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Whole-body vibration exposure among tractor operators at the tractor seat: Impact of tillage operation, speed and operator weight

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Abstract

This study presents a comprehensive evaluation of whole-body vibration (WBV) exposure among operators of the URSUS 5312 agricultural tractor during primary and secondary tillage operations, including ploughing, harrowing, and ridging. The investigation focuses on the influence of operational variables—namely forward velocity and operator body mass—on the transmission of vibrational energy through the operator's seat interface. Vibration data were acquired using GM63A vibration meter mounted on the tractor seat base, and analysed in accordance with ISO 2631-1 standards to assess health risk thresholds. Results demonstrate that ploughing at the maximum operational speed of 6.25 kmh^{-1} induced the highest seat-transmitted vibration, with a dominant frequency of 30.52 Hz, whereas harrowing at the minimum speed of 2.25 kmh^{-1} produced the lowest vibration magnitude (5.52 Hz). A strong positive correlation was observed between travel speed and WBV intensity. Additionally, operator mass significantly influenced vibration transmission characteristics, with a heavier operator (96 kg) experiencing elevated vibrational amplitudes (25.52 Hz) relative to a lighter operator (76 kg), who recorded a substantially lower frequency (7.87 Hz). Measured WBV levels frequently exceeded the Exposure Action Value (EAV) specified by international vibration exposure standards, underscoring the potential for cumulative musculoskeletal strain, spinal degradation, and other occupational health risks. Accordingly, the study recommends limiting continuous field operation to no more than 3 hours per day, with intermittent rest periods of at least 30 minutes to mitigate adverse health effects.

Keywords: Whole-Body Vibration; Tillage Operation; Tractor Speed; Operator Weight

1. Introduction

Whole-body vibration (WBV) exposure remains a critical occupational health concern for agricultural tractor operators, particularly during soil-engaging operations. Exposure to WBV is influenced by multiple operational and anthropometric parameters, including tillage type, ground speed, and operator body mass. Prolonged exposure to WBV has been strongly associated with physiological discomfort, diminished task performance, and chronic musculoskeletal disorders, especially in the lumbar spine region [1].

Tillage operations such as ploughing, harrowing, and ridging impart distinct vibrational profiles to the operator through the tractor-seat interface. Among these, ploughing has consistently been reported to produce the highest vibration amplitudes, attributed to deeper soil penetration and greater draft resistance, compared to harrowing and ridging [2, 3]. The excitation frequencies generated during these operations often coincide with the natural resonant frequencies of the human body, thereby increasing the risk of resonance-related spinal injury [2, 4].

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Speed is another primary contributor to WBV intensity. Empirical studies have demonstrated a positive correlation between increased tractor speed and WBV magnitude, with higher velocities often resulting in daily exposures that exceed ISO 2631-1 recommended limits [5, 6, 7]. Moreover, variations in forward speed can alter the dominant frequency spectrum, which in turn affects operator comfort, stability, and biomechanical stress [8].

Operator weight, commonly represented through body mass index (BMI), further modulates vibration transmissibility. Heavier operators are reported to experience different WBV transmission characteristics, potentially due to alterations in seat suspension dynamics and damping efficiency [9]. These findings underscore the necessity for adaptive seating systems capable of compensating for variations in operator anthropometry [9, 10].

A detailed understanding of these interrelated variables is essential for the development of engineering controls aimed at reducing WBV exposure, thereby enhancing operator safety, comfort, and long-term occupational health.

2. Material and methods

2.1. Study Area

The experimental field, measuring approximately 1,483.8 m^2, was situated within the Yelwa Campus of Abubakar Tafawa Balewa University, Bauchi, Nigeria. The geographical coordinates of the study site range between latitudes 9°03′ and 12°03′ N, and longitudes 8°05′ and 11°00′ E. To characterize the soil properties of the test site, samples were extracted at a depth of 30 cm from multiple representative locations across the field. The samples were subjected to laboratory analysis to determine key soil physical properties, including particle size distribution (texture), gravimetric moisture content, and bulk density. Additionally, in-situ soil compaction measurements were conducted using a penetrometer at three standard depth intervals: 0–10, 10–20 and 20–30 cm, following the methodology described by [2].

