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Characteristics of Vibration that Alter Cardiovascular Parameters in Mice

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We hypothesized that short-term exposure of mice to vibration within a frequency range thought to be near the resonant frequency range of mouse tissue and at an acceleration of 0 to 1 m/s^2 would alter heart rate (HR) and mean arterial pressure (MAP). We used radiotelemetry to evaluate the cardiovascular response to vibration in C57BL/6 and CD1 male mice exposed to vertical vibration of various frequencies and accelerations. MAP was consistently increased above baseline values at an acceleration near 1 m/s^2 and a frequency of 90 Hz in both strains, and HR was increased also in C57BL/6 mice. In addition, MAP increased at 80 Hz in individual mice of both strains. When both strains were analyzed together, mean MAP and HR were increased at 90 Hz at 1 m/s^2, and HR was increased at 80 Hz at 1 m/s^2. No consistent change in MAP or HR occurred when mice were exposed to frequencies below 80 Hz or above 90 Hz. The increase in MAP and HR occurred only when the mice had conscious awareness of the vibration, given that these changes did not occur when anesthetized mice were exposed to vibration. Tested vibration acceleration levels lower than 0.75 m/s^2 did not increase MAP or HR at 80 or 90 Hz, suggesting that a relatively high level of vibration is necessary to increase these parameters. These data are important to establish the harmful frequencies and accelerations of environmental vibration that should be minimized or avoided in mouse facilities.

Abbreviations: HR, heart rate; MAP, mean arterial pressure; RFR, resonance frequency range.

Excessive levels of vibration are widely seen as a potential cause of organ injury and physiologic changes in laboratory animals, including altered heart rate (HR), mean arterial pressure (MAP), and circadian rhythm;[15,19,20] therefore, vibration can affect animal welfare or research integrity. Sources of vibration in animal facilities are diverse and difficult to control. Vibration can be generated by components of the animal care facility, including cage wash equipment, autoclaves, animal transfer stations, and ventilated racks as well as by physical plant construction[22] and municipal traffic near the animal facility. Moreover, the frequencies and acceleration of vibration that induce physiologic changes are not well known. Studies performed in humans[4-7] have shown that exposure to prolonged vibration at an acceleration of 0.5 m/s^2 for 8 h induces harmful effects.[23] Vertical vibration at frequencies of 0 to 63 Hz is reported to be most harmful in humans.[25] Although vibration can be detrimental to laboratory animals, a concern expressed in the new edition of the *Guide for the Care and Use of Laboratory Animals*,[14] no information is currently available concerning the frequency ranges or acceleration that exert harmful effects in laboratory animals.

The resonance frequency range (RFR) is the range of frequencies at which an object most readily vibrates and the range over which an animal may sense, respond to, and suffer adverse effects from vibration.[12,13] Our laboratory has established that the approximate RFR for mice is 31 to 100 Hz at 0.3 to 1.0 m/s^2, with most individual mice registering RFR values lower than 80 Hz.[27] However the physiologic effects of vibration in this range have not been determined. The goal of the current study was to determine whether vibration-induced changes in MAP and HR occurred within this frequency range.

When testing the adverse effects of vibration or sound it is necessary to determine which of these play a larger role in inducing physiologic changes; this task is challenging because both sound and vibration can occur concomitantly. Delineating the separate contributions of sound and vibration in causing adverse effects and the mechanism whereby these occur need to be addressed when studying the adverse effects of vibration in animals. The current study determines the effects of vibration on MAP and HR in the absence of a contribution of sound to changes in these parameters.

Stress is a leading risk in the development of cardiovascular disease.[11] In laboratory animals, stress can cause cardiovascular, neuroendocrine, and immunologic changes,[3,9,26,31] and previous research has demonstrated that vibration can cause disorders of the central autonomic nervous system.[21] This component of the nervous system helps to control MAP, HR, peripheral blood flow, digestion, and respiratory rate as well as other physiologic processes. Animal distress would be presumed to be the reason for any changes in cardiovascular parameters due to vibration, but previous research showed that vibration caused increases in blood flow and pressure in anesthetized dogs and pigs.[10] We used radiotelemetry to study vibration-induced changes in MAP and HR in conscious and anesthetized mice to determine whether anesthesia mitigated these changes.

