Low-Frequency Stress Elicitation for VR Training

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***Abstract*—Low-frequency sounds have been reported to elicit stress and discomfort under certain conditions. This is a very interesting effect for Virtual Reality (VR) training simulations focusing on skill acquisition and practice under stressful conditions, such as doctors, surgeons, firefighters, airline pilots, police officers, teachers or even teachers or university professors. Low-frequency sounds can be easily added to existing VR simulations to create more realistic stressful situations. However, they may have major health risks. The range, amplitude, and exposition duration to which low-frequency could be safely and efficiently used in VR are still unknown. With this paper, we aim to foster more research on the topic by providing a concise summary of previous work as well as suggesting a possible low-frequency condition suspected to safely increase stress.**

***Index Terms*—VR Training, Stress, Audio Low-Frequency**

I. Introduction

Virtual Reality (VR) can be used as a training method with which human beings learn to perform certain tasks by repeatedly executing them in a VR environment. VR training is utilized across several domains, including education, military, aviation, and healthcare [1], [2]. Bosse et al. [3] explored to which extent VR-based training can be used to improve professional skills of people that have to act in dangerous circumstances, such as law enforcement, public transport, and health care. The ability to replicate real-world scenarios in a controlled virtual environment has proven ideal for learning and practicing decision-making skills under heavy strain or in dangerous situations [4].

In this paper, we propose to investigate alternatives to achieve stress elicitation using low audio frequency. The main advantages are: i) a context-independent mechanism (not depending on a particular training environment context), ii) subconscious (below or at the limit of human perception threshold), iii) low cost and iv) low CPU usage and small memory footprint. Therefore, such a technique should be applicable to any current or future VR training with minimum modification and performance cost.

Currently, there is no general consent on how dangerous low frequencies are, or which side effects may occur, especially in VR. Consequently, our first research step focused on collecting relevant data on limits, possible advantages, and dangers for VR simulation. The rest of this paper reviews previous studies and identifies a possible set of frequencies and intensities for future investigations.

II. Low-Frequency and Stress Elicitation

Low-frequency sound waves are in a 0-100 *Hz* range, with ultra-low frequencies below 20 *Hz*, the so-called infrasound. They are barely audible. In today's urban landscape such low frequencies can be emitted by amplified music or ventilation systems. In general, they are perceived through body vibrations and a characteristic *humming* noise. To a certain extent, these low frequencies are "heard" and "felt" at the same time.

Low frequencies have also been proven to have different thresholds and effects on the human body such as annoyance [5] or performance degradation [6]. They have been categorized as an uncontrollable stressor which generates a greater sympathetic nervous system activation as well as a higher skin conductance [7]. Additionally, it has been established that annoyance and loudness reaction to low frequencies are sometimes higher than to noise at the same sound pressure level (*SPL*) [8].

III. Low-Frequency and Health Risks

One important problem is the fact that most of the relevant research has used high rates of Decibel (*dB*) surpassing the threshold of discomfort of 90-95 *dB* (see Table I). In most of the studies it has been discovered that the average damage/loss of hearing threshold is $>=$ 140 *dB* [9], also causing pain (140 *dB* at 20 *Hz*, 165 *dB* at 2 *Hz*) or even eardrum rupture (between 185-190 *dB*) [5]. For exposures to infrasound for 24 hours, the set limit is 120-130 *dB* to prevent damage to the auditory system [10]. This is contrary to the casual threshold of 100 *dB* resulting in serious damage already after 8 hours [11]. A more comprehensive summary of current research regarding low frequencies and their other effects on the human body is presented in Table I.

Overall, previous work indicates that although infrasound played for a short duration are not be harmful below 140 *dB*, a careful approach is necessary (i.e., below 100 *dB*), especially if the exposure is of a long-term kind. Also based on previous work, we can identify the following values as suitable for safe investigations of low-frequency in VR: i) a range from 6 to 8 *Hz*, ii) with exposition that should be about 20 minutes, but no longer than 50 minutes, iii) while using an intensity of 90 *dB*. Figure 1 summarizes the suggested range, amplitude, and exposition duration to safely explore audio stress elicitation in VR training applications.

IV. Conclusion

This paper discussed the opportunities to elicit subconsciously stress during VR training simulations with low-frequency sound waves. Our contribution is i) a summary of previous work (Table I), and ii) the identification of possible audio low-frequency conditions to safely experiment their impact during VR training (Figure 1). However, only empirical studies could now answer the question: *Can a low-frequency sound safely elicit stress in VR, especially with a short-time exposure?*

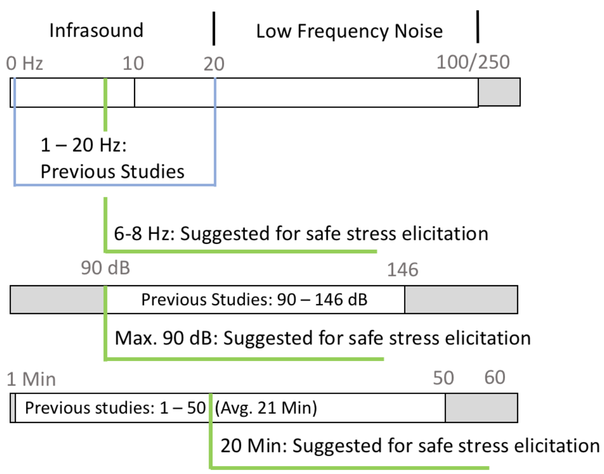

Fig. 1. Overview of Suggested Low Frequency Conditions

TABLE I
LOW-FREQUENCY SOUND WAVE EFFECTS ON HUMAN BODY

Paper	Frequency *Hz*	Intensity *dB*	Duration *Min*	Effects
[12]	7.5	130	50	No negative effects
[13]	6, 12, 16	95, 110, 125	*Unknown*	Increased diastolic and decreased systolic blood pressure
[14]	2 - 10	130 - 146 binaural	1	clear vertical nystagmus in 85% - 7 *Hz* most efficient
[15]	7	125, 132, 142	up to 30	No performance reduction
[16], [17]	0.6, 1.6, 2, 4, 7, 12	14, monaural/bilateral	*Unknown*	No significant effect on task performance
[18]	5 - 10	100 - 135	15	Feelings of fatigue, apathy, pressure on the ears
[19]	8 -100	90 - 120	1 - 5	No findings
[20]	14 - 16	125	long-term	Increased diastolic and decreased systolic blood pressure
[21]	1 - 20	up to 144	8	Painless pressure on ears; Safe for healthy persons
[22]	10 - 15	130 - 135	30	No changes in autonomic nervous system functions
[6]	2 - 15	115	36	Degrading of performance

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