is converted to Spinal Stress (MPa) with:

$$\sigma_{MPa} = \frac{S_{ed}k}{10^6} \tag{7}$$

Where:

k = lumbar stiffness constant (~5×10^4 Pa per m/s²), based on biomechanical studies.

10^6 = conversion from Pa to MPa

Supporting studies report lumbar axial stiffness in the 40–70 kN/m range [12]. The lumbar stiffness constant (k) represents the biomechanical relationship between vertical acceleration and compressive stressors experienced at the L4/L5 spinal segment. This parameter is derived from previous experimental studies [11], [12] to ensure consistency with the nature of the human spine and the resistance of spinal structures to external pressures. This constant also assists Sed to provide a physiologically supported estimation of spinal stress rather than a purely kinematic measurement.

The normalization of the metrics to an 8-hour reference period is aligned with the vibration ergonomics standards and applied research that defines daily exposure in terms of an eight-hour equivalent reference period [2], rather than a fixed second-by-second duration. In practical field assessments, this reference period is frequently implemented using rounded or approximate values close to eight hours to facilitate computational consistency and comparison across short-duration measurements, without materially affecting exposure classification or threshold interpretation. Since ISO 2631-1 expresses whole-body vibration metrics such as RMS, VDV, and Sed as normalized daily equivalents, minor deviations from the exact 28 800 s duration have negligible influence on risk categorization relative to ISO action and exposure limit values. As such, a reference duration of 28 000 s was adopted in the study as a pragmatic representation of the standard eight-hour exposure period.

Moreover, the extrapolation of vibration measurements of a short term to an 8-hour window corresponds with the fact that the human body biologically responds to vibration, based on cumulative `dosage rather than isolated exposure events [15]. This provides the opportunity to scale measurements taken in short durations to represent a full working day, while assuming similar exposure patterns. This is widely adopted in field studies where a continuous 8-hour monitoring is impractical [10]. Furthermore, exposure to vibration occurs for motorcycle riders and gig economy riders intermittently throughout the day. Thus, the study adopted the normalization of 8 hours as it provides a standardized basis for comparing different ride durations against established thresholds.

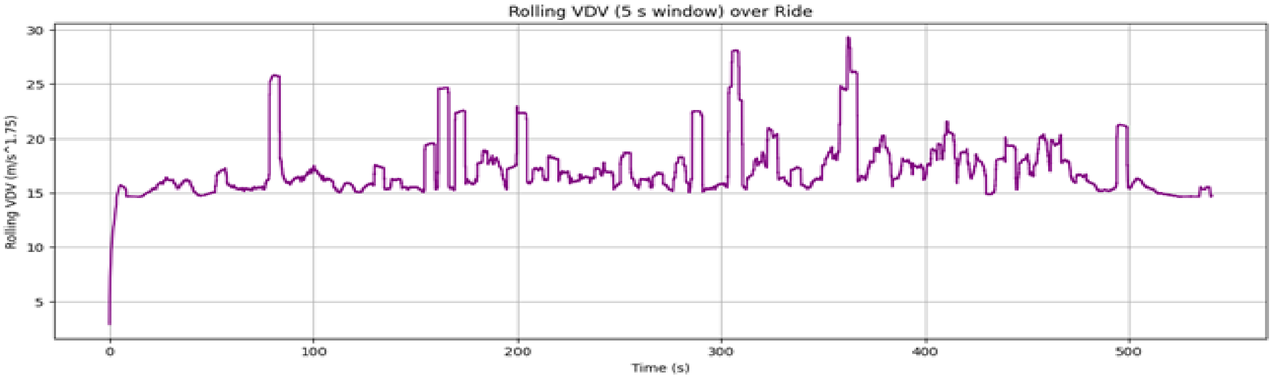

Fig. 3. Rolling Vibration Dosage Value (VDV) for the test ride.

Normalized mean values for RMS, VDV, and Sed for 8 hours were used for drawing conclusions, and a graphical representation of rolling Vibration Dose Value (VDV) for 5s window for the ride is produced to illustrate the variations in vibration exposure during the test ride.

3. RESULTS

The VIBRI-SAFE system successfully quantified vibration exposure and estimated spinal compression during the observed motorcycle ride. The normalized 8-hour Vibration Dosage Value (VDV_8) was $27.639\text{m/s}^{1.75,}$ which exceeds the caution threshold of $17\text{m/s}^{1.75}$ as suggested by [2], indicating substantial cumulative vibration exposure experienced by the motorcyclist over the ride. The commonly referenced VDV_8 threshold of $17\text{m/s}^{1.75}$ is typically identified as the borderline level of vibration exposure that a human can sustain over an 8-hour period. Exceeding this threshold over time is associated with an increased probability of adverse health effects for the motorcycle riders, including lower back pain, spinal degeneration, and cumulative musculoskeletal damage.