Currently there are no direct data regarding the frequencies and accelerations of vibration that produce physiologic changes in mice. Our goal was to test the hypotheses that mechanical vibration of 31 to 100 Hz induces changes in MAP and HR in conscious mice. In addition, these experiments established the minimal levels of acceleration required to cause these changes. Therefore, our findings help to establish standards against which environmental vibration can be compared and assessed

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to estimate potential effects on animal wellbeing and research outcomes.

Materials and Methods

Animals and housing. We chose C57BL/6 mice because of their frequent use as a background strain for transgenic mice and due to their inbred nature. Because genetic factors might affect the perception and response to vibration, we also tested the outbred CD1 strain. Male C57BL/6 and CD1 mice (weight, 25 to 30 g; Charles River, Raleigh, NC) were housed in polycarbonate, microisolation cages. Cotton nesting squares (Nestlets, Ancare, Bellmore, NY) and red transparent plastic nest boxes (Ancare, Bellmore, NY) were used for environmental enrichment. Mice were exposed to a standard 12:12-h photoperiod. Rodent laboratory chow (no. 5001, Lab Diet, St Louis, MO) and water were provided free choice. All procedures met the standards in the *Guide*[14] and were approved by Duke University's IACUC.

Implantation of transmitters. Transmitters were implanted aseptically. Before surgery and approximately 10 h later, buprenorphine (0.05 mg/kg SC) was administered for pain management. Mice were anesthetized with isoflurane (induction: 2.5% to 3%, maintenance: 0.5% to 1.5%). The transmitters (weight, 2.2 g; volume, 1.4 mL; model HD-X11, Data Sciences International, St Paul, MN) were implanted in male C57BL/6 and CD1 mice according to the manufacturer's standard procedures. Briefly, after the removal of the hair on the ventral surface of the neck, a 1.5-cm midline incision was made, and the mandibular glands were separated by using sterile cotton-tip applicators. The left carotid artery was exposed, and 6-0 nonabsorbable sutures were passed underneath the isolated artery. The most cranially placed suture was used to permanently ligate the carotid artery whereas the suture closer to the heart was used to temporarily occlude blood flow for placement of the catheter. The catheter was advanced in the left carotid artery until it reached the aortic arch. The transmitter was positioned subcutaneously along the lateral flank, between the forelimb and hindlimb. Once the transmitter was in place, the leads were tunneled subcutaneously to the desired electrocardiograph electrode locations. One lead was positioned approximately 1 cm to the left of the xyphoid process, and another led from the neck incision to the right pectoral muscle. After surgery, the mice were kept in their home cages, which were placed partially on a warm-water blanket (42 °C) until the mice became active. The mice had 1 wk for recovery before any experiments were performed.

Measurement of HR and MAP. HR and MAP were measured in conscious, telemetered C57BL/6 and CD1 mice enclosed in a plastic, transparent, roofed cylinder that confined the mice to the center of the vibrating table but that allowed limited movement. The mice were confined to the center of the table so that the acceleration and frequency of the vibration was consistent and to preclude potential exposure of animals to varied vibration around the periphery of the table. Mice were tested individually. A section of cardboard was placed within the cylinder above the mouse to ensure that the mice did not rear onto its hindlegs and kept all 4 feet on the table (Figure 1). The actuator (Shaker V201, Brüel and Kjær North America, Norcross, GA) was used to induce vertical vibration for frequencies lower than 80 Hz (the upper limit of this equipment); another actuator (model U5856001, 3B Scientific, Hamburg, Germany) was used to generate frequencies of 80 Hz or above. The accelerometer was placed directly beneath the mouse on the vibration table so that the values reported are the actual frequency and acceleration of exposure.

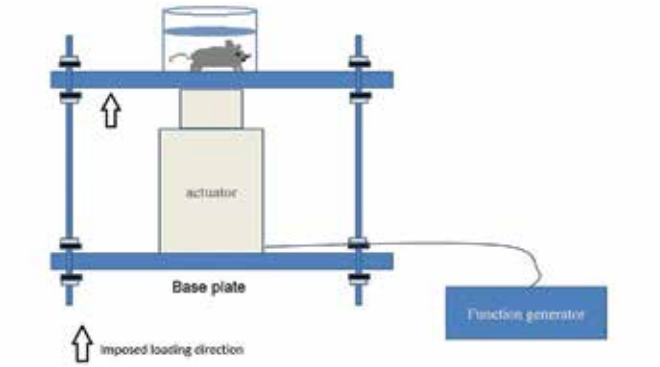

Figure 1. Diagram of the vibration system.