2.2. Test Subjects

Three male participants from the Department of Agricultural and Bioresource Engineering, Faculty of Engineering and Engineering Technology, Abubakar Tafawa Balewa University (ATBU), Bauchi, voluntarily participated in the study. All subjects possessed a minimum of seven years of practical experience in operating agricultural tractors, ensuring familiarity with typical field conditions and machine controls. Table 1 presents the anthropometric and physiological characteristics of the participants, including age (years), body weight (kg), height (m), body surface area (BSA, m^2), and body mass index (BMI, kgm^{-2}). These parameters were measured to account for individual variability in vibration transmissibility and biomechanical response. Prior to data collection, the objective and methodology of the study were clearly explained to the participants. Each subject was screened for any pre-existing medical conditions or sensitivities related to WBV exposure. Written informed consent was obtained from all participants, and ethical considerations regarding participant safety, anonymity, and voluntary participation were strictly observed throughout the study.

Table 1 Physiological Parameter of Operators Selected

Particulars	O_1	O_2	O_3
Age, yrs	45.00	34.00	32.00
Weight, kg	96.00	79.00	76.00
Height, m	1.73	1.73	1.72
BSA, m^2	4.60	3.8.0	3.7.0
BMI, kgm^{-2}	32.10	26.41	25.40

2.3. Test Tractor and Implements

The experiment was conducted using a URSUS 5312 agricultural tractor (Figure 1), configured with three rear-mounted tillage implements: a disc plough, a disc harrow, and a disc ridger (Figures 2, 3 and 4, respectively). Each implement was adjusted to operate at a uniform tillage depth of 30 cm to ensure consistency across trials. The technical specifications of the tractor and implements are presented in Tables 2, 3, 4 and 5. These include relevant parameters such as engine power, implement dimensions, disc diameter, number of discs, implement weight, and working width. To evaluate the impact of forward velocity on whole-body vibration (WBV) exposure, three discrete travel speeds—

2.25, 4.25, and 6.25 kmh^{-1}—were selected based on operational recommendations and prior research [11]. These speeds were maintained consistently during each tillage operation using engine throttle control and gear ratio adjustment.

Figure 1 URSUS 5312 Model

Figure 2 Disc Plough

Figure 3 Disc Harrow

Figure 4 Disc Ridger

Table 2 Tractor (Ursus-5312) Specification

Engine	**Specification**
Maximum Engine power (kw)	75
Engine revolution (rpm)	2200
No. of engine cylinders	4
Fuel Tank Capacity (Liter)	75
Maximum Speed (kmh-1)	30
Maximum Torque (Nm)	261
Weight (kg)	2815 to 3375
PTO (rpm)	540 min./1100 max.

Table 3 Disc Plough Specification

Specification	Dimension
Number of furrows	2, 2+1, 3, 3+1
Furrow width	254 mm
Maximum working depth	300 mm
Longitudinal clearance	522 mm
Furrow wheel diameter	508 mm
Tractor Compatibility	50-85 hp

Table 4 Disc Harrow Specification

Specification	Dimension
No. of Discs	10, 12, 14
Disc	
Disc Harrow Frame width	126 mm
Disc Harrow Frame Thickness	5.5 mm

Table 5 Disc Ridger Specification

Specification	Dimension
Max. Row spacing	711m
Clearance (under Frame)	550 m
Tractor Compatibility	45-85 hp
Depth	1,050 mm

2.4. Experimental Design

The study employed a Randomized Complete Block Design (RCBD) to evaluate the effects of selected independent variables on whole-body vibration (WBV) exposure during tractor operations. Three experimental factors were considered: Factor A – Tillage Operation: Ploughing, Harrowing, and Ridging; Factor B – Tractor Forward Speed: 2.25, 4.25, and 6.25 kmh^{-1}; Factor C – Operator Body Weight: 96, 79, and 76 kg. The full factorial combination of these levels resulted in 27 treatment combinations (3 × 3 × 3). Each treatment was replicated three times to ensure experimental reliability and minimize variability, yielding a total of 81 experimental runs. The working width of the URSUS 5312 tractor was approximately 2.0 meters. Each experimental plot was 30 meters in length, resulting in a plot size of 60 m^2 (2 × 30 m). A 10-meter buffer swath was maintained on both sides of each plot to allow for speed stabilization before and after data collection, thus ensuring uniform operational conditions during vibration measurements [11]. The collected data were subjected to Analysis of Variance (ANOVA) to determine the statistical significance of main and interaction effects among the treatment factors. Post-hoc comparisons were conducted using Tukey's Honestly Significant Difference (HSD) test at a significance level of $\alpha < 0.05$ to identify statistically significant differences among treatment means.

