



EVALUATION OF RAMP-INDUCED VIBRATION EXPOSURE LEVEL FOR A PREGNANT WOMAN COMMUTING ALONG URBAN ROADS IN GHANA

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ABSTRACT

Vibration exposure on humans is a global concern for mechanical and structural engineers as well as occupational health safety regulators. A number of theories and vibration estimation equations have been propounded by researchers as well as international bodies and each technique is associated with some form of limitations in practice. This work is centered on evaluating the exposure level of the vibrations felt on the pregnant occupant's tummy during wheel-to-ramp banging encounter for a vehicle maneuvering over speed ramps. An instrumented underwear jacket was used to pick signals from volunteered non-belted pregnant occupants during some routine trips along bumpy roads. The jacket makes use of accelerometers and gyroscopic and rotation sensors concealed in its pockets to sense and record the ramp-induced vibration signals. The data obtained from these subjects were evaluated using power spectral density (PSD) and estimated vibration dose value (eVDV). Routine trips for subjects along bumpy roads experienced high energy levels – based on PSD values – than those trips on roads sections that had no speed ramps. The eVDV levels realized were about three-fold that of the recommended levels per the ISO 2631-1 and BS 6841 standards adopted. A typical eVDV values of between 58 to 70 $ms^{-1.75}$ was found for the average pregnant occupant during short travel times which is above the recommended maximum ISO 2631-1 permissible dose value of 17 $ms^{-1.75}$. It is suggested that a detachable pregnant occupant car seat ought to be developed to attenuate the excessive amplitudes of vibration felt by pregnant occupant.

Keywords: Instrumented jacket; pregnant occupant; acceleration; power spectral density (PSD); estimated vibration dose value (eVDV)

1.0 INTRODUCTION

From the viewpoint of social and the travel pattern analysts, women make more trip-chaining activities per day than men and most lower income-women class prefer to use public transit (Wachs, 1997; Wegmann & Jang, 1998). The ratio of women who travel by motor vehicle to work equalizes that of men and they go for shopping tour as much as twice that of men (Srinivasan, 2005). And most of these commutations are usually via motor vehicle transport. It is also interesting to note that women sustain higher strains, sprains, contusions abrasions and internal injuries than their men counterparts during vehicle impact endurance (Dellinger, 2005). Road accessibility, reduction in



casualties, congestion, and pollution are of concern by most road policy documents (Vagland, 2011; Noble, 2005; Zohir, 2005).

In Ghana, speed ramps are used to check over-speeding of drivers on roads. However, the standards specified in the blue books of Ghana Highway Authority (GHA) have not been fully implemented. This has escalated the already hectic hurdles that drivers and passengers have to bear while commuting along bumpy roads. Community members illegally erect speed ramps to check over-speeding in their localities without any kind of monitoring by GHA. The situation is so weird that it poses a serious ‘speed-ramp-hazard’ on the road, especially for drivers who are first time users of that section of road in question. The pervasiveness of the ‘speed-ramp-hazard’ on the road has the potential to limit the frequency at which pregnant women engage in trip-chaining duties for their respective households. It also imposes social, physical and psychological burden on them (Akowuah, Ampofo & Andoh, 2015).

Usually, the emitted ramp-induced vibrations are so huge that it needs much to be desired. Vehicle occupants, especially the pregnant woman has no option than to endure all the discomfort from the place of boarding to the final destination. The cumulative shocks may or may not cause any subsequent disorders depending upon the exposure levels. A number of exposure assessments techniques that exist have been done by various researchers to assess the level of ride quality and comfort for road vehicle (Abdullah, 2012; Corte, Duarte, Batista & Silva, 2011).

Power spectral density (PSD) is one of the most stable signal assessment technique used for analyzing vibration signals. PSDs are typically used to describe random vibration environments like those specified in military and commercial test standards. The levels of vibration exposure to vehicle occupant could be predicted by performing PSD analysis on measured vibration signal acting on the occupants’ body. Human feeling of vibration is also evaluated by established standards known as global measures or comfort indicators. The most widely used ones are the International Standard Organization ISO 2631-1 (1997) and the British Standard Institution BS6841 (1987). They are highly recommended and universally acceptable for evaluating the impact of vibration on human body.

Two common estimators used are the root mean square and root mean square proposed by Griffin (1996) and BS 6841 (1987) are given by Equations 1 and 2 as follows.

$$rms = \left[\frac{1}{T} \int_0^T a^2(t) dt \right]^{1/2} \dots\dots\dots(1)$$

$$rmq = \left[\frac{1}{T} \int_0^T a^4(t) dt \right]^{1/4} \dots\dots\dots(2)$$

Where $a(t)$ is the vertical acceleration recorded as a function of time (t) and is measured in ms^{-2} . Equation 2 is relatively a better measure for shock impacts on the human body (Griffin, 1996) than Equation 1. This is because rms underestimate the impacts of sudden transient shocks on human body.