To allow mice to acclimate, recording of HR and MAP was not initiated until at least 2 h after their transfer to the table. The vibration protocol was not initiated until these parameters remained consistently at baseline levels (an additional 2 to 3 h). Cardiovascular data were collected before and during vibration trials by using specialized software (Dataquest ART 4.3, Data Sciences International).

Experimental procedure. The primary goal of this project was to determine the range of vibration frequencies that cause increases in MAP and HR and to identify the effect of acceleration magnitude on those values in C57BL/6 (n = 3) and CD1 (n = 3) mice. Once those values were identified, we performed 3 additional studies. To confirm that prolonged high acceleration did not induce increases in MAP and HR at frequencies that did not cause cardiovascular changes in the initial experiment, we assessed the effects of vibration on HR and MAP when the acceleration was held constant for an extended time at each specific frequency in C57BL/6 (n = 3) and CD1 (n = 3) mice. In addition, to determine whether consciousness was required for vibration-induced changes in MAP and HR, we exposed anesthetized C57BL/6 (n = 2) and CD1 (n = 1) mice to vibration. Finally, we determined the minimal acceleration necessary to cause increases in HR and MAP in C57BL/6 (n = 2) and CD1 (n = 1) mice. The same pool of mice was used in all experiments.

To test the effects of increasing acceleration at various frequencies, telemetered C57BL/6 and CD1 mice were exposed to whole-body, sinusoidal vibration ranging from 30 Hz to 110 Hz in 10-Hz increments (Figure 2). To ensure that MAP and HR had returned to baseline levels between testing at each frequency there was a 5-min recording period to establish the baseline prior to any vibration exposure and a 30-min recovery phase, during which the mice remained undisturbed, between test frequencies. In addition, MAP and HR data were collected for 30 s before the vibration exposure of 4 min 30 s at each frequency. The acceleration at each test frequency was increased from 0 to 1.45 m/s^2 over 4 min 30 s.

A subsequent set of experiments was performed to determine whether prolonged exposure to high-acceleration vibration increased HR or MAP at frequencies that failed to increase MAP or HR in the previous experiment. To this end, the acceleration was held constant at 1 m/s^2 for 4 min 30 s. To control for the sound produced by the vibration table, MAP and HR were measured in C57BL/6 (n = 2) and CD1 (n = 2) mice that were placed beside the vibration table when it was set at vibration levels of 1 m/s^2 at 80 and 90 Hz.

To determine whether increases in MAP and HR were caused by factors related to consciousness or were due to autonomic nervous system activity in the absence of consciousness, anesthetized C57BL/6 and CD1 mice were exposed to vibration at

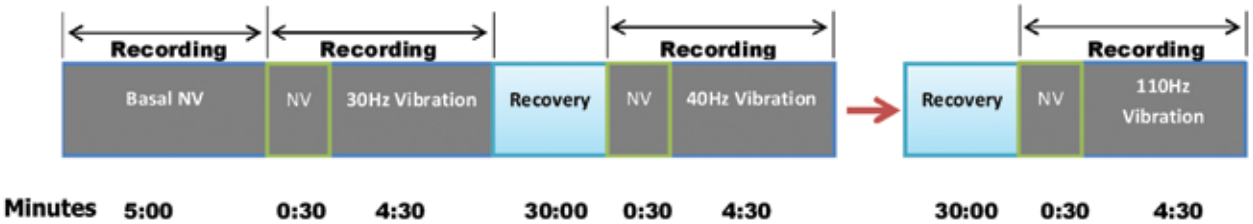

Figure 2. Diagram of the protocol for data recording. Telemetric MAP and HR were recorded (gray boxes) for 30 s without vibration and then with vibration for 4 min 30 s, during which acceleration increased from 0 to 1.45 m/s^2. A 30-min recovery period was included after each frequency tested to ensure that the MAP and HR either remained or had returned to baseline levels. NV, no vibration.

frequencies from 30 to 110 Hz at a constant acceleration of 1 m/s^2. Anesthesia consisted of isoflurane (induction, 2.5% to 3%; maintenance, 1.5% to 2.0%) and was maintained in the mice by way of a nose cone that was affixed so that it didn't contact the vibration table.

