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Original Research Article

Study on the Responses of ANS to the Vibration and Mental Workload of the Body

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Abstract:

Introduction: It explains how the autonomic nervous system can be negatively impacted by elements like whole-body vibration, mental burden, and poor ergonomics. These effects are investigated by measuring “heart rate variability (HRV)”. When the sympathetic branch of the autonomic nervous system is activated, whole-body vibration has a negative effect on comfort, causes physiological changes, and impairs cognitive functions.

Aims and Objectives: This study examines how “whole-body vibration (WBV)” and mental workload affect sympathetic activity and sympathovagal regulation in the “autonomic nerve system (ANS)”.

Methods: The purpose of this research was to examine the effects of WBV and MWL on HRV and cognitive performance in a group of 24 healthy, right-handed male college students. Subjects used a vibration simulator to encounter five different scenarios: WBV only, low MWL only, high MWL only, WBV with low MWL, and WBV with high MWL. “Human reactivity voltage (HRV)” was recorded using ECG electrodes, and their interaction was thoroughly examined in a lab setting using randomised condition sequences and around one-hour trials.

Results: In Table 1, WBV, LMWL, and HMWL had different time-domain HRV values during active periods, showing complicated physiological-cognitive interactions. Table 2 shows that WBV has higher frequency-domain HRV characteristics than LMWL and HMWL, indicating parasympathetic activity. Figure 1 displays the preparatory, warm-up, and alternating activity-rest stages of the experiment. Figure 2 shows independent variable and time-domain interaction patterns.

Conclusion: The research conducted revealed that “whole-body vibration (WBV)” and psychological stresses have an effect on the autonomic nervous system, leading to changes in sympathetic activity and sympathovagal regulation.

Keywords: Human Reactivity Voltage (HRV), Autonomic Nerve System (ANS), Heart Rate Variability (HRV).

Introduction

The manner in which drivers react to environmental conditions is a crucial component in the domains of safety and ergonomics. The individuals are exposed to a variety of stressors, such as whole body vibration (WBV) within the frequency range of 2-21 Hz, mental workload (MWL), and ergonomic variables. There is evidence to show that cognitive processing and physical demands may have a dysregulating effect on the autonomic nervous system. These factors may be linked to cardiovascular illnesses, diabetes, obesity, metabolic disorders, and shared characteristics of chronic and acute stress in biological processes [1,2].

The investigation of oscillations in between the heartbeats, known as R-R intervals, can potentially indicate a misproportion in the autonomic nervous system. This is commonly referred to as "heart rate variability." Scholars have employed heart rate variability (HRV) as a means to investigate the potential impact of various stressors on the autonomic nervous system. This analysis has primarily focused on domain variables of time [3]. Additionally, frequency domain factors that include the low-frequency (LF) component in association with the sympathetic reaction, the high-frequency (HF) part in association with parasympathetic response, and the LF/HF ratio indicative of sympathovagal balance have been utilized in these investigations [4].

The study conducted by Ryu and Myung demonstrated that the physiological reaction of the body to a dual task involving both mental and tracking arithmetic is characterized by sympathetic innervation and a reduction in the average RR interval. In their study, Fallahi et al. (year) discovered a statistically significant positive association among traffic and many physiological indicators, including heart rate, root mean square of the consecutive differences, the standard deviation of normal-to-normal intervals, and the low frequency to high-frequency ratio [5]. In general, there exists a direct correlation between the intensity of laboratory-induced mental stressors,like time of reaction, and the stroop task, mental arithmetic, as well as real-life mental stressors, like monitoring traffic or driving, and the level of the low-frequency (LF) component and LF/HF ratio. Conversely, there is an inverse correlation between the intensity of these stressors and the high-frequency (HF) component [6].