Equations 1 and 2 have a limit in terms of defining the beginning and ending exposure times of such vibration estimation. Therefore, estimators known as vibration dose value (VDV) and its modified form called estimated vibration dose value, eVDV as presented in Equation 3 and 4 respectively are better estimators. Interestingly, the ISO2631-1 and BS 6841 offer a possibility of using such estimators to estimate occupant comfort (Burdzik & Konieczny, 2013).

$$VDV = \left[\int_0^T a^4(t) dt \right]^{1/4} \dots\dots\dots(3)$$

$$eVDV = 1.4 rms.t^{0.25} \dots\dots\dots(4)$$



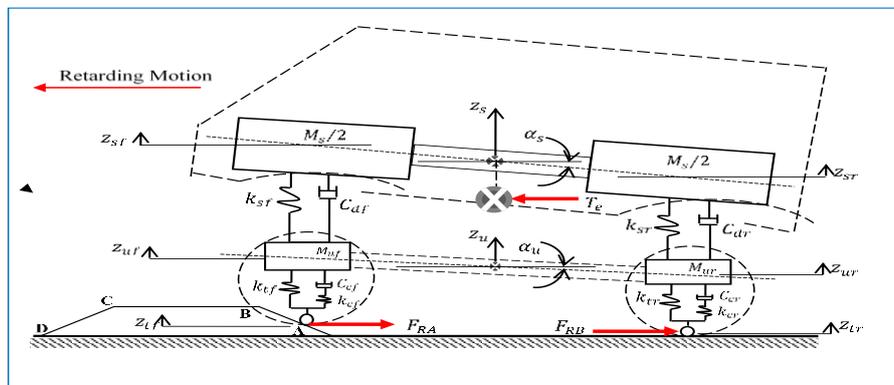
Where $a(t)$ is the instantaneous vertical acceleration in m/s^2 , rms is the root mean square value of acceleration and t is the vibration exposure time. Equation (4) is usually preferred in the quantification of vibration as it is an alternative measure of occupant ride comfort in the occupant environment.

It is important to note that even though these equations and standards exist, there has not been any conscious effort to practically collate signals and assess vibration exposure levels of pregnant women who commute along bumpy roads. Therefore, the objective of this work was to acquire the vibration impact signals meted-out to the tummy of pregnant occupant as vehicle maneuvers over speed ramps and to estimate the exposure level of ramp-induced vibration (RIV) for the pregnant occupant.

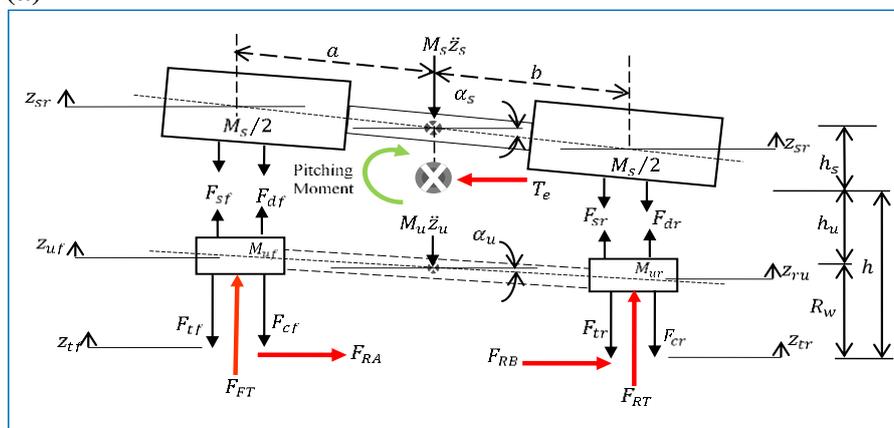
2.0 METHODS AND MATERIALS

Analytical Perspective

The analytical perspective of the ramp-induced vibrations was considered by examining the dynamical forces that act on the sprung mass of a vehicle under wheel-to-ramp interactions in order to deduce the corresponding linear and rotary motion equations of the vehicle as it bounces over speed ramps. From Figure 1, a vehicle approaching a speed ramp would undergo a retarding motion and the associated linear and angular equations of its sprung mass using a Modified Half Car Model is given by Equations 1 and 2.



(a)



(b)

Figure 1: Vertical Jumps and Pitch motions of the Modified Half Car Model (a) and corresponding Free Body Diagram (b). (Authors' analytical work, 2017)



Equations 5 and 6 respectively represent the linear and angular accelerations occurring in the sprung mass of the vehicle. The occupant in the vehicle is also subjected to a proportion of these accelerations depending upon the seat cushioning. Figure 2 portrays the vehicle-to-pregnant occupant interaction during wheel-to-ramp banging. Figure 2(a) demonstrates the vertical motion dynamics whilst Figure 2(b) depicts that of the pitching motion of upper body with forelimb support.

$$\ddot{z}_s = \frac{1}{M_s} [k_{sf}(z_{sf} - z_{uf}) + C_{df}(\dot{z}_{sf} - \dot{z}_{uf}) + k_{sr}(z_{sr} - z_{ur}) + C_{dr}(\dot{z}_{sr} - \dot{z}_{ur}) + \frac{1}{2} M_s \ddot{\alpha}_s a - \frac{1}{2} M_s \ddot{\alpha}_s b + F_{RT} + F_{FT}] \dots \dots \dots (5)$$

$$\ddot{\alpha}_s = \frac{1}{I_{ys}} [-k_{sf}(z_s + a\alpha_s - z_{uf})a - C_{df}(\dot{z}_s + a\dot{\alpha}_s - \dot{z}_{uf})a + k_{sr}(z_s - b\alpha_s - z_{ur}) + C_{dr}(\dot{z}_s - b\dot{\alpha}_s - \dot{z}_{ur})b - F_R(R_w) + T_e h_s + aF_{FT} - bF_{RT}] \dots \dots \dots (6)$$

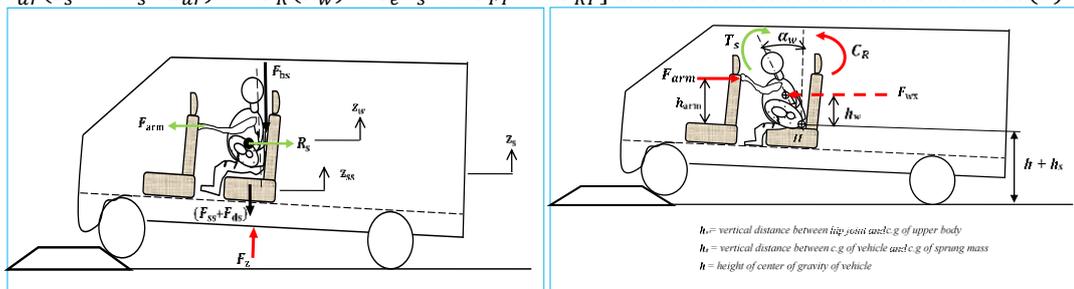


Figure 2: Vibratory motion of pregnant occupant within the sprung mass. (a) Vertical motion and (b) Angular (pitch) motion. (Authors' analytical work, 2017)