Table 6 Experimental Procedure

Factor A: Tillage Operations	Factor B: Tractor Forward Speeds	Factor C: Tractor Operators
T1: Ploughing T2: Harrowing T3: Ridging	S1: 2.25 kmh^{-1} S2: 4.25 kmh^{-1} S3: 6.25 kmh^{-1}	O1: 96 kg O2: 79 kg O3: 76 kg
Experimental Design	RCBD	
Replication	3	
Treatments	x 3 x 3 x 3 = 81	

2.5. Data Analysis

Vibration data were collected using a GM63A hand-held vibration meter (Figure 5), with its technical specifications detailed in Table 7. The device was mounted securely on the tractor seat to measure seat-transmitted whole-body vibrations (WBV) during field operations. Each operator—representing three distinct body weight categories (96, 79 and 76 kg)—independently operated the URSUS 5312 tractor across the three predefined forward speeds (2.25, 4.25 and 6.25 kmh^{-1}) and under each tillage condition: ploughing, harrowing, and ridging. During each operation, WBV readings were recorded in real-time to capture the effect of the interaction between operator weight, speed, and tillage type on vibration intensity at the seat interface. All collected data were statistically analysed using Analysis of Variance (ANOVA) to determine the significance of main and interaction effects among the treatment factors. Statistical significance was evaluated at a confidence level of $p < 0.05$, and mean comparisons were conducted using Tukey's Honestly Significant Difference (HSD) test to identify differences between treatment means where applicable.

Figure 5 Vibration Meter and Sensor

Table 7 Vibration Meter Specification

Characteristics	Specification
Measurement range of acceleration	0.1-199.9 ms^{-2} peak
Measurement range of velocity	0.1-199.9 mms^{-1} rms
Measurement range of displacement	0.001-1.999 mm
Measurement frequency range of acceleration	10 Hz-1 KHz (LO) 1 KHz-15 KHz (HI)
Measurement frequency range of velocity	10 Hz-1 KHz (LO)
Measurement frequency range of displacement	10 Hz-1 KHz (LO**)**

3. Results and Discussion

3.1. Effect of Tillage Operation on Seat-Transmitted Vibrations

Figure 6 illustrate the influence of different tillage operations on the vibration levels recorded at the tractor seat. Among the three operations assessed, ploughing produced the highest mean vibration magnitude at 24.68 Hz, which was statistically significant ($p < 0.05$) when compared to the other operations. This elevated vibration level is attributed to the intense soil penetration and disturbance characteristic of ploughing, which generates substantial dynamic forces transmitted to the tractor frame and subsequently to the operator seat. These findings are consistent with prior studies such as [11]. Harrowing, on the other hand, resulted in the lowest mean vibration at 8.23 Hz, indicating minimal transmission of mechanical oscillations from the implement to the operator, likely due to its relatively shallow and less forceful soil interaction. Ridging recorded a mean vibration level of 16.33 Hz, representing an intermediate level of WBV exposure. The values were found to be significantly different from both ploughing and harrowing, suggesting that the degree of soil contact and implement aggressiveness directly correlates with the magnitude of seat-transmitted vibrations. These results highlight the importance of tillage operation type in determining WBV exposure levels, with ploughing posing the greatest ergonomic and health risk due to elevated vibration frequencies.