The available information suggests that drivers commonly encounter a significant degree of mental workload (MWL) during the execution of regular driving activities. The primary cause of road accidents is performance faults, specifically problems related to the divided attention required for multitasking while driving. According to existing evidence, there is a positive correlation between the amount of mental workload (MWL) and the probability of engaging in dangerous behaviors [7]. This relationship can be attributed to a diminished state of conscious awareness and a decline in psycho-motor performance. Nevertheless, the current body of research provides limited information about the correlation between mental workload (MWL) levels and the occurrence of car accidents [8]. Recent studies have indicated that various mental and physical stressors have the potential to increase the Mental Workload (MWL) of drivers, consequently leading to a detrimental impact on human performance. The available literature on the relationship between physical stressors and ergonomic risk factors and the perception of mental workload (MWL) is limited and lacks comprehensive documentation. Drivers are subjected to different amounts of whole-body vibration (WBV), noise, climatic conditions, and additional occupational risk factors [9,10].

Individuals may encounter whole-body vibrations in several scenarios, such as while embarking on public transportation modes including buses, trains, ships, and aeroplanes, as well as when travelling in cars. Additionally, individuals residing in close proximity to heavily trafficked streets may also experience exposure to whole-body vibrations. Whole-body vibration is a significant stressor that has a substantial impact on the perception of comfort inside a particular setting. For industrial settings, transportation vehicles, and buildings, standard parameters are supplied to determine permissible limits of whole-body vibration exposure [11,12].

The investigation of the comfort related with vibration exposure has been the subject of numerous research studies. The impact of whole-body vibration on human health encompasses both physiologic and psychological aspects, contributing to overall well-being. The advantage of this substance is it has the potential to induce changes in cardiac rhythm, blood pressure, and respiratory patterns. Additionally, it may lead to feelings of exhaustion, bodily discomfort, and somnolence, as well as manifestations of anxiety and despair. Certain levels of vibration have the potential to induce actual harm to the human body [13]. For example, extended periods of exposure to vibration have been found to be a significant factor in the development of severe low-back diseases among those who operate tractors. Hand-transmitted vibration has been found to be linked to a range of vascular, neurological, and musculoskeletal problems. In addition to having physiological ramifications, vibration can also impede the execution of routine tasks. There exists empirical evidence suggesting that the presence of whole-body vibration, occurring at frequencies commonly seen during vehicular transportation, such as trains, aircraft, or automobiles, can significantly impact an individual's ability to engage in cognitive tasks such as reading, writing, and consuming beverages [14].

At the physiological level, vibration serves as a stressor by altering the functioning of the Autonomic Nervous System (ANS). The autonomic nervous system (ANS) comprises two major divisions, namely the parasympathetic nervous system (PNS) and the sympathetic nervous system (SNS). An elevation in social networking site (SNS) engagement and a reduction in parasympathetic nervous system (PNS) activity serve as markers for an escalation in the stress response. Several studies have indicated that exposure to vibration leads to heightened activation of the sympathetic nervous system (SNS) [13]. This can be attributed to the requirement of sustained attention in order to successfully complete a task. In a study conducted by Zhang et al. (2018), it was shown that there was a rise in sympathetic nervous system (SNS) activity within a time frame of 15 to 30 minutes following whole-body vibration at a frequency bandwidth of 4 to 7 Hz. Additionally, the study identified a concurrent increase in sleepiness levels while simulated driving. The authors claim that the rise in social networking site (SNS) engagement is indicative of heightened cognitive exertion (mental strain) aimed at sustaining alertness levels while experiencing drowsiness during the task. This finding has been corroborated by subsequent studies [14]. In a study conducted by Jalilian et al. (2019), it was observed that individuals engaged in a visually challenging cognitive task experienced a more pronounced elevation in sympathetic nervous system (SNS) activity when exposed to vibrations with a frequency ranging from 3 to 20 Hz and an intensity of 0.6 m/s2, as compared to a condition where no vibrations were present. The participants who were exposed to vibration while doing a working memory test also experienced a rise in their social networking site (SNS) engagement [15].