Figure 3 depicts the relative positions and forces during the motion dynamics of the upper part of the pregnant woman – including the tummy muscles and foetus for the ‘to’ and ‘fro’ linear vertical motions (A) and angular motions (B). Figure 3(A) is composed of the normal posture (a) in which the occupant of mass (m_w) is relaxed in a seat of springiness, k_{st} and damping coefficient, C_{st} . The exaggerated forward shift posture (b) due to clockwise pitch moment in which the pregnant occupant’s is assumed to have springy and cushy buttocks muscles with foetus diving down the liquor and occupant’s upper body and legs raised upward by the base excitations, P_{wz} . Whilst Figure 3(B) composed of normal posture (a and b) and exaggerated backward shift posture (c and d) due to clockwise and anticlockwise respective pitch moments about the hip joint, H. Here, the effective resisting couple (C_E) equivalent to the product moment of inertia of the upper body of the pregnant woman, I_{yw} and the angular acceleration, $\ddot{\alpha}_w$ at which the upper body and foetus are alternately tossed forward and backward.

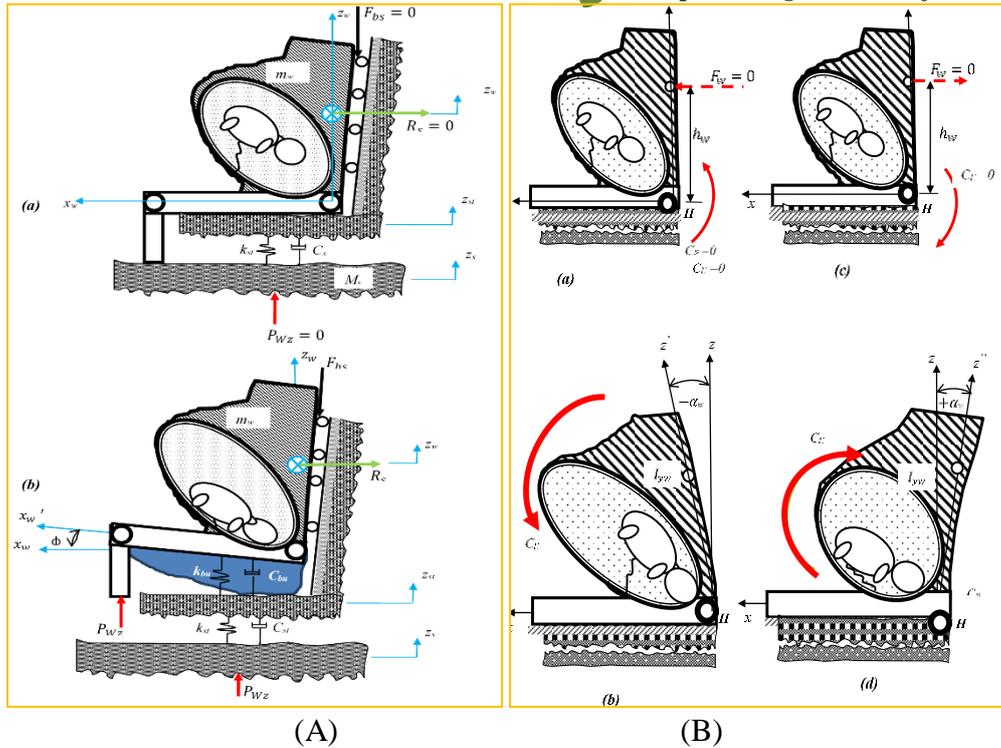


Figure 3: Linear (vertical) vibratory motion (A) versus angular (pitching) vibratory motions (B) of seated pregnant occupant. (Authors' analytical work, 2017)

The corresponding linear and angular motion equations of the pregnant occupant based on some assumptions are given by Equations 7 and 8.

$$\ddot{z}_w = \frac{1}{m_w} \left[M_s \ddot{z}_s - \mathbf{k}_{ef}(z_w - z_{ss}) - \mathbf{C}_{ef}(\dot{z}_w - \dot{z}_{ss}) - \mu_s R_s \cos \theta_s + \frac{1}{2} M_s \ddot{\alpha}_s a - \frac{1}{2} M_s \ddot{\alpha}_s b + F_{RT} + F_{FT} \right] \dots \dots \dots (7)$$

$$\ddot{\alpha}_w = \frac{1}{I} \left[-k_{sf}(z_s + a\alpha_s - z_{uf})a - C_{df}(\dot{z}_s + a\dot{\alpha}_s - \dot{z}_{uf})a + k_{sr}(z_s - b\alpha_s - z_{ur}) + C_{dr}(\dot{z}_s - b\dot{\alpha}_s - \dot{z}_{ur})b - F_R(R_w) + T_e h_s + aF_{FT} - bF_{RT} - F_{arm} h_{arm} \right] \dots \dots \dots (8)$$

Where; $\ddot{\alpha}_w$ is the angular acceleration of pregnant woman and m_w and I are the mass and moment of inertia of the woman respectively. Also, z_s , \dot{z}_s and \ddot{z}_s are the displacement, velocity and acceleration of sprung mass in z-direction whilst z_w , \dot{z}_w and \ddot{z}_w are displacement, velocity and acceleration of woman in z-direction. The eight terms in the parenthesis of Equation 7 are – from left to right; the sprung mass inertial force, seat cushion spring force, seat cushion damping force, occupant's backside friction, front inertial force due to pitching, rear inertial force due to pitching, rear base excitation force and front base excitation force. Whilst the nine terms in the parenthesis of Equation 8 are - from left to right; the front spring torque, front damping torque, rear spring torque, rear damping torque, braking torque, engine traction torque, front base excitation torque, rear base excitation torque and occupant's arm torque.