A final experiment was performed to confirm the range of minimal acceleration that caused MAP and HR changes. This experiment was performed by using vibration at 80 and 90 Hz and constant accelerations of 0.50 m/s^2 and 0.75 m/s^2. Both C57BL/6 and CD1 mice were tested as described for previous experiments in which the acceleration was held constant for 4 min and 30 seconds at each frequency.

Data analysis. Specialized software (Dataquest ART 4.3, Data Sciences International) was used to record the cardiovascular parameters in our mice. This software continuously monitors and records measured values at 10-s intervals. Therefore, the MAP and HR data points in the graphs are the values at each 10-s interval during 5 min (300 s). The 300-s duration included an initial period of 30 s to ensure that MAP or HR was at baseline, followed by 270 s of recording during vibration. The HR value was calculated automatically from the MAP signal. Recorded data were analyzed by using the same software and the results exported to a spreadsheet (Excel, Microsoft, Redmond, WA). Results are presented as mean ± SEM. One-way repeated-measure ANOVA (Excel, Microsoft) was used to investigate differences between frequencies. Values tested were the sum of MAP or HR data within frequencies of individual mice or groups of mice from approximately 0.75 to approximately 1.45 m/s^2. A Tukey test was used to test for significant differences between frequencies of vibration and baseline values. Differences were considered statistically significant a P level of 0.05 or less. Only sustained changes in MAP and HR and those consistently occurring between mice during vibration exposure were considered to have resulted from vibration; occasional changes that did not persist during exposure were considered to reflect other factors.

Results

Effects of vibration at constant frequency and increasing acceleration on HR and MAP. Compared with baseline values in both C57BL/6 and CD1 strains, the mean MAP increased significantly ($P \leq 0.05$) when mice were exposed to vibration at 90 Hz (Figure 3). The MAP (mean ± SEM) at 90 Hz did not differ between the 2 strains (C57BL/6, 108.2 ± 7.2 mm Hg; CD1, 99.5 ± 8.2 mm Hg). In addition, the MAP tended to peak at approximately 1 m/s^2 compared to baseline and did not show a further significant increase from 1 to 1.45 m/s^2. Although the mean values of 3 mice of each strain did not increase at 80 Hz, 2 C57BL/6 and 1 CD1 mouse demonstrated significant ($P \leq 0.05$) increases in MAP at this frequency compared with their own baseline values (data not shown). MAP did not show sustained increases during vibration from 30 to 70 Hz or at 100 Hz or 110 Hz in either strain or at any acceleration tested. When all 6 mice were combined, MAP measurements demonstrated increases ($P \leq 0.05$) at 90 Hz (Figure 4 A), but persistent increases in MAP were not noted at frequencies from 30 to 80 Hz, at 100 Hz, or at 110 Hz.