Method

Research Design: The objective of this study was to investigate the impact of “whole-body vibration (WBV)” and “mental workload (MWL)” on “heart rate variability (HRV)” and cognitive function in a sample of 24 healthy right-handed male university students, using a controlled laboratory experiment. Individuals who met particular requirements were exposed to five different experimental conditions: “whole-body vibration (WBV)” alone, low-level “mental workload (MWL)”, high-level “mental workload (MWL)”, WBV combined with low-level “mental workload (MWL)”, and WBV combined with high-level mental workload (WBV.HMWL). A specialised vibration simulator was utilised during the experiment to generate three-dimensional vibrations at different frequencies. Meanwhile, the participants were involved in a computerised dual task that required them to simultaneously do compensatory tracking and a choice response time task. “Heart rate variability (HRV)” was measured by the use of “electrocardiogram (ECG)” electrodes—the examination of data involved variables in both the time and frequency domains. The experimental conditions were randomised in their sequence, and each trial had a duration of approximately one hour per person. The chosen research methodology facilitated a thorough investigation of the interaction among “whole-body vibration (WBV)”, “mental workload (MWL)”, “heart rate variability (HRV)”, and cognitive function within a controlled laboratory setting.

Inclusion and exclusion

Inclusion

- Healthy right-handed male university students who average 24 years old must participate.
- Normal or corrected-to-normal vision indicates no substantial visual impairments.
- Participants should not have serious medical issues that could affect the study's goals.

Exclusion

- Patients who cannot give informed written permission are excluded from the trial.
- Participants must not have a history of drinking, smoking, or drug misuse.
- Persons with BMIs below 22 or above 24 kg/m² are excluded.

Statistical Analysis: The study used repeated-measures Analysis of Variance to assess the mean and interaction effects of independent variables on heart rate variability (HRV). HRV alterations under different situations were examined using this method. The least significant difference (LSD) test was used for post hoc testing to find pairwise differences between conditions. This revealed which factors significantly affected HRV. Cohen's d statistic quantified effect size, revealing effect magnitude. The study's findings were better assessed using SPSS® for Windows® version 20 for statistical analysis and GraphPad Prism version 7 for data visualisation.

Result

Table 1 compares time-domain heart rate variability (HRV) values during active periods and emphasises many key findings. WBV impacted HRV in these ways, as mean RR intervals (39.05 vs. 49.1, p = 0.01) and SDNN (standard deviation of NN intervals) values (0.01 vs. 0.005, p = 0.002) differed from LMWL. WBV and high-level mental workload (HMWL) had different HRV responses, as seen by mean RR intervals (39.05 vs. 61.2, p = 0.001) and SDNN values (0.01 vs. 0.02, p = 0.02). These findings show that WBV or mental workload considerably impacts HRV values during active times. Other comparisons under other situations show varying HRV outcomes during these activities, revealing complex physiological-cognitive relationships.

Table 1: Comparing active period time-domain heart rate variability parameters

Active period*	Mean RR		SDNN†		RMSSD‡	
	Mean difference	p value	Mean difference	p value	Mean difference	p value
WBV vs LMWL	39.05	0.01	7.9	0.002	2.826	0.41
WBV vs HMWL	61.2	0.001	8.9	0.02	2.89	0.49
WBV vs WBV.LMWL	49.1	0.01	7.89	0.005	3.889	0.32
WBV vs WBV.HMWL	53.02	0.01	6.91	0.01	0.88	0817
LMWL vs HMWL	09.49	0.39	0.5	0.79	-0.2	0895
LMWL vs WBV.LMWL	4.09	0.79	0.09	0.87	1.49	0716
LMWL vs WBV.HMWL	2.99	0835	-1.69	0.3	-2.1	0.91

HMWL vs WVB.LMWL	-8.9	0636	-0397	0.8	1.48	0.51
HMWL vs WBV.HMWL	-8.47	0494	-1.89	0.41	-2	0.41
WBV.LMWL vs WBV.HMWL	-0.18	0.88	-2.61	0.39	-3.48	0.09

The frequency-domain parameters of HRV in active individuals under different situations are presented in Table 2 below. The parasympathetic activity was increased during whole-body vibration (WBV), as measured by an increase in high-frequency (HF) power, as compared to low-level mental workload (LMWL) and high-level mental workload (HMWL). Changes in autonomic modulation were also highlighted by significant changes in the LF/HF ratio, a marker of sympathovagal balance. For instance, in comparison to HMWL, WBV increased the LF/HF ratio, suggesting a switch to sympathetic dominance. These results provide new insight into the complex relationship between a person's physiological reactions and their cognitive tasks by suggesting that WBV and mental workload levels each have separate and measurable effects on HRV.

