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EXPERIMENTAL ANALYSIS OF HUMAN LUMBAR VERTEBRAE DURING PROLONGED DISTANCE DRIVING

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ABSTRACT

Back pain is commonly associated with a heavy driving or a person driving for a very long period. Inexpensive vehicles have a low system of absorbers such that the person behind the wheel and the passenger will experience pain in their back. This is mainly caused by several factors, such as the condition of the road, the performance of the absorber system of the vehicle and also the condition of the person inside the vehicle itself. This paper will discuss the factor that can be prevented and optimized to reduce whole-body vibration that might lead to fatigue.

Keywords: lumbar vertebrae, whole-body vibration, long distance driving.

INTRODUCTION

Whole-body vibrations occur when the human body is in contact with a vibrating surface. Oscillations in the frequency range from 1 to 80 Hz are called vibrations in existing standards [1]. For higher frequencies, the human body becomes less and less sensitive. Movements with frequencies below 1 Hz are denoted as motions and the excitation with such low frequency movements produce motion sickness [2]. The effects of vibrations on human spinal from hydraulic steering system was investigated to lies a bit higher than the perception level, which causes stress and sickness on the human body [3, 4].

The main function of the lumbar spine is to bear the weight of the body. If an individual's joints are not functioning properly of even worse, dislocated discs, they are at harm of getting lumbar spine injury. These vertebrae are much larger in size to absorb instant shock and provide comfort while carrying heavy load in various postures, such as standing, squatting and bending [5]. A lumbar sprain or strain happens when someone has an excessive mechanical demands put onto the surrounding muscles, or ligaments or both.

A small electric potential across the muscle is produced when a muscle is pulled, or in other words, contracted. Surface electrodes can sense this muscle activity potential when placed over the muscle. The signal produced is then sensed by the electrodes. The device amplified the signal to produce clearer readings and recorded with the device. It is known as the EMG [6].

Whole-body vibration can response activity in the electromyogram (EMG) part of lumbar back muscles of seated persons [7]. Many of the modelling approaches before have come out with mathematical equations which assumptions made that restrict the actual performance of the vehicular vibration impact [8, 9].

The standard in measuring vibration is the ISO 2631-1. It is an international standard titled Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration [10]. This standard states that the measurement of vibration needs to be on the position as shown in Figure-1. The measured vibration is classified in Table-1 (a) to value the level of comfort of the person. Vibration of more than 0.5 m/s^2 is considered harmful to the person as it will make him uncomfortable even though in the earlier state he was not moving.

As stated in previous studies, the specified frequency range for whole-body vibration is between 0.5 to 80 Hz. For instance, motion sickness is associated with frequencies below 1 Hz [11] and specifically from 0.1 to 0.5 Hz [12, 13]. Table-1 (b) shows that the relevant frequency ranges for vibration exposure [14].

Table-1. a) Levels of comfort for vibration environments, b) Frequency ranges for vibration exposure.

Measured vibration (m/s^2)	**Level of comfort**
Less than 0.315	Not Uncomfortable
0.315 to 0.63	A Little Comfortable
0.5 to 1	Fairly Uncomfortable
0.8 to 1.6	Uncomfortable
1.25 to 2.5	Very Uncomfortable
More than 2	Extremely Uncomfortable

(a)

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Axis	Frequency (Hz)	Effect
Vertical	0.5	Motion sickness, Nausea, Sweating
	2	Whole-body moves as one
		Difficulty positioning hands
	4	Vibration transmitted to head
		Lumbar vertebrae resonate
		Problems writing or drinking
	4-6	Resonance of gastrointestinal system
	5	Maximum discomfort
	10-20	Voice warbles
	15-60	Vision blurred resonance of the eyeballs
Horizontal	<1	Increased postural sway
	1-3	Upper body destabilized
	>10	Backrest is a prime cause of vibration transmission to body

(b)

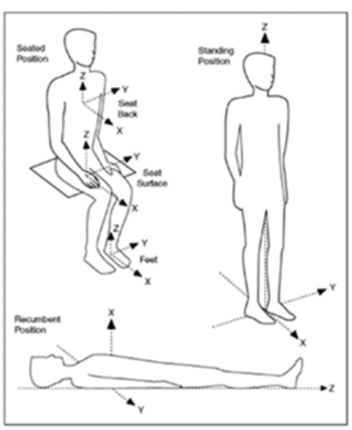

Figure-1. Measurement axes of whole-body vibration in the human body.

