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Technical note

# Deviations in frequency and mode of vibration in whole-body vibration training devices with long-term and regular use

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ABSTRACT

Research regarding whole body vibration training (WBVT) and its practical use may be hindered by the fact that WBVT devices generate frequencies and/or modes of vibration different from their preset adjustments. This research aimed to clarify whether prolonged regular use can generate such deviations in frequency and mode of vibration.

Three WBVT devices, each used for approximately 13 months in two research projects, were tested with an accelerometer before start of the 1st study, after four months, and after 13 months (the completion of the 2nd study). Divergences between the preset and measured frequencies were calculated for all measurements. Furthermore, the total harmonic distortion (THD), an index for signal deviations from a perfect sine wave, and the sum signal-to-modulation-noise-ratio (SMNR), an indicator of fidelity, were recorded.

One device had a significantly larger machine run time than the other two, and it displayed the most pronounced signs of impaired function concerning frequency, mode of vibration, and random variability (SMNR) after prolonged use.

These results indicate that prolonged use will result in divergences between the preset and actual applied frequencies as well as in the mode of vibration and other accuracy measurements.


## 1. Introduction

Whole body vibration training (WBVT) has frequently been the subject of scientific research in recent times and has been practically applied in mass sports, competitive sports, and therapy [1–4]. The intensity of WBVT is regulated by the duration of each training session, the frequency, the amplitude, and the body position, as well as the exercises performed using the device [5–7]. One of the most important research aims regarding the use of WBVT has been identifying the ideal composition of these exercise parameters and the appropriate mode of vibration for each application [7–9]. All these parameters and their interactions result in a specific exercise stimulus, influencing the effects of an exercise [10]. Research regarding this has potentially been hindered by WBVT devices generating and transmitting frequencies and/or modes of vibration different from their preset adjustments [11].

It can be assumed that divergences from preset frequencies of 10% or greater appear regularly, and are increased by loading such devices with users [12–14]. It has been postulated that such divergences might be due to discrepancies between manufacturers and varying device types as well as their drives, the rigidity of materials, or possible software failures [9,11]. This implies that potentially identified ideal frequency ranges for specific uses may be applied very inaccurately, or not at all [11]. Thus, identifying potential divergences between preset frequencies and modes of vibration given by the manufacturer and the signals that are actually applied is of great importance for the application of WBVT in practice and future research as well as for the interpretation of previous research results in which devices were used without considering this issue. No prior research has conducted a longitudinal measurement of possible divergences between the manufacturer information and the practically applied mode of vibration.

This research addressed the question of whether prolonged, regular use of WBVT devices has an effect on their fidelity to preset frequencies and modes of vibration by measuring three devices used in two consecutive research projects. It was assumed that the analysed devices would show divergences between the preset and applied frequencies that had increased or not existed at delivery, as well as in the mode of vibration, as a function of machine run time.

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## 2. Materials and methods

Three measurements each were taken from the three WBVT devices with tilting platforms on mid-axes (Galileo Fit Novotec Medical GmbH, Durlacher Str. 35, 75172 Pforzheim, Germany) in a longitudinal research design. These devices apply sinusoidal vibrations at an amplitude of 0–5.2 mm depending on foot position and a frequency of 5–30 Hz. The maximum load for these devices was specified to be 200 kg. These devices are widely used in research and practice. All three devices were used for approximately 13 months in two consecutive research projects investigating the use of WBVT as a workplace-based sports activity in a large public administration, and were tested using a tri-axial accelerometer before the start of the first study, after approximately four months of use, and finally after approximately 13 months (the completion of the second study). Two devices were located on the third floor in a room normally used as a first aid room, where one of them was positioned next to a mirror (GF3R) which enabled subjects to check their body position. The third device was located on the fifth floor in a similar room. All devices were used regularly during the 13 months. All three devices were delivered new for the studies. These studies were approved by the ethics committee of the Hannover Medical School.