Table 2: Frequency-domain heart rate variability characteristics for active individuals and combined periods

Active period*	Low frequency (LF)		High frequency (HF)		LF/HF ratio	
	Mean difference	p value	Mean difference	p value	Mean difference	p value
WBV vs LMWL	-0.59	0.82	6.61	0.004	-0.29	0.51
WBV vs HMWL	-2.41	0.51	5.87	0.004	-1.51	0.007
WBV vs WBV.LMWL	-4.39	0.04	4.03	0.1	-0.69	0.31
WBV vs WBV.HMWL	-5.49	0.03	4.89	0.02	-1.49	0.02
LMWL vs HMWL	-1.69	0.51	-0.48	0.81	-1.09	0.01
LMWL vs WBV.LMWL	-3.82	0.1	-2.47	0.31	-0.39	0.4
LMWL vs WBV.HMWL	-4.91	0.05	-1.59	0.39	-1.1	0.03
HMWL vs WVB.LMWL	-2.01	0.39	-1.87	0.22	0.69	0.21
HMWL vs WBV.HMWL	-3.09	0.31	-1.02	0.6	-0.06	0.79
WBV.LMWL vs WBV.HMWL	-1.08	0.49	0.91	0.69	-0.81	0.91

The trial times and trend illustrated in Figure 1 demonstrate the systematic experimental chronology. The study commenced with a preliminary phase lasting 10 minutes, which was afterwards succeeded by a brief warm-up session lasting 1 minute. Subsequently, a recurring sequence of 5-minute periods of physical activity alternated with 5-minute times of rest was implemented, facilitating the evaluation of "heart rate variability (HRV)" and cognitive functioning across different circumstances within a controlled laboratory environment.

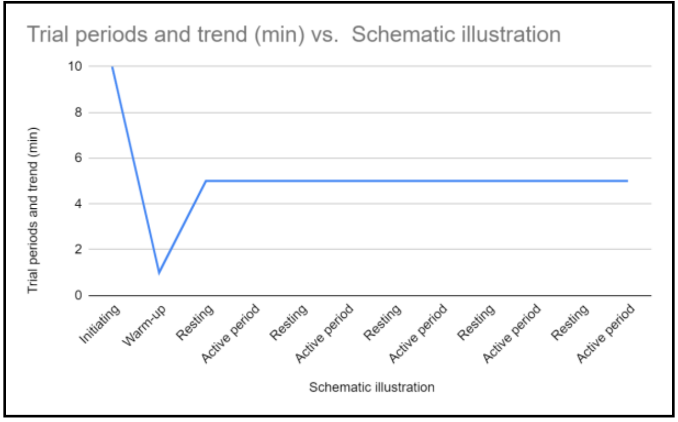

Figure 1: Schematic illustration of the trial periods and trend

Figure 2 shows independent variable trends and time-domain variable interactions. Each condition's mean is shown. Resting (770) and WBV alone (810) show millisecond trends. LMWL (740) and HMWL (730) reduce HRV trends. As in normalised units (n.u), WBV (83) has a higher HRV than the rest (77). Both LMWL (81) and HMWL (85) have different patterns. Unitless measurements indicate the same trends, with WBV alone (5.1) higher than the rest (3.9), and LMWL (5.8) and HMWL (6.9) displaying separate patterns. These findings imply independent variables affect HRV under different situations.