The weighted Root Mean Square (RMS_8) normalized for 8 hours was $1.418 m/s^{2,}$ which surpassed the 8-hour average RMS comfort limit of $0.315 m/s^2$ and the caution level of $0.5 m/s^2$ according to ISO 2631-1 [15]. This suggests a higher likelihood of health risk if such exposure is sustained in the long run. The estimated 8-hour Static Compression Dose (S_{ed}) was 0.978MPa compared to the caution threshold of 0.8MPa, highlighting potential concern for long-term lumbar spine stress for the users.

A closer inspection of the rolling VDV profile (Figure 3) indicates that peak vibration events roughly correspond to specific segments of the chosen riding route. The peak vibration points can be attributed to the impacts of uneven pavement, speed bumps, and road surface transitions near residential and campus access areas. The selected route for the study is also characterized by frequent speed bumps, rumble strips, and occasional potholes, which are typical of urban and campus-adjacent road environments. Such traffic deterrent features introduce repeated, instant, high-intensity vibration inputs during the ride. As such, these localized spikes suggest that road-induced excitation, rather than steady engine vibration alone, plays a dominant role in cumulative exposure in this study's context.

4. DISCUSSION AND RECOMMENDATIONS

The results from the VIBRI-SAFE monitoring system indicate that motorcycle riders are exposed to whole-body vibrations that frequently exceed established caution thresholds for both Vibration Dose Value (VDV) and Static Compression Dose (S_{ed}), with RMS accelerations also surpassing ISO 2631-1 comfort and caution limits. The rolling VDV data showed high levels of vibration peaks that may have been caused by road conditions, potholes, and mechanical responses from the motorcycle while in operation. Although the majority of the ride remains in a moderate exposure range (VDV ~15–20 $m/s^{1.75}$), the short-duration, high-amplitude spikes significantly contribute to cumulative exposure, aligning with previous studies suggesting that intermittent vibration events can have disproportionate effects on spinal loading and lumbar stress [2]. This supports the importance of calculating complementary metrics such as VDV alongside average vibration levels (RMS) for a more informed ergonomic risk assessment.

It is reasonable to assume that motorcycle-related factors, such as the condition of the vehicle, are likely contributing to higher vibration levels, as older motorcycle models that may have worn-out suspension systems may tend to transmit more vibration to the rider. Furthermore, road surfaces may also contribute to higher motorcycle vibration levels, as deteriorated or uneven road surfaces might amplify the vibration exposure levels. Thus, it is crucial to consider both mechanical and environmental factors when evaluating rider health risks.

Table 1. Summary of the findings.

Metric	8-hour normalized value	Caution value based on ISO 2631-1 [2], [16]	Remark
VDV	$27.639 m/s^{1.75}$	$17 m/s^{1.75}$	Extreme exposure
RMS	$1.418 m/s^2$	$0.5 m/s^2$	Substantial exposure
S_{ed}	0.978MPa	0.8MPa	Slightly concerning exposure

Moreover, the S_{ed} values exceeding the 0.8 MPa caution threshold indicate that lumbar spinal compression is at a slightly concerning level. Repeated daily exposure to slightly higher levels of static compression on the spine could contribute to long-term musculoskeletal issues. Such issues include lower back pain and disc degeneration, which align with previous studies such as [2], which provided evidence linking chronic whole body exposure to spine-related MSDs among professional drivers and frequent riders.

Furthermore, the findings are particularly crucial for gig economy riders and food delivery riders as they might experience prolonged daily exposure to whole body vibrations while operating under time pressure, extended working hours, and varying road conditions that increase cumulative vibration exposure. Such chronic whole body vibration exposure in such populations has been associated with musculoskeletal disorders such as lumbar disc degeneration, chronic lower back pain, and reduced postural stability.

On the other hand, it is crucial to explore how the findings of this study can be applied to university commuters, food delivery riders, and gig economy workers, as prolonged daily vibration exposure represents a significant but under-recognized occupational health risk. The findings of the study offer a practical approach to quantify and manage this exposure by translating vibration metrics into actionable guidance. From a practical perspective, sustained RMS_8 values ($1.418 m/s^2$) that exceed the caution level prescribed by ISO2631-1 ($0.5 m/s^2$) may indicate the need for suspension inspection of the motorcycle or seat cushioning upgrades. Similarly, elevated VDV_8 values ($27.639 m/s^{1.75}$) could inform recommended maximum daily riding durations to the riders, prompting them to take breaks appropriately. Such exposure-based guidelines can support preventive maintenance scheduling, route planning, and rider education initiatives, particularly for delivery platforms where riders may accumulate several hours of daily exposure.