### 2.1. Equipment and measurement procedure

For each measurement, an ADXL 326 tri-axial accelerometer (Analog Devices Inc., One Technology Way, P.O. Box 9106, Norwood Massachusetts, U.S.A.) was placed on a small blank (70 mm × 30 mm) in a custom-made PVC container (100 mm × 50 mm) with an on-line amplifier fixed to the WBVT device with double-sided adhesive tape. The accelerations of the device in the *x*-, *y*-, and *z*-directions were recorded under different settings [11]. This allowed accelerations in all three dimensions to be recorded. According to Rauch et al. [11], this measurement method is well-established and recommended for the purpose of this research. By placing the accelerometer in a PVC container, the accelerometer could be perfectly aligned with the surface of the device, thus measuring the chosen setting exactly. The accelerometer was connected to a standard personal computer and data was recorded with a custom-made data acquisition program running under Agilent VEE Version 9.0 (Agilent Technologies Deutschland GmbH, Herrenberger Str.130, 71034 Böblingen, Germany) at a sampling frequency of 910 Hz (50,000 samples were recorded during each measurement, equivalent to a recording of 80 s each). The accelerometer was calibrated in its PVC container before measurement began by activating it with a shaker.

A pilot run was conducted before each measurement to ensure that the position of the container with the accelerometer was correct and the container was appropriately fixed. In each case the accelerometer was positioned depending on the foot position during training. In addition to measurements at the preset frequencies of 10, 20, and 30 Hz in foot position three, one measurement was conducted under a loaded condition (20 Hz, foot position three) in order to identify if the vibration mode and/or applied frequency of the devices were affected by an external load. Since it is impossible to apply passive standardized weights to WBVT devices due to the movement of the weights and the impossibility of adequate fixation, an investigator (male, 35 years of age, 105 kg ± 1 kg: controlled before each measurement) with experience using WBVT devices acted as the external load. A semi squat position (knees 120° flexion) was chosen as this is a frequently practiced and recommended position of use. Only socks (of the same type for each measurement) were worn such that all devices were loaded equally. The key resultant measurements were the divergences in frequency and mode of vibration between the preset conditions and the signals actually occurring at different frequency settings (10, 20, and 30 Hz) and an amplitude of 3 mm, as well as for one measurement under load at a preset 20 Hz.

It was possible to assess the exact machine run time because every device stored the corresponding data in an internal memory bank which was read out after the study period concluded. Thus, it was possible to evaluate the existence of significant differences between the three devices regarding the machine run times and mean intensities (frequency and amplitude) they were used at.

### 2.2. Data analysis

To monitor the functionality of training devices as well as the efficiency of their workouts, meaningful attributes were required to rate their technical condition and characterize the impact derived use. Such attributes can be applied as measurements for performance evaluation and classification. The validity of these attributes depends on the performed activities and scope of application. A sample record of acceleration data in the time and frequency domains is illustrated in Fig. 1.

Due to the periodic structure of the accelerations measured from the WBVT devices, primary focus was placed on the frequency domain features obtained via Fourier Transformation (FT). A wide range of spectral signal properties have been reported in the literature [15,16]. One widely used feature for WBVT is the fundamental frequency $f$. It was of special interest to obtain the percent deviation of the measured vibration frequency from the preset value $\Delta f$. The other relevant attributes considered in this study were the total harmonic distortion (THD) and the sum signal-to-modulation-noise-ratio (SMNR) proposed as the vibration signal for a randomly modulated periodic signal [17,19]. The THD specifies the perceived divergence of the measured mode of vibration from a perfect sine waveform. The sum SMNR quantifies the amount of random variation induced by non-linear vibrations relative to the underlying pure periodicity according to the equation $S = \sum_{k=1}^{K} \rho(k)$, where $\rho(k)$ represents the SMNR at a frequency component $k$ [18]. The SMNR serves as an efficient indicator for assessing the stability and regularity of vibrations in WBVT devices and can be applied to identify device failures or malfunctions. Low SMNR values indicate low fidelity and stability. To extract these features and check the significance of their results, the collected data was evaluated by means of established statistical signal processing and tests in MATLAB, regarding the data on machine run time, and SigmaPlot, regarding the mean intensities of use. The results of this analysis are presented using boxplots, a useful established method of comparing distributions and related parameters from different data sets. Additionally, a paired $t$-test was performed to determine whether the differences between the calculated means from the first and third measurements were statistically significant. Both the boxplot and $t$-test evaluation methods were shown to represent differences at a significance level of 0.01 (99% level of confidence). The results of the statistical $t$-test were represented by the $p$-value, which indicates that two groups are either correlated or different. As the $p$-value was smaller than the predefined significance level, it could be declared that there is a statistically significant difference between the two data sets [20].

## 3. Results

The researcher acting as an external load reported no side effects during or after using the devices. All measurements were performed at a sampling frequency of 910 Hz for a FFT size of 65,536 points. Evaluations were performed for each of the three measurement sessions with different frequency settings as well as