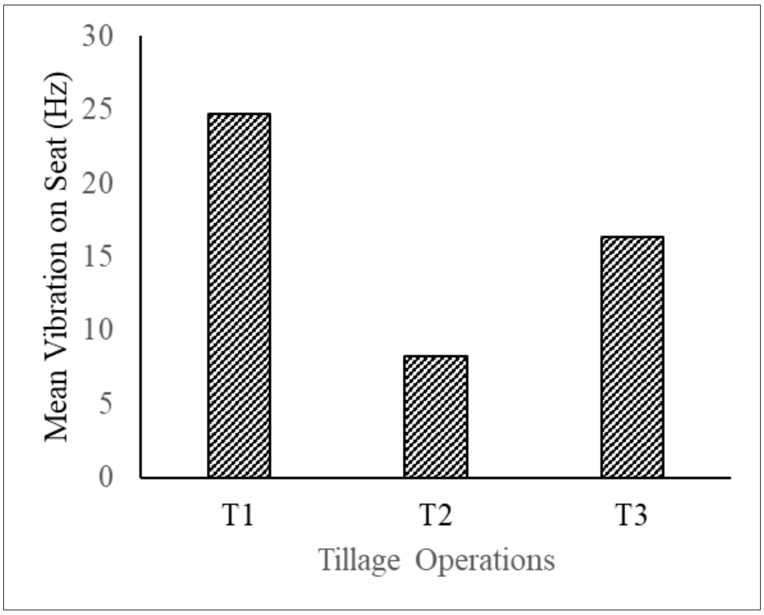

Figure 6 Effect of Tillage Operation on Seat-Transmitted Vibrations

3.2. Effect of Forward Speed on Seat-Transmitted Vibrations

Figure 7 presents the effect of varying tractor forward speeds on the mean vibration levels recorded at the operator's seat. The data reveal a clear and statistically significant trend ($p < 0.05$), where increased ground speed correlates with elevated vibration intensities. At the lowest speed of 2.25 $km{\cdot}h^{-1}$, the mean seat vibration was recorded at 12.34 Hz, representing the lowest vibration exposure across the speed treatments. This reduced vibration level is attributed to the lower kinetic energy and minimal dynamic interaction between the implement and the soil, resulting in less transmission of oscillatory forces through the tractor chassis. As the forward speed increased to 4.25 $km{\cdot}h^{-1}$, the mean vibration rose to 15.87 Hz, which was significantly higher than the lowest speed but lower than the maximum. This intermediate value suggests a proportional increase in vibration magnitude with speed, reflecting the influence of increased ground contact forces and implement-induced soil disturbance. The highest speed of 6.25 $km{\cdot}h^{-1}$ produced the greatest mean vibration level at 21.03 Hz, significantly exceeding the levels observed at lower speeds. This pronounced increase in WBV is likely a result of intensified soil-tool interaction and higher mechanical excitation of the tractor frame. These findings are consistent with those of [3], who reported a direct relationship between operational speed and whole-body vibration exposure in field conditions. The results confirm that forward speed is a critical parameter influencing operator exposure to WBV and must be optimized to balance field productivity and operator safety.

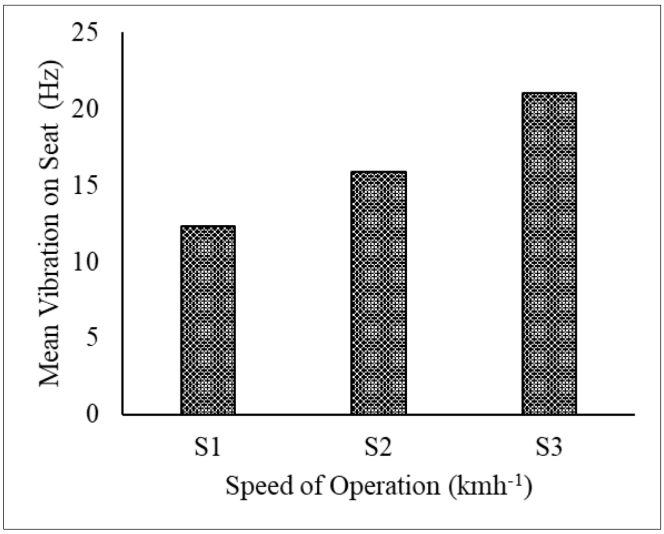

Figure 7 Effect of Forward Speed on Seat-Transmitted Vibrations

3.3. Effect of Operator Weight on Seat-Transmitted Vibrations

Figure 8 illustrates the influence of operator body weight on the mean whole-body vibration (WBV) levels measured at the tractor seat. The data indicate a statistically significant variation ($p < 0.05$) in vibration response across the three weight categories: 96, 79, and 76 kg. The heaviest operator (96 kg) experienced the highest mean vibration level of 17.30 Hz, consistent with findings by [12]. This elevated vibration may be attributed to increased static and dynamic loads acting on the tractor seat and suspension system, potentially amplifying the transmission of mechanical oscillations from the vehicle chassis to the operator interface. The 79 kg operator recorded an intermediate vibration level of 16.42 Hz, which was significantly different from both the heavier and lighter subjects. This suggests that vibration transmission characteristics vary nonlinearly with body weight, likely due to differences in damping interaction between the seat suspension and operator body mass. The lightest operator (76 kg) experienced the lowest mean vibration, measured at 15.53 Hz, which was significantly lower than that of the 96 kg operator. The reduced vibration exposure for lighter operators may result from lower applied static loads, allowing for more effective isolation performance of the seat suspension. These findings underscore the relevance of anthropometric factors—specifically body weight—in influencing the vibrational dynamics of operator-seat systems. The results support the need for ergonomically adjustable seating systems that can accommodate a range of operator body weights to minimize WBV exposure and enhance ride comfort and occupational safety.