Several targeted strategies can also be suggested to reduce the negative impacts of the high exposure levels or to dampen the vibrations during the rides. Firstly, riders should perform regular inspections and maintenance of suspension components, shock absorbers, and tires, as worn parts are major contributors to elevated vibration exposure. It is suggested that the older motorcycles be refurbished with vibration-damping seats or ergonomic cushioning to lower spinal compression and RMS acceleration, while manufacturers and mechanics should consider suspension tuning optimized for comfort without compromising handling, particularly for motorcycles used in long commutes or delivery services. Secondly, road authorities should prioritize repairing potholes, uneven surfaces, and other irregularities in high-traffic-prone areas, and consider resurfacing with vibration-absorbing materials to reduce daily exposure. Riders should receive education on posture, seating, and handlebar adjustments to distribute vibration more evenly and incorporate periodic breaks during long rides to mitigate cumulative stress. Adoption of low-cost, IoT-based monitoring systems like VIBRI-SAFE that might be integrated with smartphone apps can provide real-time feedback and alerts when exposure reaches caution thresholds, enabling informed adjustments in routes or riding behavior. Future research can explore the effects of vibration exposure with motorcycles under different conditions, with different riders, and on different road conditions for a higher level of validity in the results. Furthermore, it is suggested that future studies should include multi-rider validation across different motorcycle categories, including scooters, sport motorcycles, and delivery motorcycles, to assess inter-rider variability and differences in the mechanical structure of different motorcycle models on vibration exposure. Incorporating statistical dispersion measures such as confidence intervals for normalized RMS_8, VDV_8, and S_{ed} values and including graphical comparisons against ISO action and exposure limit values across riders would greatly contribute to enhancing generalizability and predictive robustness in future studies. Longitudinal studies may also be carried out to link whole-body vibration exposure to musculoskeletal disorders, which can support the development of predictive models for injury risk and prevention.

4.1 Practical Deployment and Commercial Scalability

VIBRI-SAFE prototype also demonstrates strong potential for real-world deployment apart from its experimental evaluation purposes. The system architecture can be integrated with a Bluetooth or Wi-Fi module to facilitate connectivity with smartphone applications to provide real-time visualisation of vibration exposure, cumulative static compression dose indicators, and threshold-based alerts. Such alerts would be helpful for the motorcycle riders to reduce speed, alter routes, or take rest breaks when RMS or VDV values exceed predefined ISO caution limits.

Multiple models of VIBRI-SAFE can be suggested for commercialized deployment. Firstly, it could be offered as a subscription-based mobile application paired with low-cost hardware for individual riders. This mobile application can be used to continuously monitor RMS and VDV values and notify riders in real time when the exposure levels exceeds ISO defined caution levels. These alerts may prompt behavioural adjustment such as speed reduction, route modification, or rest breaks, which transform the experimental system from a passive monitoring tool into an active ergonomic intervention application. This can also be integrated into fleet management platforms for delivery and logistics companies to monitor rider exposure and to improve safety compliance. The proposed subscription-based mobile application model would also enable scalable deployment of VIBRI-SAFE for both individual and commercial users. Utilizing this proposed model, riders would access real-time exposure analytics, historical data tracking, and personalized recommendations through a mobile platform, provided they have an active subscription to the platform. Similarly, fleet operators would be able to monitor aggregated rider exposure for occupational safety and health compliance.

Secondly, motorcycle manufacturers and service centres could also adopt this system as a diagnostic tool to assess suspension health and the condition of the other mechanical parts during maintenance cycles. These deployment pathways enhance the industrial relevance of the system and demonstrate its potential impact beyond academic evaluation.

5. CONCLUSION

This study confirms that motorcycle riders are exposed to whole body vibrations exceeding ISO 2631-1 caution thresholds, and its cumulative and short-term high amplitude shocks significantly contribute to lumbar spine stress. A limitation of the study is that it only tested one motorcycle type, on a single route, and under one rider condition, which may affect the overall generalizability. Variations in motorcycle design, suspension systems, rider weight, posture, and riding style would significantly influence the characteristics of vibration transmission. Thus, the results presented should be interpreted as indicative rather than representative of all riding conditions. The findings highlight the importance of combining RMS and VDV metrics for accurate ergonomic assessment and suggest practical measures such as motorcycle maintenance, ergonomic adjustments, posture training, road improvement, and real-time monitoring with low-cost IoT systems. Future research should explore diverse motorcycles, riders, and long-term musculoskeletal outcomes to strengthen predictive and preventive strategies.

