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SHORT COMMUNICATION

VARIABILITY OF VIBRATIONS PRODUCED BY COMMERCIAL WHOLE-BODY VIBRATION PLATFORMS

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Objective: **Whole body vibration has been studied in populations experiencing neuromuscular degradation, including the elderly and individuals with neurological disorders, but methodological standardization is required to clarify its therapeutic effects. The characteristics of the vibrations actually delivered by commercial platforms are rarely measured or reported. Our objective was to quantify the vibrations (frequency, amplitude and peak acceleration) produced by several commercial platforms across different settings.**

Methods: **Laser and accelerometer recordings were used to measure the vibrations of 7 vibration platforms. Four loads (0 kg, 45 kg, 68 kg, 91 kg) and 3 vibration frequencies were used (30 Hz, 40 Hz, 50 Hz), totaling 12 combinations.**

Results: **In all platforms, vibration amplitude and peak acceleration varied as a function of the load used ($p<0.001$ in all cases). In most platforms, the actual frequency of vibration differed from the intended frequency (actual/intended ratio ranging from 0.83 to 1.19), as a function of load and frequency. These results imply that subjects of different weights could be receiving different vibrations.**

Conclusion: **Investigators should characterize and report the vibrations actually delivered in their studies, in order to increase the quality of evidence in whole body vibration studies.**

Key words: whole body vibration; vibration platforms; vibration frequency; peak acceleration; vibration amplitude; vibration; osteoporosis; neurological disorders.

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INTRODUCTION

Whole body vibration (WBV) has been proposed as an intervention with potential benefits (i.e., strength, endurance, power, bone mass) for several clinical populations, including individuals with spinal cord injury (1), multiple sclerosis (2), Parkinson's disease (3), and the elderly (4, 5). There is mounting evidence that WBV can help combat various aspects of musculoskeletal degradation, including muscle atrophy (5) and osteoporosis (6). The amplitude and frequency of the applied vibration are known to affect the efficacy of the intervention and the potential for adverse events. For example, the frequency of vibration can modulate physiological variables including activation (7–9), blood flow (1) or standing balance (4), but poorly chosen frequencies can result in motion sickness or muscle damage (6, 10). However, studies evaluating WBV employ a wide range of different vibration parameters and vibration platforms (7–12), and this lack of standardization is impeding the scientific community's ability to arrive at a consensus regarding the therapeutic effects of WBV. One obstacle is that the characteristics of the vibration delivered by commercial platforms, as opposed to the intended WBV parameters, are poorly characterized and often not reported. Indeed, if the manufacturer specifications do not provide an accurate reflection of the vibrations actually being delivered to study subjects, then the onus must be on investigators to characterize and report the nature of these vibrations, in order for meaningful comparisons to be possible across different studies. In this study, we investigated the hypothesis that the actual output of most commercial vibration platforms exhibits variability around the desired output, in a manner dependent on the load and desired output. In order to be suitable for well-controlled research studies, a vibration platform should produce the same amplitude of vibration regardless of the load placed on it (i.e., the weight of the subject) and/or regardless of the selected frequency of vibration. In addition, the actual frequency of vibration should match the value specified by the user on the device's dial, regardless of the weight on the platform.

METHODS

Testing was conducted on 7 different vibration platforms on the same day. The platforms used were the Juvent (Juvent Medical, Inc., Somerset, NJ, USA), the Power Plate (Power Plate International Ltd., London, UK), the VForce (Dynatronics Corporation, USA), the VibePlate (VibePlate, Lincoln, NE, USA), the Wave Airflex (WAVE Manufacturing Inc., Windsor, ON, Canada), the Wave ProElite (WAVE Manufacturing Inc., Windsor, ON, Canada), and a custom Wave device (WAVE Manufacturing Inc., Windsor, ON, Canada) in use by our group that provided more control over the vibration parameters and used a different motor than the other Wave devices to produce the vibrations. The Juvent and Vibeplate used a vertical mechanism to generate the

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vibrations whereas the other platforms used a rotational mechanism. This choice of platforms was a convenience sample of devices with a commercial presence in the WBV market at the time of data collection. For each device, 3 different vibration frequencies were used (30 Hz, 40 Hz, and 50 Hz), in combination with 4 different passive loads (0 kg, 45 kg, 68 kg, and 91 kg weights attached to the platform using straps), for a total of 12 combinations of vibration parameters per device. The frequencies used were selected based on evidence in the literature regarding the range that may be most beneficial for bone health, as identified in a previous review (6). An earlier study by our group also reviewed the experiences of individuals with and without SCI while using two of the devices included in this study and found that the range of frequencies used here was generally well tolerated, with higher frequencies being preferred (13). For vibration platforms that had different amplitude settings (e.g., "low" and "high"), both conditions were used in turn and analyzed individually.