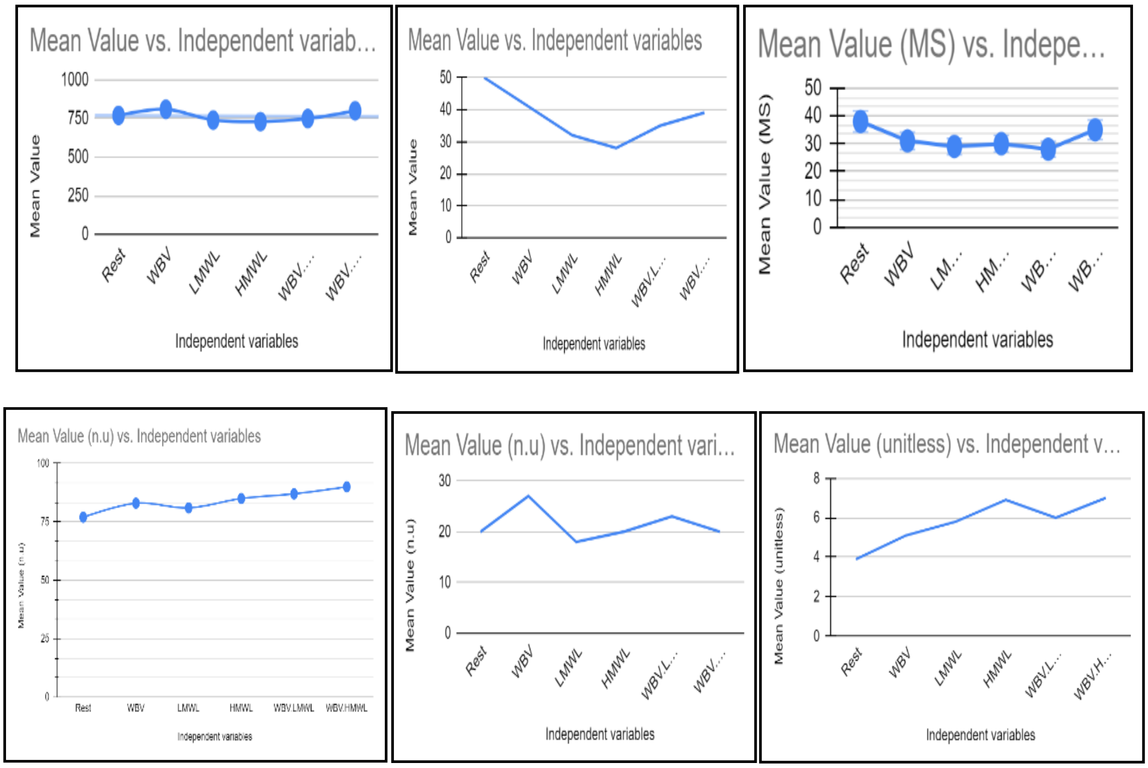

Figure 2: Trends and interactions of independent variables on time-domain variables

Discussion

A revolutionary building methodology has been devised, whereby a camera is placed onto a construction apparatus, facilitating the operator's ability to remotely manipulate the machinery. This control is facilitated by synchronising the machine's vibrations with the visual feedback provided through virtual reality (VR) technology from the operator's perspective. Indices pertaining to alterations in heart rate (HR) and physical oscillation, such as multiscale entropy (MSE) and heart rate variability (HRV), can thereafter be assessed among the operators. Given that these indices are numerical indicators of autonomic regulation within the cardiovascular system, they can serve as a valuable tool for evaluating operational stress [16]. The aim of the study conducted previously was to assess the alterations in heart rate (HR) and body vibration experienced by machine operators, as well as to explore suitable approaches to machine operation, taking into account the psychological burden.A novel approach was devised to determine the optimal duration of operation by taking into account the operational stress and effectively mitigating the physical vibrations to maintain them within an acceptable threshold. The study aimed to elucidate the association between psychological stress and physical vibration in the context of driving duration of construction machines, an area that has not been extensively investigated in prior research [18].