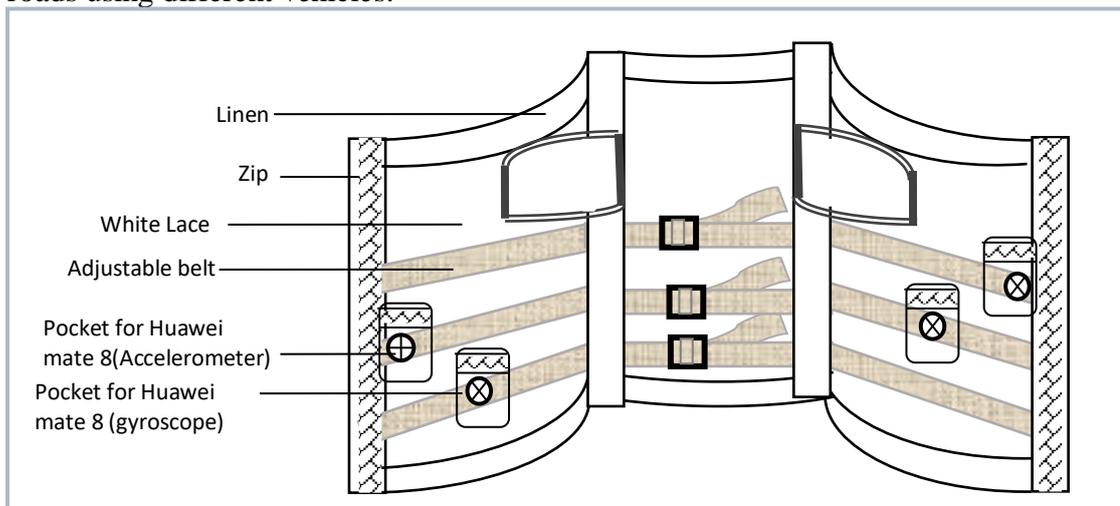
Experimental Measurement of the 'RISSGT'

A non-intrusive measurement of ramp-induced vibration (RIV) signals were done and the signals obtained were herein called ramp-induced signals sensed on gravid tummy (RISSGT). The task was to record vibratory impact signals emanating from the tummy of volunteered pregnant women via the use of an engineered outfit known as instrumented jacket - coined by author - as depicted in Figure 4a. The adjustable



instrumented jacket (Figure 4b) was used to conduct a number of on-road tests to measure vibration signals around the lower abdomen of pregnant women who ply bumpy roads to their routine workplaces, market centres and health care facilities, among others. Three volunteered pregnant women were selected and taken through professional counselling and training by experts. Each participant selected the preferred route to be used for the travel test as well as the type of vehicle.

During the test sessions, ramp-induced vibration signals were recorded on the pregnant tummy for three subjects along bumpy road sections. Whilst in a control test, ramp-free vibrations signals were recorded for two subjects on road sections that had no speed ramp. Test sessions were conducted for each of the subjects at their own convenient times for distinct gestational ages (in weeks). The times for the test sessions were scheduled to coincide with their usual daily trips to hospital, market and workplace among others. The Huawei mate 8 sensors recorded data points on accelerations(m/s^2), angle of rotations(quaternion) and gyroscopes (angular speed) of the ramp-induced vibrations on the belly of the pregnant occupants (subjects) on different sections of roads using different vehicles.



(a)



(b)



(c)

Figure 4: Instrumented jacket worn by volunteered pregnant woman.

(a) Schematic view, (b) Inner portion of the improvised version used and

(c) Seated a volunteer during a road test. (Authors' experimental work, 2017)

The test sessions were scheduled within the 7th month of pregnancy corresponding to the gestational ages of 28 to 32 weeks. Prior to participating in the study, each subject



was asked to fill out a health questionnaire and to read and sign a consent form. Three relevant sensors on the Hauwei mate 8 smart phone were simultaneously activated together with a stop watch. The phone was then secured in the jacket by zipping it in the pocket of the jacket. The pregnant woman worn the jacket and adjusted it to suit her belly with assistance of a Midwife. The participant boards the vehicle to a prescribed destination – which is between 10 to 15-minute drive. A follow-up vehicle escorted the test vehicle. Upon arrival at the said destination, the smart phone was carefully unzipped from the respective pockets and the Sensor Kinetic pro application was halted from further recordings. The data points recorded by the active sensors of the Hauwei mate 8 smart phone were saved with a unique file name in an automatic directory called the Sensor Kinetic Charts folder. The saved data points were then converted to comma separated variables (CSV) format on the smart phone using the same software application and stored on a memory chip.

3.0 ANALYSIS AND DISCUSSION OF RESULTS

The retrieved CSV data was then opened in Microsoft Excel and converted to Excel Workbook for compatibility, easy organisation and analysis of the data. All the necessary adjustments of the data were done in the Excel format before the data was imported to Matlab workspace for coherent data analysis. For easy analysis of the huge bunch of data, a code was written in Matlab M-file and used to generate the respective aperiodic responses in the graphical form as found in subsequent sections.

