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ELUCIDATION OF ENHANCEMENT PHENOMENA OF THE SOUND PRESSURE LEVEL AND REPETITIVE COMPONENTS WHEN APPLYING PRESSURE NEAR THE SOUND SOURCE

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Abstract. *It was previously discovered that the sound pressure level (SPL) and repetitive component of sound generated by a music box increased when applying pressure near the music box using a thin acrylic board. Applying this phenomenon, it is possible to increase the SPL and intelligibility of sound without increasing the amount of electric power used. The present study used four types of boards and three types of sound sources (i.e., a music box, loudspeaker, and mobile phone) to reproduce and clarify increases in the SPL and repetitive component due to pressurization near the sound source in more detail. It was found that a 0.5-mm-thick acrylic or plastic board produced the highest SPL and most repetitive component. The phenomenon could not be reproduced well for the loudspeaker or mobile phone. By incorporating a mechanism that generates this phenomenon inside a loudspeaker, it is possible to increase the SPL and intelligibility of existing loudspeakers and mobile phones.*
Keywords: Pressurization, Sound pressure level, Repetitive component

1. **Introduction.** There has been much research on the generation and propagation of sound sources in various fields, including physics, phonetics, musical instrument acoustics, and architectural acoustics. Acoustic measurements indicated that a violin's sound post (the stick that connects the top board and the back board of the violin) [1], pillars under the floor of a temple [2], and soil and rock pressure in a tunnel constructed employing the new Austrian tunneling method [3] affect sound in its propagation from the sound source to the human ear. This phenomenon cannot be explained by traditional musical instrument acoustics or architectural acoustics.

In a comparison of sounds generated with and without the sound post of the aforementioned violin, the sound pressure level (SPL) was higher and the degree of the repetitive component contained in the sound, which is quantified as the effective duration of the autocorrelation function (ACF), τ_e, was longer in the case with the sound post than in the case without the sound post. In a similar way, a music box to which pressure was applied by bending a thin acrylic board produced sound with a higher SPL and longer τ_e [1]. The floor of the aforementioned temple was stressed by pillars under the floor and the aforementioned tunnel constructed employing the new Austrian tunneling method was stressed by a lock bolt and concrete, and the stress increased the SPL in both cases [2,3]. This is considered to be a kind of resonance. Previous studies have investigated the effects of resonance such as the effects of resonance of a top plate, string, and wall on the pitch and SPL of the component of musical instruments [4-6]; however, effects of the resonance on the overall SPL and repetitive components have not been considered.

Using the phenomenon that the SPL and the repetitive component are increased by applying pressure in the vicinity of a sound source, it is possible to improve the SPL and speech intelligibility of sound generated from a sound source such as loudspeakers because τ_e that quantifies the repetitive component of a monosyllable is highly correlated with the percentage of accurately perceived articulation of the monosyllable [7]. This phenomenon simply results from the force applied in the vicinity of the sound source, and complicated calculations, such as those for noise suppression using adaptive signal processing and speech emphasis, and a system that realizes the phenomenon are thus unnecessary. Furthermore, it is possible to increase the SPL and speech intelligibility without additional power consumption.

The present study reproduced the above phenomenon using four types of board, three types of sound sources, and different strengths of pressurization to clarify the characteristics of the phenomenon. Clarification of the characteristics will allow loudspeakers to be developed with higher SPL and speech intelligibility for the same input power and electric power. Using this principle, it is expected that various products, such as the loudspeakers of public address systems, televisions, and car audio systems, will improve as a ripple effect.

The remainder of the paper is organized as follows. Section 2 describes the experimental framework used to evaluate the performance of the pressure applied in the vicinity of the sound source. Section 3 describes results for different sound sources, namely a music box, loudspeaker, and mobile phone. Section 4 summarizes the results and proposes directions of future research.

2. **Methods.** A board and sound source were placed on a wooden table in an anechoic chamber, and the sound generated by the sound source was recorded with an omnidirectional microphone placed 50 cm from the sound source. Figure 1 shows the experimental setting in which a music box and a board are installed. One side of the board was fixed to the wooden table, the other side of the board was fastened with a clip, the clip and the thread fixed to the wooden table were tied, and the pressure applied to the board was varied. Experiments were carried out under three pressure conditions. Pressure was applied only by the weight of the board and the clip itself under the weak pressure condition, by bending the board through 45 degrees under the mid-range pressure condition, and by bending the board through 70 degrees under the strong pressure condition.