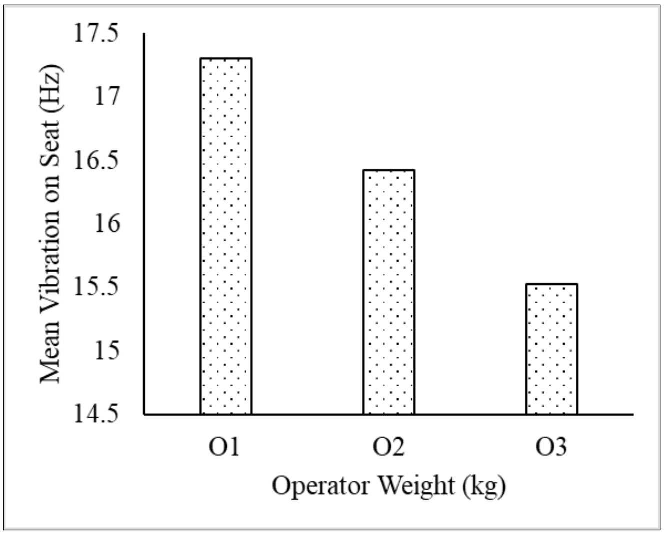

Figure 8 Effect of Operator Weight on Seat-Transmitted Vibrations

3.4. Combined Effects of Tillage Operation and Forward Speed on Seat-Transmitted Vibrations

Figure 9 presents the interaction effects between tillage operation type and tractor forward speed on mean vibration levels measured at the operator's seat. The analysis reveals a statistically significant interaction ($p < 0.05$), demonstrating that both tillage intensity and operational speed jointly influence whole-body vibration (WBV) exposure. During ploughing, the mean vibration increased markedly from 19.45 Hz at 2.25 kmh^{-1} to 30.52 Hz at 6.25 kmh^{-1}. This substantial rise underscores the compounded impact of aggressive soil penetration and high-speed operation. The findings align with [11], confirming that intensive tillage at elevated speeds generates the highest vibration magnitudes due to elevated dynamic loads and soil-tool interaction forces. Harrowing, in contrast, consistently produced the lowest vibration levels across all speed settings. The mean vibration ranged from 5.52 Hz at 2.25 kmh^{-1} to 10.65 Hz at 6.25 kmh^{-1}. These relatively low values reflect the less intrusive nature of the harrow's soil interaction, which results in reduced excitation of the tractor structure and more favourable WBV conditions for the operator. Ridging demonstrated an intermediate vibration profile, with mean values of 12.07, 15.00, and 21.93 Hz at 2.25, 4.25, and 6.25 kmh^{-1}, respectively. These values suggest that while ridging imposes more load and vibration than harrowing, it remains less severe than ploughing in terms of WBV transmission. These results emphasize the necessity of joint optimization of tillage operation type and forward speed to mitigate WBV exposure. Specifically, high-speed ploughing poses the greatest risk to operator comfort and long-term musculoskeletal health. Conversely, operations such as harrowing—particularly at lower speeds—present more favourable vibration profiles, making them safer for prolonged field tasks. Therefore, operational planning should integrate both the nature of the tillage task and appropriate speed selection to enhance occupational safety and machine ergonomics.

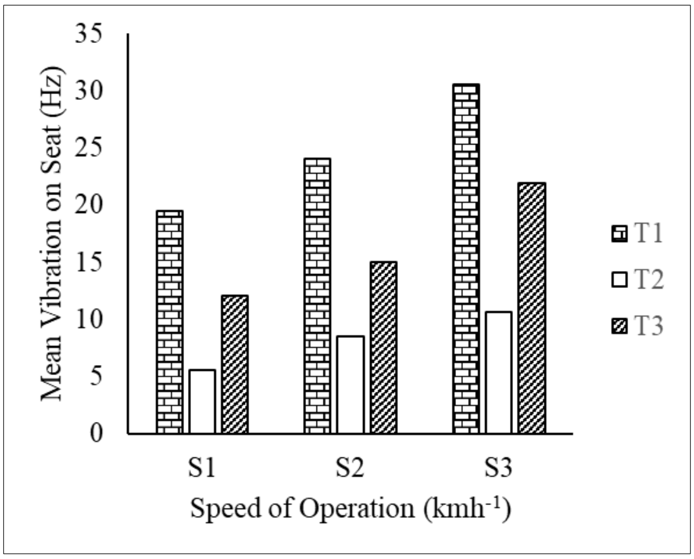

Figure 9 Combined Effects of Tillage Operation and Forward Speed on Seat-Transmitted Vibrations