The evaluation of the data obtained for all the three subjects were performed based on two major indicators, namely, Estimated Vibration Dose Value (eVDV) and Power Spectral Density (PSD). As a control, similar signals were recorded for Subjects '2' and '3' (*hereafter referred to as 'Subject 2 control' and 'Subject 3 control'*) along ramp-free road sections and analysis made using the same indicators. Each subject was engaged in two road test and the RISSGT signals recorded include acceleration (m/s^2), angular velocities (rad/s) and rotation angles (degrees). The impact level of these signals were assessed based on the aforementioned standards indicators. Only signals in the vertical and horizontal longitudinal planes were evaluated as prescribed by the model of this study. The number of data points recorded for the test, the gestational age, the average velocity of vehicle during the road test and type of indicator under consideration as well as the unique file name of the recorded data sets have been captured as distinctive headings for all plots for easy identification.

Commuting along Bumpy Roads

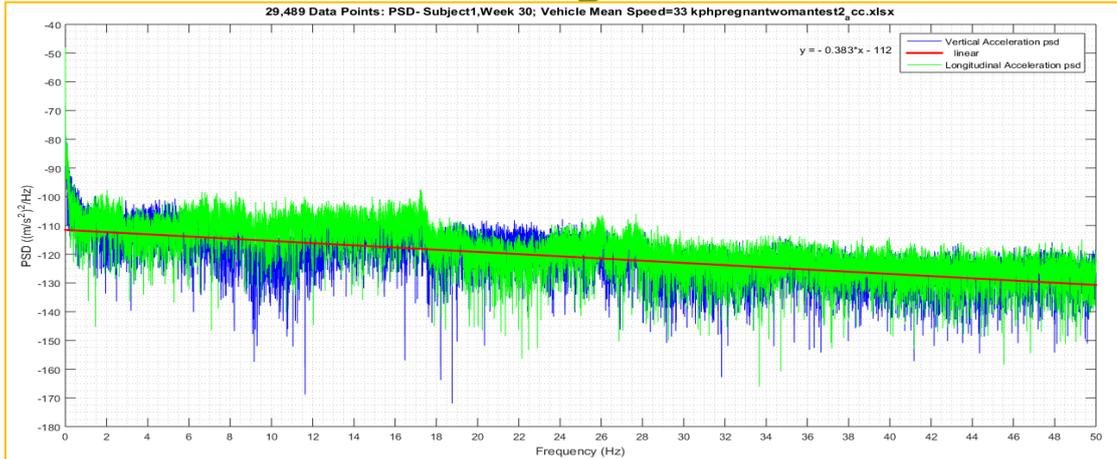
At a sampling frequency of 100 Hz, a total of 30,876 data points was recorded in a 5-minute test drive. All data points were filtered using the Low Pass Filter feature of the Pro Sensor Kinetics software while picking up the RISSGT signals. As suggested by a number of vibration researchers (Rubin, Turner, Müller, Mitra, McLeod, Lin, & Qin, 2002; Harris and Piersol, 2002; Griffin, 1996; Bendat and Piersol, 2000), RMS values of random signals do not present much details on the harmful nature of the signals and other assessment techniques are required. Power spectral density of the signals were plotted in this instance to predict the dangerous frequency regime of the signals. The plots shown in Figure 5a is a sample PSD plot for the signals picked from subject one. The energy levels of the signals generally decrease from frequency of 0 Hz up to the Nyquist frequency of 50Hz (half of the sampling frequency) with absolute energy level gradient of nearly $0.38 \text{ m}^2\text{s}^{-2}$. In the analysis of these test results for subject one it was noticed that the frequencies were highly unstable from 0 – 18 Hz of frequency range.



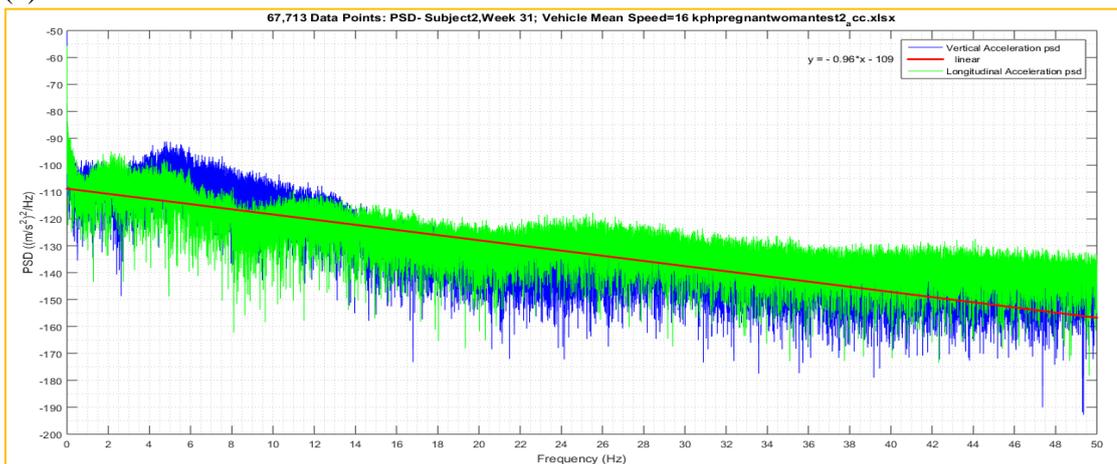
This confirms earlier inferences drawn by a number of vibration researchers (Mansfield, 2004; Bovenzi, 2005) that the human body is susceptible to lower frequency range of less than 10 Hz. The PSD values of the horizontal accelerations for subject one were relatively higher than the counterpart vertical accelerations, except between frequency range of about 0.2Hz to 1Hz, 0.3Hz to 4.5Hz and 10Hz to 14Hz where lower values were realized. Unfortunately, the random nature of these results makes it difficult to comprehensively discuss the results described in Figures 5a, but there exists a more interesting quantitative indicator called estimated vibration dose value, eVDV. An eVDV value indicates the level of vibration exposure to persons exposed to vibrations. The plots in Figures 6a shows the actual eVDV and the predicted eVDV values generated based on the RMS accelerations obtained from the signals of subject one. From Figure 6a, the ISO 2631-1 upper limit on human health was exceeded after 170 seconds for subject one. During a 5-minute drive, the occupant would endure an eVDV of $58 \text{ ms}^{-1.75}$ as against the recommended level of $17 \text{ ms}^{-1.75}$ and this could lead to foetal distress and lower back pain of pregnant occupant (Bovenzi, 2010, Bovenzi, & Hulshof, 1998) and the perceived abdominal pain associated with commuting along bumpy roads (Akowuah et al., 2015).