For each combination of parameters, the vibrations produced were characterized by two types of sensors. A laser displacement measuring tool (LK-500, Keyence Co, Osaka, Japan) was used to measure the amplitude of vibration produced. Three uniaxial accelerometers (3041A2, Dytran Instruments Inc, Chatsworth, CA, USA), one on top of the plate and two on the sides, were used to measure the peak acceleration of vibration (in this case the peak acceleration is the maximum reading obtained from the accelerometer in a given period of the vibration). A sampling frequency of 2,000 Hz was used for both recording devices. The actual frequency of vibration was also measured from the accelerometer data. The laser signals were filtered using a 5^{th}-order Butterworth band-pass filter with a pass band between 20 Hz and 60 Hz. For each set of parameters, recordings began 10 s after the platform was turned on to allow vibrations to reach steady-state, and lasted 10 s.

In order to evaluate the vibration platforms against the specifications specified in the Introduction, we examined for each platform the range of values observed over the 12 parameter combinations for the following 5 variables: (*i*) norm of the peak acceleration vector (including both vertical and horizontal components); (*ii*) vertical component of the peak acceleration vector; (*iii*) horizontal component of the peak acceleration vector; (*iv*) peak-to-peak amplitude of vibration; and (*v*) ratio of actual frequency produced to intended frequency specified on

Table I. *Range of values observed for different vibration characteristics as the load (weight) is varied, for different vibration platforms and 3 different intended frequencies of vibration (30 Hz, 40 Hz, and 50 Hz)*

Vibration platform	Magnitude (norm) g	Magnitude (vertical) g	Magnitude (horizontal) g	Amplitude mm	Frequency (actual/theoretical)[a]
30 Hz frequency setting					
Juvent	0.10–0.69	0.10–0.68	0.02–0.09	0.02–0.20	1.00–1.00
PowerPlate (low setting)	3.59–3.94	3.20–3.71	1.08–1.73	1.06–1.57	0.98–0.98
PowerPlate (high setting)	6.90–8.30	6.40–7.82	1.22–2.77	2.26–3.18	0.92–0.98
VForce (low setting)	3.79–4.99	2.19–2.87	3.10–4.09	1.19–1.40	0.96–0.97
VForce (high setting)	6.25–7.85	3.70–4.86	3.93–6.55	1.37–2.77	0.90–0.94
VibePlate	0.77–1.74	0.18–0.92	0.74–1.47	0.03–0.25	0.87–0.91
Wave Airflex (low setting)	1.96–2.11	1.90–2.11	0.09–0.59	0.44–1.28	0.96–0.97
Wave Airflex (high setting)	5.16–6.15	5.04–6.14	0.29–1.11	1.42–3.32	0.90–0.96
Wave ProElite (low setting)	1.80–1.96	1.72–1.90	0.49–0.59	0.40–0.65	1.06–1.07
Wave ProElite (high setting)	4.97–5.34	4.84–5.19	0.89–1.26	1.22–1.61	0.99–1.07
Wave Custom (low setting)	1.01–1.53	0.61–1.04	0.80–1.12	0.24–0.33	0.95–0.96
Wave Custom (high setting)	3.58–4.32	2.16–2.96	2.85–3.15	0.65–0.72	0.91–0.95
40 Hz frequency setting					
Juvent	0.15–0.49	0.15–0.48	0.03–0.09	0.02–0.05	1.00–1.00
PowerPlate (low setting)	6.17–6.96	5.84–6.38	1.92–2.79	1.04–1.25	0.98–0.99
PowerPlate (high setting)	11.58–12.71	11.05–12.45	1.96–3.46	2.12–2.26	0.92–0.98
VForce (low setting)	6.66–7.02	2.08–3.85	5.87–6.57	0.70–1.18	0.95–0.98
VForce (high setting)	9.10–13.31	5.91–7.92	6.81–10.70	1.61–1.99	0.87–0.95
VibePlate	2.98–4.13	1.72–3.56	2.08–2.44	0.26–0.64	1.10–1.19
Wave Airflex (low setting)	3.58–3.83	3.55–3.74	0.22–0.81	0.37–0.71	0.98–0.99
Wave Airflex (high setting)	8.97–10.90	8.96–10.89	0.19–0.66	1.28–2.29	0.92–0.99
Wave ProElite (low setting)	2.82–3.14	2.75–3.02	0.65–0.84	0.40–0.46	1.02–1.03
Wave ProElite (high setting)	8.27–8.80	8.16–8.69	1.29–1.39	1.18–1.38	0.96–1.02
Wave Custom (low setting)	1.89–2.54	1.32–1.82	1.35–1.77	0.17–0.28	0.97–0.99
Wave Custom (high setting)	6.09–6.94	4.25–5.19	4.36–4.79	0.39–0.55	0.93–0.96
50 Hz frequency setting					
Juvent	0.43–0.67	0.42–0.67	0.05–0.08	0.02–0.05	1.00–1.00
PowerPlate (low setting)	9.14–10.19	8.52–9.56	2.70–3.86	0.98–1.03	0.96–0.98
PowerPlate (high setting)	16.80–18.50	16.45–18.01	3.40–4.34	2.13–2.38	0.91–0.98
VForce (low setting)	10.45–10.88	3.72–6.07	8.91–9.99	0.79–0.90	0.95–0.98
VForce (high setting)	13.30–19.53	8.02–11.18	10.60–16.01	1.52–1.76	0.83–0.96
VibePlate	2.96–3.94	1.66–2.94	2.45–2.72	0.31–0.54	1.06–1.11
Wave Airflex (low setting)	5.55–6.01	5.54–5.99	0.37–1.17	0.38–0.49	0.98–0.99
Wave Airflex (high setting)	13.44–16.29	13.40–16.29	0.36–1.03	1.14–1.62	0.89–0.98
Wave ProElite (low setting)	4.00–4.41	3.92–4.23	0.80–1.66	0.39–0.40	0.99–0.99
Wave ProElite (high setting)	11.60–11.81	11.33–11.67	1.83–2.47	1.14–1.26	0.93–0.98
Wave Custom (low setting)	3.36–4.00	2.63–2.97	2.09–2.72	0.16–0.25	0.98–0.99
Wave Custom (high setting)	9.77–11.46	7.28–8.46	6.52–7.72	0.34–0.45	0.93–0.97