Therefore, thorough investigations on human vertebrae response to vibration become more important. As the quality of life becomes more important, not only the driver's health aspect is important components of the acceptability of a vehicle, but also the level of tolerance discomfort caused by seat and steering also plays crucial role. We investigate the effect based on the driver's profile within the range that we consider suitable for the research.

METHOD

A. Assumption

We first assumed that in real life, we are dealing with different types of human, determined by many elements. As in real condition, there are so many varieties of aspects from ages, health condition, and weight and so on. So, we set the ideal range of the human subject.

Table-2. Ideal range of human subject.

Aspect	Range	Explanation
Age	20 - 29	This is the age where the body condition is at its best
Gender	Male	Female has different vertebrae structure, so the effect of vibration will be different
Health condition	With a few or less health condition	Health condition concerning the area of musculoskeletal and the back bone area
Weight	45 – 79 kg	An ideal weight for most people

This is to ensure that the data that is collected can be grouped according to the range. People that are not in the group can be put into another group according to those aspects.

B. Human subject

A male human subject is used in the experiment. He is an example of a normal healthy human male driving a car for a long distance. No medication is taken 24 hours prior to the test and neither any history of back pain nor any surgery done to his vertebrae.

C. Condition of the human subject

A set of questionnaires was given to the subject, to notify his current health condition and preferences prior to the test. Any changes at the end of the test is also considered. The questions in the set are as follows:

Table-3. The details of the human subject (a) Medical details (b) Set of questionnaires.

Aspect	Details
Age	24
Gender	Male
Weight	75 kg
Height	167 cm
Race	Malay

(a)

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		YES	NO
1	Have you recently experienced any back pain disorder?		/
2	Are you taking any medication prior to this test?		/
3	History of back pain: i.e. broken vertebrae, swelling, strain		/
4	Genetic disease related to vertebrae		/
5	Any bone narrow transplant?		/

(b)

D. Driving procedure

The human subject who is the driver is asked to drive a Proton Saga BLM car from Gombak, Selangor to Juru, Penang for the duration of 3 hours and 36 minutes.

E. Driving route

The driver is asked to use Projek Lebuhraya Utara-Selatan (PLUS) Highway as his route. The highway has some slanted ramp, unexpected downhill, bumpy roads in some parts, and also some unflatten roads (due to road constructions) especially in the regions of Perak. He must obey all the traffic laws and drive the car under the speed limit.

F. Sensors

During the driving period, EMG patches were used to obtain EMG signal. The accelerometer (that was put on the driver's seat) is also used to measure vibration in tri-axial position as shown in Figure-2.

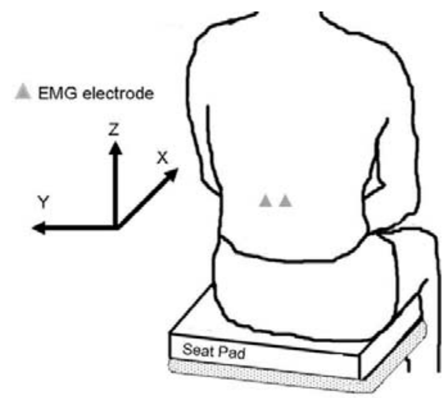
G. Software

All the data were recorded to the respective devices, gTec™ gMobilab+ (for EMG signal) and HVM100 Vibration Monitor (for vibration from the seat). The data obtained were analyzed using Matlab and Blaze™ software.

H. Experimental setup

As explained in Figure 3, the setup is done on the driver's side of the car. HVM100 Seat pad accelerometer is put on the driver's seat and is connected to the vibration monitor to record all the data during the period of the test. Meanwhile, electrode patches are put on the driver's back muscles (lumbar area). The electrodes are then connected to the gMobilab+ via cables for the device to record the data and signal from the muscular activity responding to the vibration. All equipment is shown in Figure-2.

(a)



(b)

Figure-2. Experimental devices: (a) HVM100 Vibration monitor and seat pad accelerometer and (b) Position of EMG electrode patches.