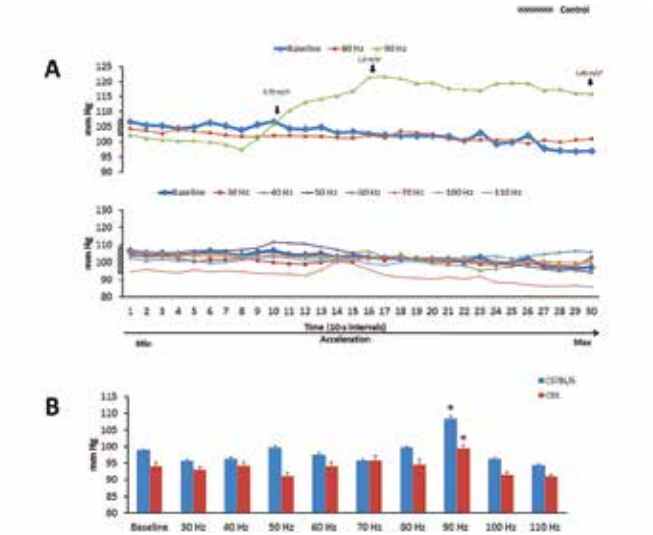

Figure 3. MAP changes during vibration of 30 to 110 Hz resulting from increasing acceleration within each frequency in C57BL/6 and CD1 mice. (A) Representative C57BL/6 mouse. The hatched bar along the y axis shows the range of MAP that was recorded for 30 s in mice without vibration. The black vertical arrow designates the approximate point on the x axis at which the acceleration reached specified values. The maximal acceleration at 90 Hz was 1.45 m/s^2 at 300 s. (B) The bar graph demonstrates that both C57BL/6 and CD1 mice had increased (*, $P \leq 0.05$ compared with baseline) MAP at 90 Hz but not at other frequencies.

Compared with baseline values, mean HR showed a persistent significant increase ($P \leq 0.05$) in C57BL/6 mice exposed to vibration at a frequency of 90 Hz (Figure 5), and there was no further significant increase from 1 to 1.45 m/s^2. The HR at 90 Hz was significantly ($P \leq 0.05$) greater in C57BL/6 mice (601.3 ± 88.3 bpm) compared with CD1 mice (510.1 ± 80.3 bpm). Although there was no sustained increase in mean HR in CD1 mice at any frequencies, the mean increased transiently at 70 and 80 Hz and subsequently returned to baseline levels. One C57BL/6 mouse and one CD1 mouse each exhibited a significant ($P \leq 0.05$) sustained increase in HR at 80 Hz relative to their own baseline values (data not shown). HR in neither C57BL/6 nor CD1 mice was increased significantly when the animals were exposed to vibration of 30 to 70 Hz, 100 Hz, or 110 Hz. When all mice of both strains were combined, HR measurements demonstrated increases ($P \leq 0.05$) at 80 and 90 Hz (Figure 4 B), but persistent increases in HR were not noted at frequencies from 30 to 70 Hz, at 100 Hz, or at 110 Hz.

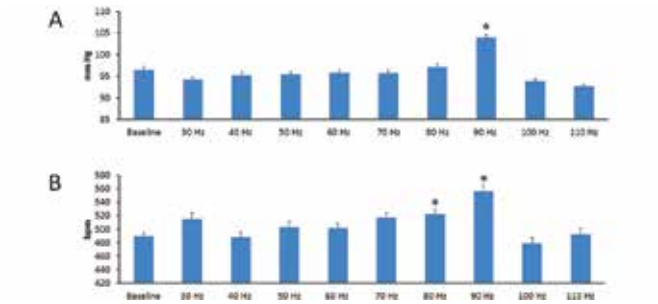

Figure 4. (A) MAP and (B) HR changes in C57BL/6 and CD1 mice combined (n = 6) during vibration of 30 to 110 Hz resulting from increasing acceleration within each frequency. MAP and HR were significantly (*, $P \leq 0.05$ compared with baseline) increased at 90 Hz; HR was increased at 80 Hz also. HR at 30 and 70 Hz increased very briefly in one mouse but immediately returned to baseline.