[a]Frequency was recorded in Hz but is expressed here as a dimensionless ratio.

the device's controls (this ratio was used instead of the actual frequency produced to facilitate comparison between cases in which the intended frequency was different). The actual frequency was computed as the peak of the Fast Fourier Transform (FFT) of the 10-s recording interval. The peak acceleration and amplitude variables were measured for each period of the vibration and are reported as the mean of those values during the 10-s recording interval.

An analysis of variance (ANOVA) was conducted comparing the results for the 4 different weights, for each platform and frequency. This analysis was applied to the acceleration and amplitude variables. It was not applied to the frequency ratio, since there is a single value for each scenario (as opposed to one value per period of vibration), and therefore no variability to analyze. Statistical significance was defined as $p<0.05$. No statistical comparison between intended frequencies was performed, because frequency influences acceleration, such that different results are to be expected.

RESULTS

Table I shows the range of values observed for each variable, in each vibration platform at each intended frequency. For example, the first line of the table shows that in the Juvent at the 30 Hz setting, as the load was varied (0 kg, 45 kg, 68 kg, and 91 kg), the norm of the magnitude of vibration varied between 0.10 g and 0.69 g, the vertical component of the vibration varied between 0.10 g and 0.68 g, the horizontal component varied between 0.02 g and 0.09 g, and the amplitude of vibration varied between 0.02 mm and 0.2 mm. For all acceleration and amplitude variables in this table, the effect of load was found to be statistically significant (every variable in every platform, $p<0.001$ in all cases).

The peak acceleration and frequency data in Table I were derived from the accelerometer data, whereas the amplitude data was obtained from the laser measurements. An example of the laser recordings is provided in Fig. 1, which illustrates the trends observed for one vibration platform, the PowerPlate (low setting). Note the decrease in amplitude as the frequency increases, as well as the increasing effect of load on actual frequency as the intended frequency increases.

The general trend observed was that increasing the frequency of vibration increased the peak acceleration (as expected) but also decreased the amplitude of vibration, which should not be the case in a well-controlled vibration device. More concerning was the fact that the load also had a significant effect on the vibration parameters in all cases. Although the frequency of vibration may be fixed for a given research study, the load will always be a source of variability across subjects. The ratio of actual to intended frequency was not always well controlled, and the ratio was found to be affected by the load in most situations: the general trend was for the ratio to be closer to one in unloaded conditions, though this was not always the case. Several devices did not produce the intended frequency even in unloaded conditions: ratios of up to 1.19 were observed in unloaded conditions, and the VForce, VibePlate, and Wave ProElite all deviated from the intended frequency by at least 5% in at least one unloaded condition (details not shown). In addition to variations produced by different load weights, Fig. 1 also clearly illustrates the fact that vibrations measured under no-load conditions can differ measurably from vibrations under loaded conditions.

DISCUSSION

We examined the variability in vibration characteristics in a variety of commercially available vibration platforms, using laser and accelerometer recordings.