A study aims to conduct a comprehensive narrative review of the existing research literature in order to provide an overview and analysis of the various mechanisms by which sound vibration affects human beings, encompassing physiological, biochemical, and neurological aspects. The primary objective is to create a comprehensive understanding of the current state of knowledge in this field and identify gaps in research that warrant further investigation. The process commences with the act of delineating music as a subset of sound, and subsequently reducing sound to its fundamental constituent of vibration [15]. The primary emphasis is placed on the examination of sound waves with low frequencies, namely those ranging from 1 to 250 Hz, which include infrasound frequencies from 1 to 16 Hz. The paper provides a description of many types of applications, namely vibroacoustics,focal applications of vibration, and whole-body vibration. The existing body of literature pertaining to the processes of reaction to vibration can be classified into three main categories: hemodynamic,musculoskeletal, neurological. The fundamental mechanisms underlying hemodynamic effects involve the activation of endothelial cells and the application of vibropercussion. The neurological effects involve the activation of protein kinases, nerve stimulation, specifically emphasising vibratory analgesia, and the formation of rhythmic coherence [16]. The musculoskeletal impacts encompass various physiological responses, including the activation of the muscular stretch reflex, the determination of the fate of bone cell progenitors, the influence of vibration on the processes of bone resorption and ossification, and the anabolic effects specifically targeting the spine and intervertebral discs. Clinical applications are comprehensively discussed in each category of study. The conclusion highlights the intricate nature of the vibrational medicine field and emphasizes the need for targeted comparative studies on various aspects such as the method of vibration delivery, the extent of body or surface stimulation, and the impact of specific intensities and frequencies on particular mechanisms. Additionally, it underscores the importance of fostering greater interdisciplinary collaboration and concentration in this area [19].

The exposure of vehicle drivers to many environmental stressors such as noise, whole-body vibration (WBV), and mental loads is a common occurrence. However, there is limited understanding regarding the impact of combined impacts from multiple stressors on mental load and performance. Research has demonstrated that the combined impact of vibration and noise can exhibit variations compared to the individual effects of either vibration or noise in isolation. For instance, previous studies have reported the presence of adverse cumulative effects on some cognitive tasks, as well as their influence on subjective evaluations such as displeasure and stress levels [17,18]. Several research examining the combined impacts of noise and whole-body vibrations (WBVs) exhibit limited ecological validity, and only a small number have explored potential effects on cognitive functioning. This stands in stark contrast to the numerous studies that have examined the impact of noise on performance. There is an argument suggesting that a potentially fruitful approach for advancing research on the combined impacts of noise and whole-body vibration (WBV) could involve the utilization of experimental methodologies and tasks that have shown effective in comprehending the influence of sound exposure on performance, such as serial recall tasks, or the effects of noise following exposure [20].

There may be a correlation between work exposure to whole-body vibration (WBV) and postural stress in a driving environment, and an increased likelihood of experiencing low back pain (LBP) issues. Two epidemiological studies conducted on bus drivers and tractor drivers revealed that there is an association between low back pain (LBP) problems and factors such as age, back injuries, cumulative whole-body vibration (WBV) dose, and postural overload. A comprehensive examination of existing scholarly works indicates that the association between whole-body vibration (WBV) and lower back ailments lacks complete elucidation. A dearth of knowledge exists regarding the health risks associated with whole-body vibration (WBV) specifically in female employees. Given the predicted exposure of several thousand women to intense whole-body vibration (WBV) in occupational settings, it is imperative to conduct a thorough investigation of the potential health effects of WBV on the female reproductive organs and spinal column [21].

A study was undertaken to examine the dose-response relationship between whole body vibration (WBV) exposure and the occurrence of low back pain (LBP) in a cohort of drivers. The study revealed a clear relationship between whole-body vibration (WBV) exposure and the occurrence of driving-related low back pain (LBP), following a dose-response pattern. No evidence of a dose-response relationship was observed between whole-body vibration (WBV) exposure and the occurrence of low back pain (LBP) at the 12-month mark. While the observed dose-response pattern provides only preliminary evidence, the results suggest that exposure to whole-body vibration (WBV) may potentially have a role in the development of driving-related low back pain (LBP) [22].

Conclusion

The study concluded that findings show that “whole-body vibration (WBV)” and mental stressors affect the autonomic nervous system. The circumstances increased sympathetic activity and compromised sympathovagal control, affecting physiological regulation. “Whole body vibration (WBV)” at 3-20 Hz increased parasympathetic activity, resulting in a multidimensional reaction. In addition, “whole-body vibration (WBV)” and mental stressors had synergistic or antagonistic effects on the autonomic nervous system, suggesting an interaction. This early study's small number of participants and lack of female representation must be considered. In addition, our study was unable to fully investigate each vibration frequency's effects. The focus of our study was heart rate variability, but adding objective metrics like galvanic skin reaction may improve our understanding.

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