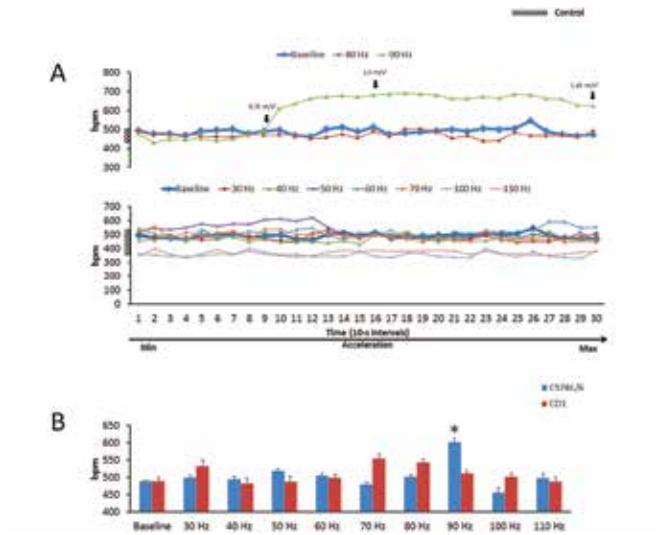

Figure 5. HR changes during vibration of 30 to 110 Hz resulting from increasing acceleration within each frequency in C57BL/6 and CD1 mice. (A) Representative C57BL/6 mouse. The hatched bar along the y axis shows the range of MAP that was recorded for 30 s in mice without vibration. The black vertical arrow designates the approximate point on the x axis at which the acceleration reached specified values. The maximal acceleration at 90 Hz was 1.45 m/s^2 at 300 s. (B) The bar graph demonstrates that C57BL/6 mice had increased ($P \leq 0.05$) HR at 90 Hz but not at other frequencies. CD1 mice did not have increased HR at any frequency. The 70- and 80-Hz frequencies significantly increased HR in CD1 mice, but the increases were not sustained during vibration exposure.

To control for the sound produced by the vibration table, C57BL/6 and CD1 mice were placed beside the vibration table when it was set at vibration levels of 1 m/s^2 at 80 and 90 Hz. No increases in HR or MAP occurred in the mice exposed to sound only (Figure 6).

Effects of vibration at frequencies of 30 to 70 Hz and constant acceleration on MAP and HR. To confirm that prolonged acceleration did not increase in MAP and HR at frequencies that did not result in cardiovascular changes during the initial experiments, we held the acceleration of vibration constant at 1 m /s^2 for 4 min 30 s at frequencies of 30 to 70 Hz. Neither HR nor MAP increased when mice were exposed to any of these frequencies (Figure 7). The frequencies of 100 and 110 Hz were not tested in this experiment because conditions of 1 m/s^2 or greater for 4 min 30 s had not altered HR or MAP.

Effects of vibration on MAP and HR in anesthetized mice. To determine whether increases in HR or MAP due to vibration

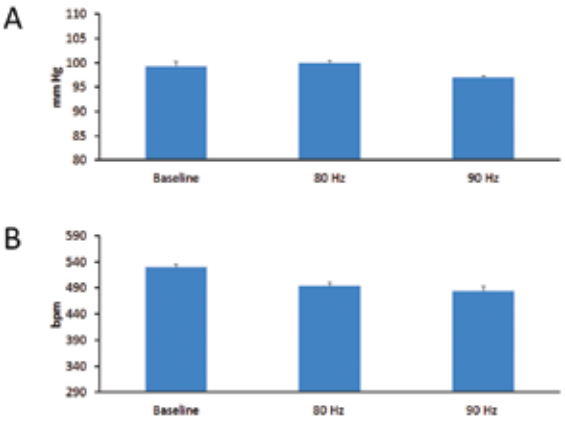

Figure 6. MAP and HR changes at 80 and 90 Hz when C57BL/6 and CD1 mice combined (n = 6) mice were exposed to the sound of the vibration table and not the vibration. The sound generated by the vibration table at these frequencies and 1 m/s^2 did not cause an increase in MAP or HR.

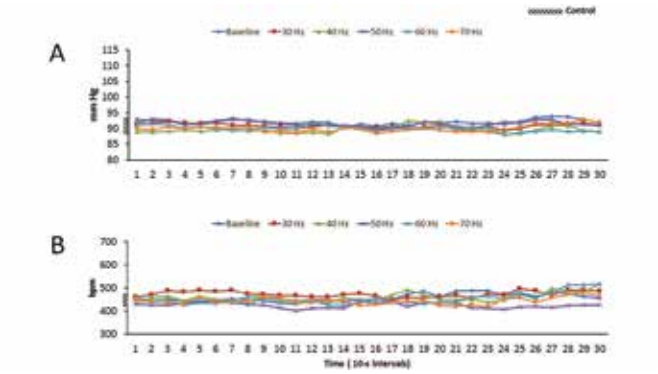

Figure 7. (A) MAP and (B) HR in C57BL/6 and CD1 mice combined (n = 6) exposed to 30 to 70 Hz of vibration with constant acceleration (1 m/s^2). The hatched bar along the y axis shows the average range of HR or MAP that was recorded for 30 s in mice without vibration.

were confined to consciousness, mice were anesthetized with isoflurane and exposed to 1 m/s^2 at 30 to 110 Hz in 10-Hz increments. No increase in HR or MAP occurred in vibration-exposed, anesthetized mice (Figure 8).