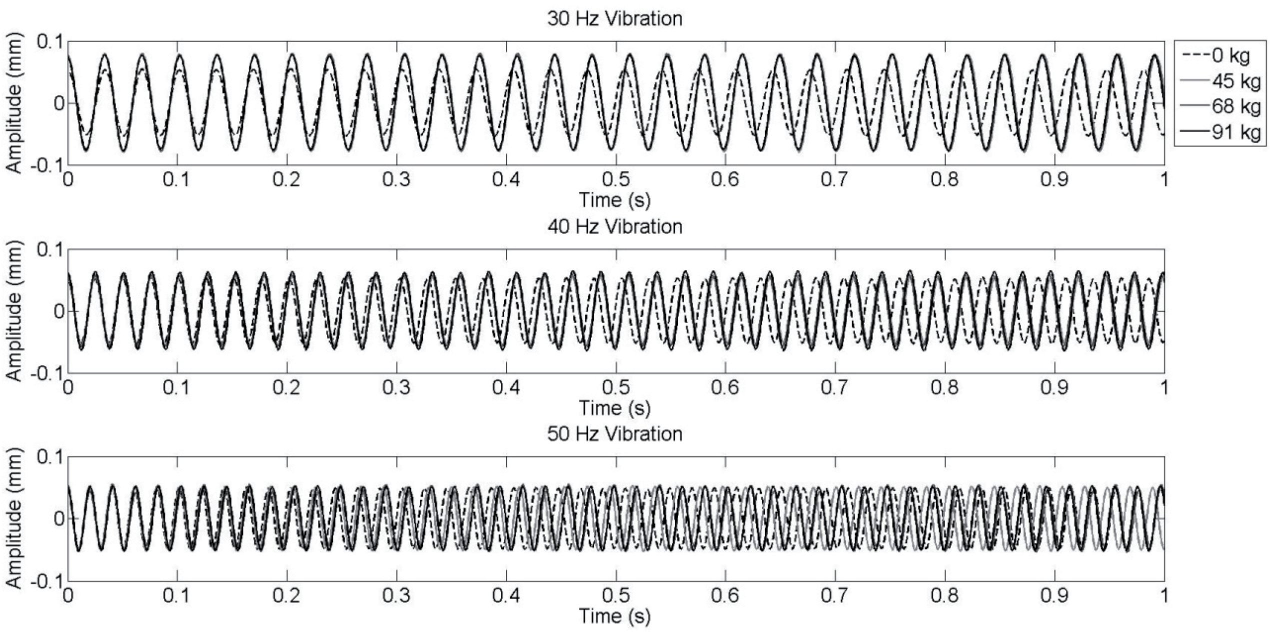

Fig. 1. Amplitude of vibration produced by the PowerPlate platform on "low" setting, for 4 different loads, when the intended frequency is set to 30 Hz (top), 40 Hz (middle) and 50 Hz (bottom). The dashed line shows the vibrations produced under a no-load condition and exhibits clear amplitude and frequency differences when compared to the loaded conditions. In each plot, the traces for the 4 different load conditions have been manually aligned at $t=0$ to make phase differences easier to see.

The peak acceleration of vibration was observed to vary greatly not only across platforms, but also within platforms. In addition, the horizontal component of the peak acceleration was not negligible in comparison to the vertical component for any of the platforms, suggesting that much of the vibrational energy is potentially being misdirected. This is a particularly interesting finding, given that the majority of all WBV studies have focused on the therapeutic effects of vertical vibration only. The actual frequency of vibration was also found to measurably deviate from the intended frequency in a majority of cases, the most notable exception being the Juvent platform where the actual and the intended frequency are the same. Our results are in line with those of Pel et al. (14), who also observed variability within and between 3 platforms as a function of load and frequency. Our study adds to that of Pel et al. by virtue of the larger number of platforms investigated, as well as by the use of the laser measurement, which enabled us to quantify the amplitude of vibration much more accurately than can be done with accelerometers. Our results also indicate larger deviations from intended frequency than what was reported by Pel et al., though this could be due to differences in the numerical precision with which the results were reported.

The position paper published by Rauch et al. in 2010 (15) provides guidelines for the reporting of WBV studies. Their recommendations include standardizing the terminology used for describing the vibrations, as well as ensuring that interventional protocols are reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines. Rauch et al. specifically highlight the need for investigators to measure the vibrations produced by the platforms used in their studies. We advocate adherence to these guidelines, with the additional recommendation that investigators take into account the fact the vibrations from a given platform can vary as a function of subject weight. Pilot measurements should therefore seek to quantify this variability.

In conclusion, our measurements emphasize the variability that exists in the vibrations produced by all of the major vibration platforms used in research studies. The weight of the subject can significantly affect the acceleration and amplitude of the vibrations delivered, as well as modify the actual frequency produced, and important differences exist between the various commercially available devices. Further, measurements obtained under no-load conditions likely do not accurately represent the vibrations actually delivered to subjects. For this reason, rather than rely on manufacturer specifications, it is imperative that investigators studying the effects of WBV carefully characterize and report the vibrations actually delivered to subjects in their studies.

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