3.5. Combined Effects of Operator Weight and Tillage Operation on Seat-Transmitted Vibrations

Figure 10 illustrates the interaction between operator weight and tillage operation on the mean vibration magnitudes transmitted to the tractor seat. The data show a statistically significant interaction effect, indicating that the mass of the operator modulates the vibrational response depending on the nature of the soil-engaging implement used. During ploughing, which imposes the most severe dynamic loading due to intensive soil disruption, vibration levels increased proportionally with operator weight. The heaviest operator (96 kg) recorded the highest mean seat vibration at 25.52 Hz, which was significantly greater than that observed for the lighter operator (76 kg), who experienced a mean vibration of 23.84 Hz. The intermediate body mass (79 kg) was associated with a mean vibration level of 24.68 Hz. These findings suggest that higher body mass increases the static and dynamic loading on the seat-suspension system, potentially reducing its isolation efficiency and amplifying the transmission of vibrational energy to the operator. In contrast, harrowing resulted in the lowest vibration magnitudes across all weight categories, with minimal variation between them. The 96 kg operator recorded a mean vibration of 8.60 Hz, marginally higher than 8.23 Hz and 7.87 Hz for the 79 kg and 76 kg operators, respectively. The limited variation indicates that harrowing generates a relatively uniform and low-intensity vibration profile, largely independent of operator body mass. For ridging, a moderate tillage operation, a more pronounced weight-related trend was observed. The 96 kg operator experienced 17.78 Hz, followed by 16.33 Hz for 79 kg, and 14.89 Hz for 76 kg. This gradient indicates that while ridging does not match the intensity of ploughing, the influence of operator body mass remains non-negligible and is more significant than in harrowing.

Overall, these results underscore the role of operator body mass as a contributing factor to whole-body vibration (WBV) exposure, particularly during high-intensity tillage operations such as ploughing. The interaction of dynamic field conditions with biomechanical loading affects the vibrational transmissibility through the seat interface. Consequently, adaptive seat suspension systems with mass-tuned damping characteristics may be beneficial for minimizing WBV transmission across varying operator anthropometrics.

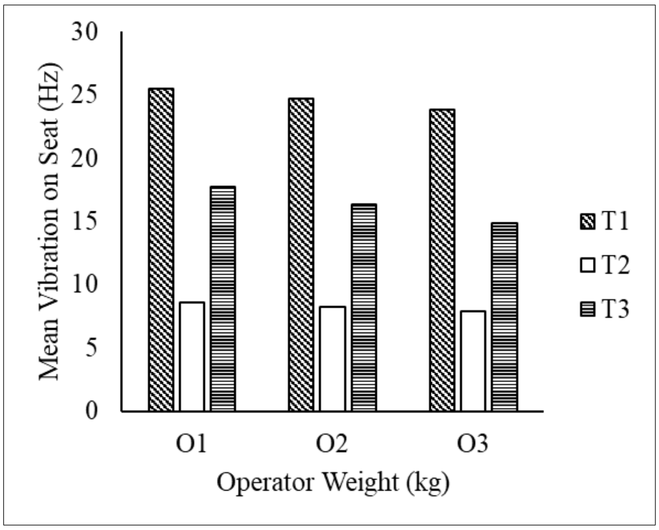

Figure 10 Combined Effects of Operator Weight and Tillage Operation on Seat-Transmitted Vibrations