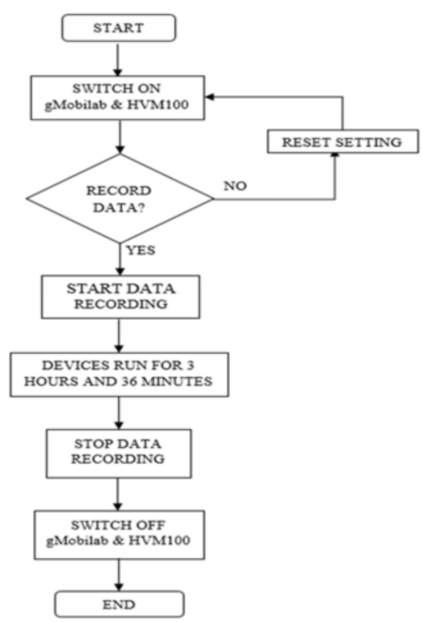


Figure-3. Flowchart of the experiment.

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RESULTS

EMG signal collects data from the back muscles when were triggered by the vibration acting upon the body. This was produced by the reaction of the muscle when there is any pressure towards the back.

Both outputs are saved in binary file (.bin) and Microsoft Excel file (.xlsx) formats respectively, and analyzed by observing their Power Spectral Density (PSD) of the sampling time. By observing the results, we can know that human body experiences various amount of vibration from the car. The back muscle triggered signals to the device via the EMG.

The data is recorded and analyzed to first, getting the sampling time and thus creating Power Spectral Density (PSD) graph. The details of the test are as follows:

Table-4. Details of (a) gTec and (b) HVM100.

Aspects	Symbol	Value	Unit
Time Taken	T	12960	s
Sample Data	-	597598844	data
Sampling Time	T_s	2.169×10^{-5}	s/data
Sampling Frequency	F_s	46111.02	Hz
Distance	d	367000	m

(a)

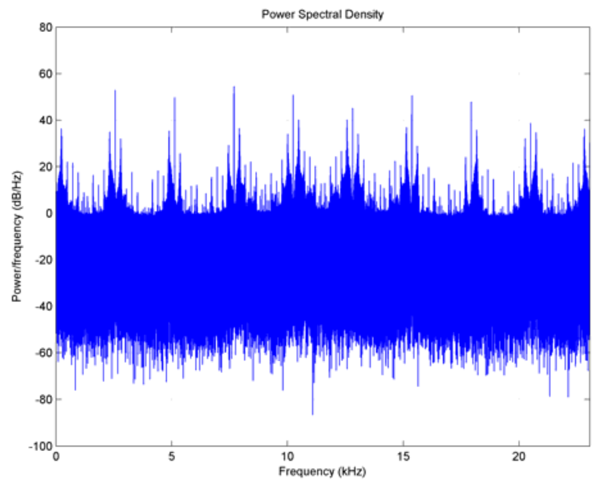
Aspects	Symbol	Value	Unit
Time Taken	T	12960	s
Sample Data	-	12960	data
Sampling Time	T_s	1	s/data
Sampling Frequency	F_s	1	Hz
Distance	d	367000	m

(b)

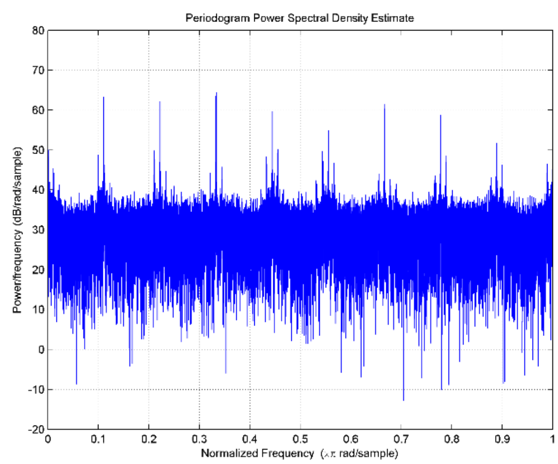
The PSD graph is obtained by calculating the sampling frequency. Then, using Matlab coding, the graph can be plotted. Note that, Matlab also has its own auto-generated PSD graph. Thus, we can compare between those two.

```
fileID = fopen('BIN FILE NAME');
X = fread(fileID);
x = X(:,1); Fs = 46111.02;
nfft = 2^nextpow2(length(x));
Pxx = abs(fft(x,nfft)).^2/length(x)/Fs;
% Create a single-sided spectrum
Hpsd = dspdata.psd(Pxx(1:length(Pxx)/2),'Fs',Fs);
plot(Hpsd)
```

A. gTec



(a)



(b)

Figure-4. Power spectral density of lumbar muscle via gTec: (a) Manually calculated F_s and (b) PSD generator.