Determination of the minimal acceleration necessary to cause increases in MAP and HR. In light of the increased MAP and HR we noted at frequencies of 80 and 90 Hz and an acceleration of 1 m/s^2, these parameters were measured in conscious mice at vibration frequencies of 80 and 90 Hz and at accelerations of 0.50 and 0.75 m/s^2. At vibration of 90 Hz, both mean MAP and HR significantly ($P < 0.05$) increased above baseline values at an acceleration of 0.75 m/s^2 but not at 0.50 m/s^2. Vibration at 80 Hz did not increase mean HR or MAP at either acceleration level (Figure 9). Therefore, the minimal acceleration necessary to cause an increase in MAP and HR at 90 Hz is between 0.5 and 0.75 m/s^2.

Discussion

Vibration has been shown to affect bone, nerves, blood vessels, and cardiovascular functions in animals.[2,8,16,18,32] Whole-body chronic vibration in mice at approximately 1 to 3 m/s^2 and up to 90 Hz over time decreased adipogenesis, lowered liver triglyceride levels,[17] and increased bone volume and bone formation.[29,33,34] Although these effects seem beneficial, vibration at similar frequencies and accelerations can cause presumably deleterious and stress-related effects of increased MAP and HR as well.

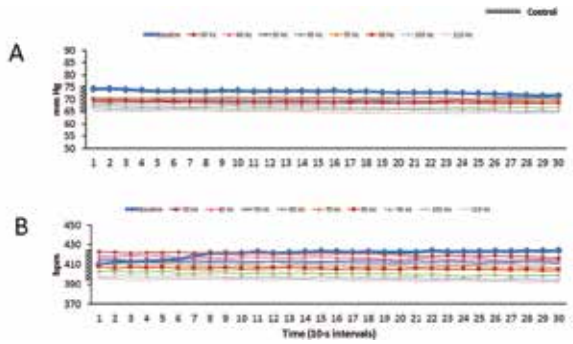

Figure 8. (A) MAP and (B) HR at various frequencies and 1 m/s^2 constant vibration in anesthetized C57BL/6 and CD1 combined mice. The hatched bar along the *y* axis shows the average range of HR or MAP that was recorded for 30 s in mice without vibration. There was no increase in MAP or HR at any frequency during anesthesia. The baseline MAP and HR are lower than control levels at some frequencies, likely because of varying depths of anesthesia.

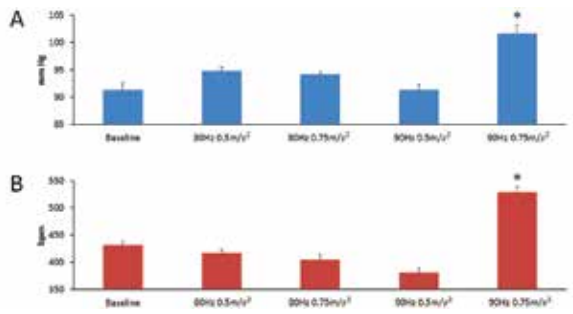

Figure 9. The minimal acceleration necessary to cause an increase in (A) MAP and (B) HR in C57Bl/6 and CD1 mice combined. The minimal acceleration necessary to cause an increase was 0.75 m/s^2 at 90 Hz.

We found that vibration with a frequency of 80 Hz and (especially) 90 Hz at 1 m/s^2 acceleration increased MAP and HR relative to baseline values in mice. However, mice exposed to vibration at 30 to 70 Hz, 100 Hz, or 110 Hz showed no change in MAP and HR values compared with those recorded when the mice were not exposed to vibration (baseline values), even when exposed to vibration at 1 m/s^2 for a prolonged period of time. In a previous study by our group,[27] the range of frequencies at which the bodies of mice either amplified or failed to attenuate the magnitude of vibration were established. This nonattenuation range (or sensitive range) can reasonably be considered to reflect the resonant frequency of mouse tissue (a composite tissue given that whole-body vibration was used). Therefore, it can be argued that the approximate range between 31 and 100 Hz is the frequency range of vibration that is most likely to affect tissue and thus induce a behavioral response in mice. Our work demonstrates that 70 to 100 Hz is the frequency range at which the cardiovascular system of mice is the most responsive to vibration, as indicated by the statistically significant changes in MAP and HR at 80 and 90 Hz compared with baseline values and compared with those at all other frequency ranges tested from 30 to 110 Hz. This range is surprisingly narrow, considering the wider range of nonattenuated frequencies that has been previously determined.[27] This narrow range may be specific to changes produced in MAP and HR; other physiologic changes may occur at a broader range of frequencies.