3.6. Combined Effects of Operator Weight and Forward Speed on Seat-Transmitted Vibrations

Figure 11 presents the interaction effects between operator weight and tractor forward speed on the mean vibration magnitudes recorded at the tractor seat. The results demonstrate that the combined influence of these two factors varies across operational speeds, with both independent and interactive effects observed. At the lowest speed of 2.25 kmh^{-1}, mean vibration levels remain low and relatively consistent across all operator weights, measured at 12.50 Hz for the 96 kg operator, 12.34 Hz for the 79 kg operator, and 12.19 Hz for the 76 kg operator. Statistical analysis shows no significant differences ($p > 0.05$) among the three weights at this speed, suggesting that at reduced forward velocity, the contribution of operator weight to seat-transmitted vibrations is minimal. The low-speed operation likely produces limited soil resistance and inertial forces, thereby minimizing vibrational energy irrespective of operator loading. At a moderate speed of 4.25 kmh^{-1}, a clear divergence in vibration response is observed with increasing body mass. The 96 kg operator experienced a significantly higher mean vibration of 17.56 Hz, compared to 15.87 and 14.19 Hz for the 79 and 76 kg operators, respectively. This trend indicates a positive correlation between operator weight and vibration magnitude under intermediate dynamic loading. It is inferred that increased operator weight alters the natural frequency and damping characteristics of the seat system, leading to greater vibrational transmission at moderate speeds. At the highest speed of 6.25 kmh^{-1}, all operator weights experience the highest vibration levels, with 21.84 Hz recorded for the 96 kg operator, 21.03 Hz for the 79 kg, and 20.22 Hz for the 76 kg. Although these values are elevated, the differences between them are statistically insignificant, suggesting that the dominant influence of speed at this level overshadows the contributions of operator body mass. At high speeds, amplified soil-tractor interactions and increased ground-induced excitation overwhelm the moderating effect of body mass on seat-transmitted vibrations. These findings underscore the importance of speed control as a primary factor in managing WBV exposure. While operator mass has a moderate influence at mid-range speeds, it is largely negligible at low speeds and overwhelmed at high speeds. This highlights the necessity of designing mass-sensitive seat suspension systems that can dynamically adjust to both operator characteristics and operating velocity, to improve vibration attenuation across varying field conditions.

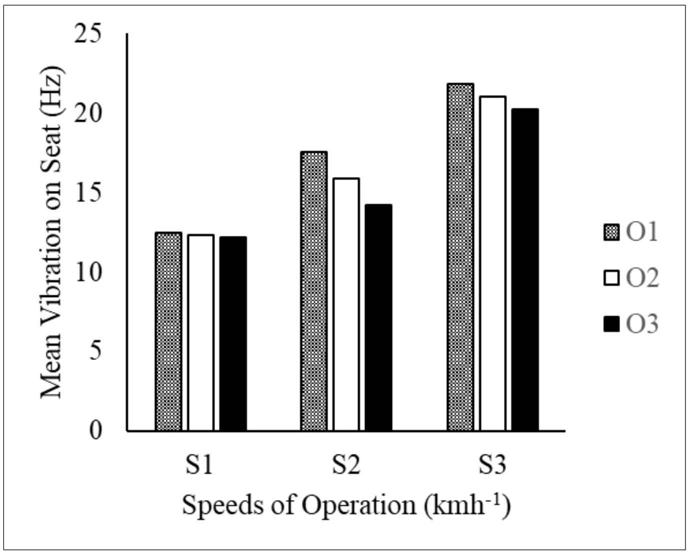

Figure 11 Combined Effects of Operator Weight and Forward Speed on Seat-Transmitted Vibrations

3.7. Combined Effects of Tillage Operation, Forward Speed, and Operator Weight on Seat-Transmitted Vibrations

Figure 12 illustrates the intricate interactions among tillage operation, forward speed, and operator weight on the mean vibration magnitudes recorded at the tractor seat. The results reveal that the combined influence of these factors leads to complex, nonlinear vibration responses, highlighting the necessity for multi-factorial consideration in vibration exposure assessment. During ploughing at 2.25 kmh^{-1}, mean vibration levels were relatively similar for the 96 kg (19.45 Hz) and 79 kg (19.43 Hz) operators, both of which were significantly lower than that of the 76 kg operator, who experienced 25.60 Hz. This suggests a possible resonance effect between operator weight and the seat–tractor dynamic system, particularly for the lighter operator. At a moderate speed of 4.25 kmh^{-1}, vibrations increased for all weights, with the 76 kg operator recording the highest vibration level (31.50 Hz)—a significant elevation compared to 96 kg (24.08 Hz) and 79 kg (22.57 Hz). At the highest speed of 6.25 kmh^{-1}, vibrations peaked for the 96 kg (30.52 Hz) and 79 kg (29.53 Hz) operators, with no significant difference between them, while the 76 kg operator experienced a reduction to 19.45 Hz, possibly due to dynamic mismatch or disengagement from the vibration source. In harrowing, the mean vibration levels remained consistently low across all combinations. At 2.25 kmh^{-1}, the 96 kg (5.52 Hz) and 79 kg (5.57 Hz) operators exhibited similarly low values, while the 76 kg experienced slightly higher vibrations (8.67 Hz). As speed increased to 4.25 kmh^{-1}, vibration levels rose modestly with no statistically significant differences among the weights (96 kg: 8.53 Hz, 79 kg: 8.40 Hz, 76 kg: 11.67 Hz). At 6.25 kmh^{-1}, although the vibration values increased further, they remained the lowest among all tillage operations, with values of 10.65, 9.63, and 5.52 Hz for the 96, 79, and 76 kg operators, respectively. These findings affirm that harrowing induces the least vibration stress, likely due to its minimal soil penetration and mechanical resistance. For ridging, moderate vibration levels were recorded. At 2.25 kmh^{-1}, the 96 kg (12.07 Hz) and 79 kg (11.57 Hz) operators showed similar values, while the 76 kg operator recorded a significantly higher vibration of 18.40 Hz. At 4.25 kmh^{-1}, vibrations increased to 15.00 Hz (96 kg), 11.60 Hz (79 kg), and a peak of 22.37 Hz for the 76 kg operator. At 6.25 kmh^{-1}, the 96 and 79 kg operators experienced 21.93 and 21.50 Hz, respectively, whereas the 76 kg operator experienced a decrease to 12.07 Hz, again suggesting non-linear vibrational behaviour. Overall, the results confirm that both operator weight and tractor speed significantly influence the magnitude of seat-transmitted vibrations, with effects that are modulated by the type of tillage operation. Notably, ploughing at higher speeds consistently produced the highest vibration levels, disproportionately affecting lighter operators, possibly due to biomechanical mismatch and reduced damping from body mass. Harrowing, on the other hand, exhibited the most favourable vibration characteristics for operator comfort across all speed and weight categories. Ridging produced intermediate effects, with a tendency for increased vibration sensitivity among lighter operators as speed increased. These insights highlight the importance of considering tri-factorial interactions when designing strategies for mitigating whole-body vibration (WBV) exposure. Optimal seat suspension systems and operator-specific speed recommendations should account for operator body mass, tillage type, and operating speed to ensure both safety and ergonomic efficiency.