The results of subject two revealed similar characterizations of the RISSGT signals when compared with those of subject one, even though the number of data points recorded for subject two were about twice that recorded for subject one. The tests were conducted during the 29th and 31st gestational age and the pregnant occupant used the same vehicle manoeuvring at respective average speeds of 29 km/h and 16 km/h along the same access route. When the PSD analysis was performed on the signals, the average energy level gradient of the signals relatively increased to an absolute value of $0.96 \text{ m}^2\text{s}^{-2}$ as against $0.38 \text{ m}^2\text{s}^{-2}$ in the PSD values of subject one. Sharp gradients of energy levels were recorded between frequencies of 0 Hz to 18 Hz in all tests as shown in Figures 5a. In general terms, the horizontal acceleration PSD relatively produced higher energy levels on the tummy of the pregnant occupants. However, between frequencies of 0 Hz to 15 Hz, the vertical accelerations dominated in terms of energy emission. From Figure 6b, the ISO 2631-1 upper limit on human health was exceeded for subject two. During the 5-minute test drive, the occupant endured an eVDV of $70 \text{ ms}^{-1.75}$.

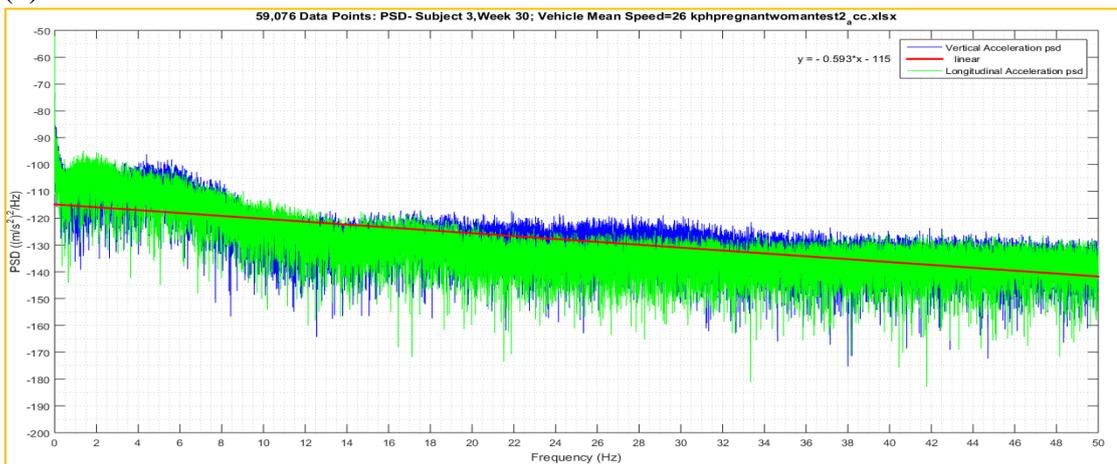
The characterized RISSGT signals for subject three generally realized intermediate values for the evaluation indicators used. The quantum of data points recorded for subject three are nearly the same as those of subject two. The two tests were conducted during the 29th and 31st gestational age and the pregnant occupant used the same vehicle manoeuvring at an average speed of 26 km/h along the same access route. An assessment of the PSD results shows an energy level gradient of $0.60 \text{ m}^2\text{s}^{-2}$ for the signals sensed from tummy of this subject. This is relatively an intermediate value among the three subjects studied. Sharp gradients of energy levels were recorded between frequencies of 0 Hz to 10 Hz as shown in Figures 5b. The vertical acceleration PSD, produced higher energy levels on the tummy of the pregnant occupant. When the eVDV assessment was performed on the signals, the ISO 2631-1 upper limit on human health was exceeded for subject three. During a 5-minute drive (Figure 6c), the occupant endured an eVDV value of $64 \text{ ms}^{-1.75}$.



(a)

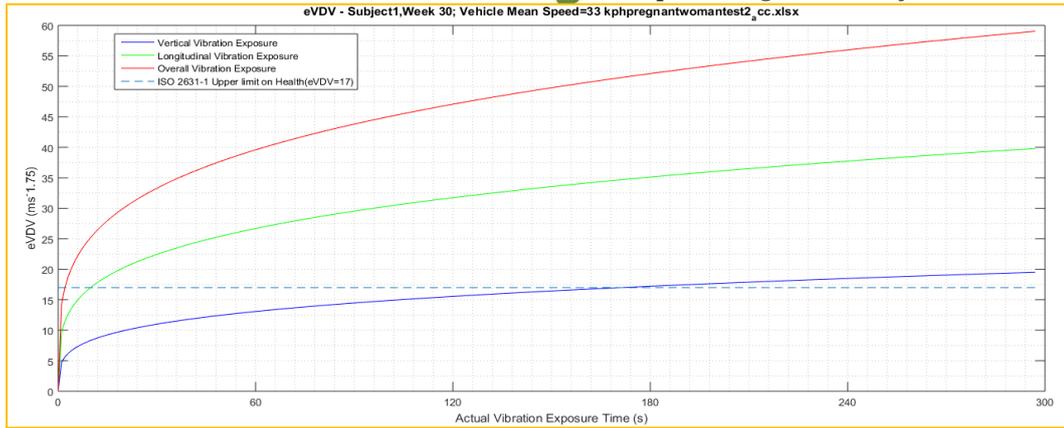


(b)