Figure-4 shows the power spectral density of lumbar muscle during the test begins. During mid-period of driving, the driver was driving the car through hills, high attitude ramps and drove up and down in quick succession. The geography of the highway is not as flat as the road in the city. Thus, the lumbar muscle absorbs the shock impact from the car.

B. HVM100

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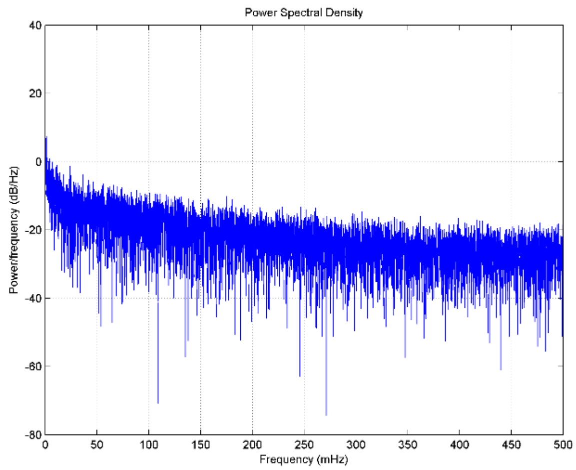
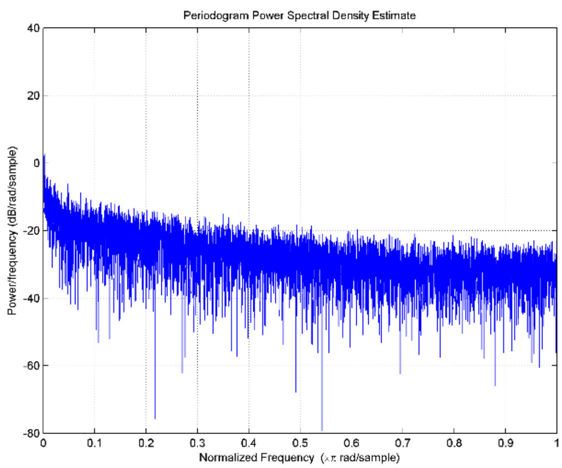


(a)



(b)

Figure-5. Power spectral density of lumbar muscle via HVM100: (a) Manually calculated F_s and (b) PSD generator.

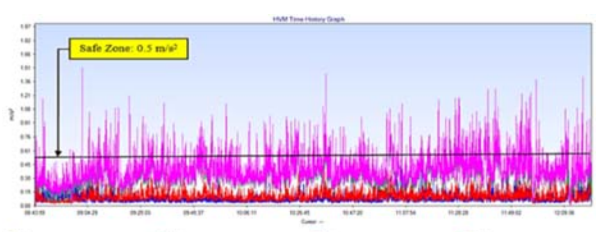


Figure-6. Acceleration from vibration during the experiment.

In Figure-6, the purple lines indicate the sum of all vibrations from three axes (X axis, Y axis and Z axis). The human subject experienced the maximum vibration amplitude of 1.51 m/s^2. Most of the time during the driving period, the sum of the magnitude of higher than the average. Too much exposure of the vibration more than 0.5 m/s^2 for too long harmed the driver's back part of the body as he complained of the back pain and lumbar sprain after the experiment ended.

CONCLUSION AND FUTURE WORK

With all the data obtained, this research will carry out different approach of modelling technique, which will make use the hybrid computational intelligence technique that combine ant colony optimization (ACO) and artificial immune system (AIS) [13, 15]. The outcome of this research will be the important algorithm of a driver's spinal model in further study on the impact of vibration. This will be emphasized more towards patient with spinal cord injury.

Noise reduction by using filtering is currently done to eliminate any unwanted signals from the test.

System identification gives us ideas that it is possible to adjust a model with a specific structure. It is necessary to determine the appropriate order and parameters for the model that best fits input–output data obtained during the experiment [16]. It is hoped that all the data obtained from the experiment can be used in optimizing vibration.

Other experiments using different type of roads are currently being tested so that the data can be verified. The type of roads chosen mainly are backroad and single-lane road. This is because those type of roads is proven to have more bumpy roads and hills. We are hoping the data will be sufficient to be analyzed.

The significance of this study is to reduce unwanted or harmful vibration using optimization. This is hoped that the study will be one of the alternate solutions for inexpensive car manufacturers in increasing their stability and performance of the cars on bumpy and uneven roads.

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