Because distress from sound could conceivably cause increases in MAP and HR in mice, we exposed them to the noise emanating from the vibration table at the acceleration (1 m/s^2) and frequencies (80 and 90 Hz) that had increased MAP and HR when mice were placed on the table. In this experiment, mice were placed on a similar table immediately adjacent to the apparatus. No increase in HR or MAP occurred under these conditions, confirming that the vibration itself was the cause of the cardiovascular changes. In addition, the sound produced by the vibration table during our experiments was analyzed and found to predominantly comprise frequencies beyond the hearing range of mice[28] and therefore likely was not a contributing cause of the changes we observed.

We wanted to explore the cardiovascular effects of conscious awareness of the vibration compared with changes that occurred independent of consciousness. The fact that anesthetized mice did not demonstrate similar increases in MAP and HR as did conscious mice suggests that awareness of the vibration is necessary for these changes to occur. Vibration-induced distress is a potential explanation for these results. A study in piglets demonstrated that vibration resulted in an increase in the blood stress indicators adrenocorticotropic hormone and cortisol.[26] Noise stress increases corticosterone secretion[1,30] and increases MAP and HR[24] in rats. Although we did not measure corticosterone, the current study points to physiologic stress as a possible explanation for the increases in MAP and HR. However, given the complexity of neural control under anesthesia, this area deserves further investigation.

Although the acceleration of 1 m/s^2 increased MAP and HR at the frequencies we tested, no significant additional increase occurred between 1 and 1.45 m/s^2, suggesting that the effect of vibration on these cardiovascular parameters plateaus after 1 m/s^2. The lowest tested acceleration that led to increases in MAP and HR was 0.75 m/s^2. Although the threshold for the perception of vibration in humans varies slightly with age, the position of the body, the body region, and the axis of vibration,[13,25] the median threshold is approximately 0.01 m/s^2 for vertical vibration between 0 and 63 Hz,[25] and 1 m/s^2 is near the human exposure limit.[23] Therefore, in the current study, vibration at 0.75 m/s^2 between 0 and 63 Hz would readily be perceived by humans, as was verified by our laboratory personnel as they performed these studies. Interestingly, in our experience, the vibration in a room housing mice that was immediately adjacent to construction for a new addition at our facility showed maximal acceleration at 0.29 m/s^2 at a frequency of 90 Hz but did not affect mouse reproductive efficacy (numbers of mice pregnant, born, weaned, and cannibalized and weaning weight). Although construction-induced vibration has the potential to cause adverse effects on animal wellbeing and research integrity, these effects appear to be highly dependent on the acceleration and frequency of the vibration generated.

We opted to test C57BL/6 mice because of its inbred nature and its use as a background strain for many transgenic mice. Although the CD1 mouse is an outbred strain, the vibration frequencies and accelerations that produced increases in MAP and HR were similar between CD1 and C57BL/6 mice, except for the failure to detect an increase in mean HR in CD1 mice. This finding may reflect experimental variability or may indicate that CD1 mice are less responsive to vibration.

In summary, changes in MAP and HR occurred when conscious, but not anesthetized, mice were exposed to vibration with a frequency of 80 or 90 Hz and an acceleration of 1 m/s^2. No sustained increases in HR or MAP occurred between 30 and 70 Hz, at 100 Hz, or at 110 Hz. The minimal acceleration that caused changes in mouse MAP and HR was between 0.50 and 0.75 m/s^2 at a frequency of 90 Hz. With knowledge of the natural sensitivity range (RFR or nonattenuation range), these

results help to establish a range of vibration that mice can perceive and that will cause physiologic changes. Therefore, our current data generated likely yield insight into how acute vibration in animal facilities affects the health and wellbeing of laboratory animals and influences facility design and research protocols. Additional work is needed to determine the physiologic and pathophysiologic effects of acute as well as chronic vibration at the frequencies and accelerations that we defined here.

Acknowledgments

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