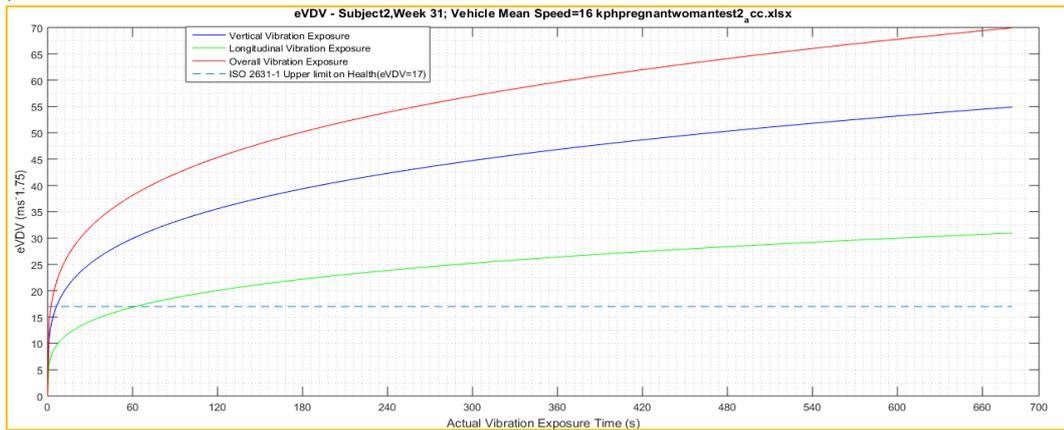


(c)

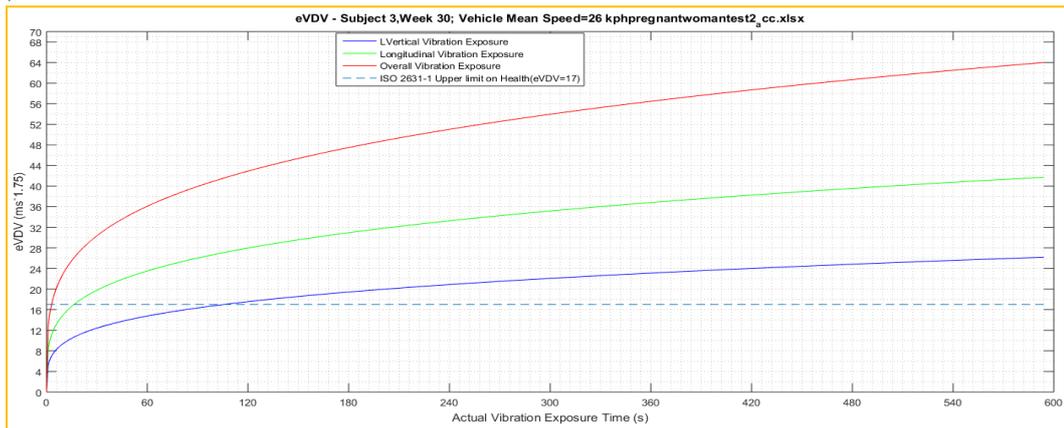
Figure 5: Acceleration Power spectral density plots of ramp-induced signals sensed on gravid tummy (RISSGT) of the pregnant occupant (a)subject 1 (b)Subject 2 and (c) subject 3 (Source: Authors' field work,2017).



(a)



(b)



(c)

Figure 6: Plots of estimated vibration dose value versus actual exposure time for (a) subject 1 (b) subject 2 (c) subject 3 (Source: Authors' filed work, 2017)



Commuting along Leveled Roads

The data points of the two control subjects obtained for the study were characterized in a similar fashion based on the same evaluation indicators used for the studied subjects. Further RISSGT signals were tapped from the last two subjects as control tests by way of conducting a test on a section of road perceived to be levelled with no speed ramps erected on them. The RISSGT signals so obtained are here after called subject two-control and subject three-control signals. The maximum and minimum signal values of the control subjects were relatively lower than that of their counterpart studied subject signals, and the trend is recurrent throughout the various indicators used.

The control experiment conducted to verify the results of subject three produced relatively better results in terms of vibrational impacts levels as shown in Figure 7. In addition, the PSD values for this control case recorded relatively lower average energy level gradient of $0.54 \text{ m}^2\text{s}^{-2}$ from the frequency range of 0 Hz to 50 Hz. A relatively gentle fluctuating and slope of energy levels were recorded at all frequencies for control subject two when compare with subject three. When the eVDV assessment was performed on the signals, the vibration exposure levels were also higher when compared with the ISO 2631-1 upper limit on human health. Moreover, the eVDV values were relatively lower when compared with the counterpart values of the studied subject three. An eVDV value of $47 \text{ ms}^{-1.75}$ was recorded for a 4-minutes' drive at an average speed of 26 km/h as depicted in Figure 8.