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REFERENCES

[1] M. Carratù, A. Pietrosanto, P. Sommella, and V. Paciello, “Smart wearable devices for human exposure vibration measurements on two-wheel vehicles,” ACTA IMEKO, vol. 9, no. 4, p. 121, Dec. 2020, doi: https://doi.org/10.21014/acta_imeko.v9i4.727.

[2] H.-C. Chen, W.-C. Chen, Y.-P. Liu, C.-Y. Chen, and Y.-T. Pan, “Whole-body vibration exposure experienced by motorcycle riders – An evaluation according to ISO 2631-1 and ISO 2631-5 standards,” Int. J. Ind. Ergon., vol. 39, no. 5, pp. 708–718, Sep. 2009, doi: https://doi.org/10.1016/j.ergon.2009.05.002.

[3] F. Sekkay et al., “Risk factors associated with self-reported musculoskeletal pain among short and long distance industrial gas delivery truck drivers,” Appl. Ergon., vol. 72, pp. 69–87, Oct. 2018, doi: https://doi.org/10.1016/j.apergo.2018.05.005.

[4] D. Nurkertamanda, W. Budiawan, Z. A. Zahra, and R. J. Gitowardojo, “Experimental design for a sustainable society among motorcyclists: The influence of road types and speeds on whole-body vibration exposure and musculoskeletal disorders in motorcyclists,” Multidisciplinary Science Journal, vol. 7, no. 2, p. 2025053, Aug. 2024, doi: https://doi.org/10.31893/multiscience.2025053.

[5] M. Parvez and A. A. Khan, “Assessment of ergonomic risk factors in occupational motorcycle riding: an experimental investigation,” Int. J. Hum. Factors Ergon., vol. 8, no. 1, p. 1, 2021, doi: https://doi.org/10.1504/IJHFE.2021.115043.

[6] S. Rana and Asaduzzaman, “Vibration based pavement roughness monitoring system using vehicle dynamics and smartphone with estimated vehicle parameters,” Results in Engineering, vol. 12, p. 100294, Dec. 2021, doi: https://doi.org/10.1016/j.rineng.2021.100294.

[7] D. Zhang, J. Tian, and H. Li, “Design and Validation of Android Smartphone Based Wireless Structural Vibration Monitoring System,” Sensors, vol. 20, no. 17, p. 4799, Aug. 2020, doi: https://doi.org/10.3390/s20174799 .

[8] J. Oxley et al., "Commuter motorcycle crashes in Malaysia: An understanding of contributing factors.," Ann. Adv. Automot. Med., vol. 57, pp. 45–54, 2013.

[9] International Organization for Standardization, "ISO 2631-1:1997. Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements," Geneva, Switzerland, May 1997.

[10] N. J. Mansfield, Human Response to Vibration. CRC Press, 2004. doi: https://doi.org/10.1201/b12481.

[11] M. J. . Griffin, Handbook of human vibration. Elsevier, 2004.

[12] N. Nawayseh and M. J. Griffin, "Tri-axial forces at the seat and backrest during whole-body vertical vibration," J. Sound Vib., vol. 277, no. 1–2, pp. 309–326, Oct. 2004, doi: https://doi.org/10.1016/j.jsv.2003.09.048.

[13] M. H. Pope, D. G. Wilder, and M. L. Magnusson, "A review of studies on seated whole body vibration and low back pain," Proc. Inst. Mech. Eng. H, vol. 213, no. 6, pp. 435–446, Jun. 1999, doi: https://doi.org/10.1243/0954411991535040.

[14] M. Hagberg, L. Burström, A. Ekman, and R. Vilhelmsson, "The association between whole body vibration exposure and musculoskeletal disorders in the Swedish work force is confounded by lifting and posture," J. Sound Vib., vol. 298, no. 3, pp. 492–498, Dec. 2006, doi: https://doi.org/10.1016/j.jsv.2006.06.024.

[15] W. Killen and T. Eger, "Position Paper-CRE-MSD 4164-5 CRE-MSD 4164-5 Whole-Body Vibration: Overview of Standards Whole-Body Vibration: Overview of Standards Used to Determine Health Risks," 2016. [Online]. Available: www.cre-msd.uwaterloo.ca.

[16] B. Shivakumara and V. Sridhar, "Study of vibration and its effect on health of the motorcycle rider," *Online Journal of Health and Allied Sciences*, vol. 9, no. 2, 2010.