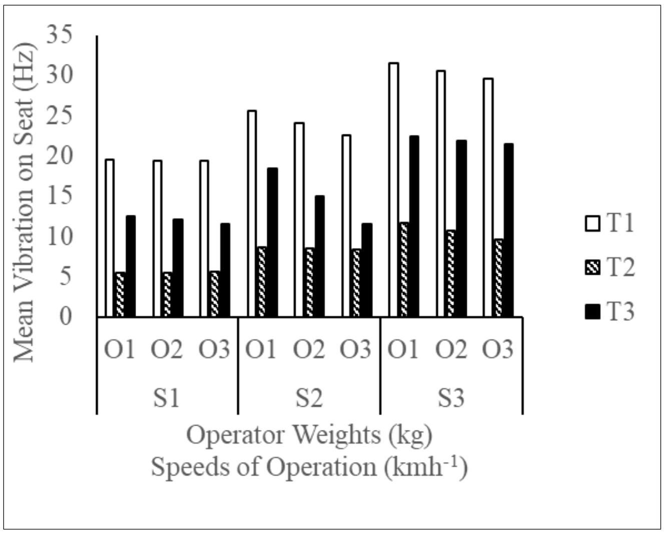

Figure 12 Combined Effects of Tillage Operation, Forward Speed, and Operator Weight on Seat-Transmitted Vibrations

4. Conclusion

This study clearly establishes that whole-body vibration (WBV) exposure at the tractor seat is significantly affected by three main factors: the type of tillage operation, the speed of operation, and the operator's body weight. Among the tillage operations evaluated, ploughing consistently generated the highest mean vibration levels, particularly at higher speeds, due to its intensive soil engagement. In contrast, harrowing produced the lowest vibration levels, making it the least stressful operation in terms of operator vibration exposure. Ridging caused moderate vibrations, falling between ploughing and harrowing, but still showing sensitivity to both operator weight and operational speed. The speed of operation played a dominant role, with vibrations increasing significantly as speed increased from 2.25 to 6.25 kmh^{-1}. At lower speeds, differences in vibration between operator weights were minimal, but at moderate and high speeds, heavier operators (especially 96 kg) generally experienced greater vibration exposure, likely due to increased static and dynamic loading on the seat and suspension systems. These findings highlight the critical importance of managing operational parameters such as field speed and the type of tillage implement used, while also considering operator ergonomics and physical characteristics. Failure to do so can lead to increased WBV exposure, which has been linked to discomfort, fatigue, and potential long-term health issues among tractor operators. Thus, optimizing tractor usage by selecting appropriate speed-tillage combinations and designing adjustable seating systems to accommodate different operator weights can significantly enhance safety, reduce fatigue, and improve operator efficiency in the field.

Compliance with ethical standards

Disclosure of conflict of interest

The author(s) declare that there is no conflict of interest.

Statement of Informed consent

Informed consent was obtained from all individual participants included in the study.

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