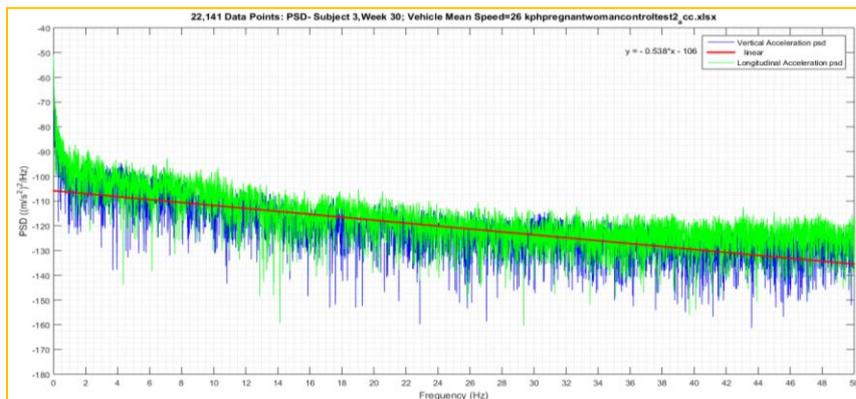


Figure 7: Acceleration power spectral density plots of RISSGT for Subject 3 control (Source: Authors' field work, 2017).

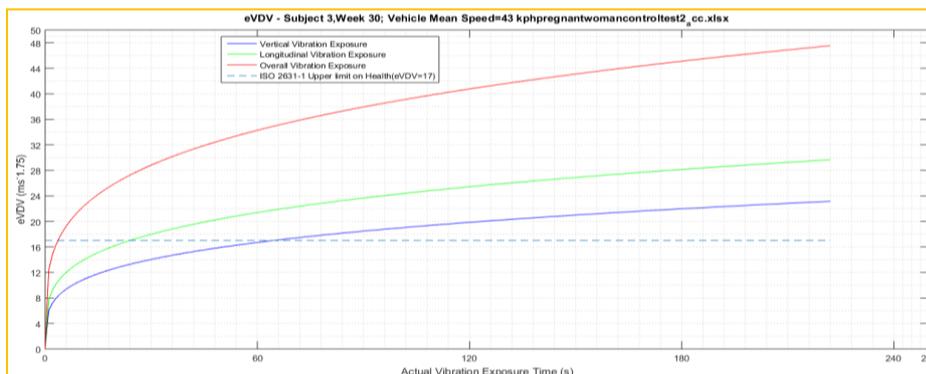


Figure 8: Plots of estimated vibration dose value versus actual exposure time for subject 3 control. (Source: Authors' filed work, 2017)



4.0 CONCLUSION AND RECOMMENDATION

Conclusion

The evaluated RISSGT signals have revealed that the permissible impact level of ramp-induced vibrations on pregnant occupant have been exceeded. On the basis of PSD values obtained after RISSGT signal evaluation, the following pontifications are made. The energy levels transmitted to pregnant occupants were more related to the pervasiveness of speed ramps on the road than average vehicle speed during the maneuver. This is because higher average vehicles speeds while passing over speed ramps did not necessarily yield higher emitted energies on the tummy of the pregnant occupant. Among the studied subjects, subject two experienced the highest energy gradient and average vehicle speed of $0.96 \text{ m}^2\text{s}^{-2}$ and 16 km/h respectively. Whilst subject three yielded an intermediate energy gradient of 0.59 but at the highest average vehicle speed of 26 km/h. Meanwhile, subject one yielded the least energy gradient of 0.38 but at the highest average vehicle speed of 33 km/h. The control for subject three yielded a relatively lower energy gradient $0.54 \text{ m}^2\text{s}^{-2}$ at an average vehicle speed of about 26 km/h.

Analogous pontification was made with regard to the eVDV values obtained from the RISSGT signal. During the 5 to 10-minute drive tests, the eVDV values recorded for the pregnant occupants were about 3 times the recommended maximum ISO 2631-1 permissible dos vale of $17 \text{ m}^2\text{s}^{-1.75}$. Based on the analysis of the RISSGT signals obtained, it is concluded that speed ramps on Ghanaian highways have cumulative effects on the pregnant occupant as suggested by the PSD and eVDV values obtained during the road test. Potholes and other road irregularities equally have harmful vibrational effects on pregnant occupants and passengers in general as indicated by the PSD and eVDV values obtained for the control subjects. Both the eVDV values for the studied and control subjects exceeded the permissible levels of the ISO 2631-1 and the BS 6841. This suggests harmful impact levels on pregnant occupants who ply along the case study roads. Invariably, the impact levels on the supposed levelled roads were influenced by potholes – leading the high level of the computed eVDVs. The implication is that apart from speed ramps, road irregularities such as potholes and bumpy patch-ups are potential vibration threat to the pregnant occupant and other vulnerable passengers.

Contribution to knowledge and Future Applications

The half car model by Krtolica and Hrovat (1990) has been modified and used to develop vertical vibration and pitching motion equations for a vehicle maneuvering over speed ramps under some stated assumptions. These equations could be used in the automobile industry to predict accelerations in the occupant environment by refining the design parameters for vehicle suspension systems, and consequently enhance the ride comfort of future vehicles. The pitching motion equation of the non-belted vehicle occupant has been developed. This equation would be useful in studying and predicting the dynamics and fatigue level of a non-belted vehicle occupant commuting along bumpy road. The overwhelmingly high eVDV values obtained in this study is an eye opener to future road safety and biomedical researchers in respect of the long-neglected vibration exposure on vehicle occupants.

Recommendations

It is recommended that re-orientation and or demolishing of all unauthorized speed ramps are the necessary first steps for reduction of pregnant women's exposure to vibrational impacts. It is recommended that road contractors should strictly adhere to the blue prints of the ramp



dimensions specified by Ghana Highway Authorities and other akin bodies in order to construct user-friendly speed ramps. It also recommended that a detachable pregnant occupant car seat ought to be developed to attenuate the excessive amplitudes of vibration felt by pregnant occupant.

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