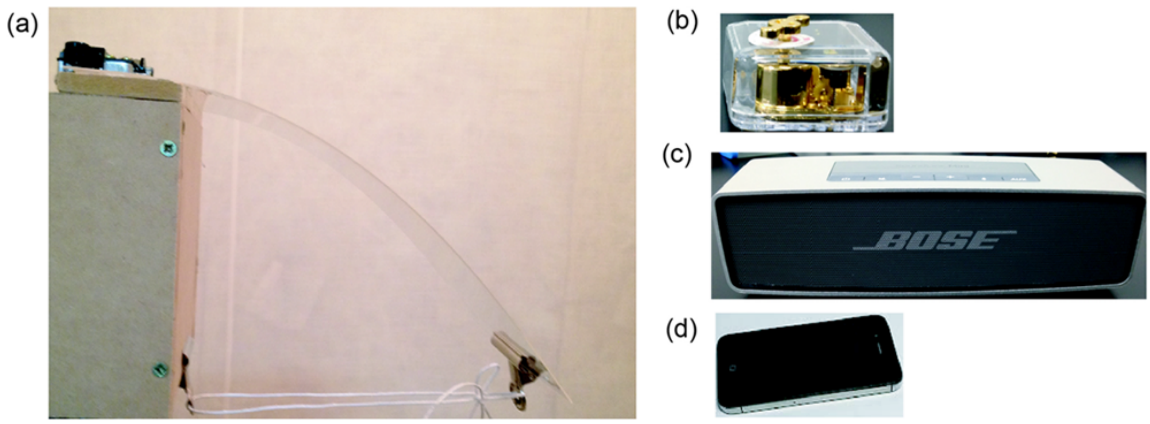

FIGURE 1. (a) Experimental setting and (b) a music box, (c) a loudspeaker, and (d) a mobile phone as sound sources

Two experiments were carried out. In Experiment 1, the effect of the board type, thickness, and bending strength were examined using acrylic boards (AC: 0.5, 1 mm), plastic boards (PL: 0.2, 0.3, 0.5, 1, 1.5 mm), hard vinyl chloride boards (KE: 0.5 mm), and low foaming sheet boards (TE: 1, 2 mm). In Experiment 2, a loudspeaker and mobile phone were used to verify whether the SPL and the repetitive component increase with pressurization near the sound source for existing loudspeakers. Music played through the music box was Let It Go and the loudspeaker and mobile phone were a Motif A (Royal Pavane) and Motif B (Sinfonietta, Opus 48, IV movement, Allegro con brio).

The ACF factors have been proposed previously for sound quality evaluation [8,9]. To calculate the ACF factors, the normalized ACF of the signals recorded from the microphones, $p(t)$, as a function of the running step, s, is defined by

$$\phi(\tau) = \phi(\tau; s, T) = \frac{\Phi(\tau; s, T)}{\sqrt{\Phi(0; s, T)\Phi(0; s + \tau, T)}}, \tag{1}$$

where

$$\Phi(\tau; s, T) = \frac{1}{2T}\int_{s-T}^{s+T} p'(t)p'(t + \tau)dt. \tag{2}$$

Here, 2T is the integration interval and $p'(t) = p(t) * s_e(t)$, where $s_e(t)$ is the ear sensitivity. $p(t)$ is the signal that was measured using the omnidirectional microphone in this study. $s_e(t)$ represents the impulse response of an A-weighted network, including the transfer functions of the human outer and middle ear, for convenience [8,9].

The A-weighted equivalent SPL, denoted L_{Aeq}, was determined from the running step, s. This means that the ACF includes L_{Aeq} as one of its factors. The other ACF factors calculated from the normalized ACF are shown in Figure 2. τ_1 and ϕ_1 denote the delay time and the amplitude of the first maximum peak and are respectively related to the perceived pitch and the pitch strength of the complex sound [8,9]. The other ACF factor, the effective duration τ_e, is defined as the time taken for the ACF envelope to reduce to 10% of its original magnitude, representing the degree of repetitive components within the signal itself. τ_e affects loudness [10]. The A-weighted and 1/3 octave band filtered SPL and τ_e were analyzed in this study.

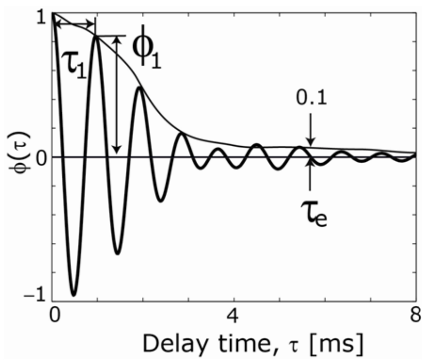

Figure 2. Definitions of ACF factors

3. **Main Results.** Figure 3 shows the effects of the type, thickness, and bending strength of the board on the music box. A higher SPL was obtained with AC and PL boards and a board thickness of 0.5 mm. A longer τ_e was obtained with AC and PL boards that were 0.5 mm thick for the mid-range bending strength.

Figure 4 shows the results of the 1/3 octave band SPL for the music box. There was a pronounced increase in the SPL between 500 and 2000 Hz for a 0.5-mm-thick AC board and 0.5- and 1-mm-thick PL boards. The amplitudes of mid-range frequencies (i.e., the frequency range between 500 and 1000 Hz) of the sound source without pressurization were low while the amplitudes of higher frequencies (i.e., approximately 2000 Hz) of the sound source without pressurization were high. These results indicate that the increase in the SPL due to pressurization near the sound source was a maximum between 500 and 1000 Hz.

Figure 5 shows the increases in SPL and τ_e when applying pressure using the 1-mm-thick PL to the loudspeaker and mobile phone. The SPL only increased under the strong

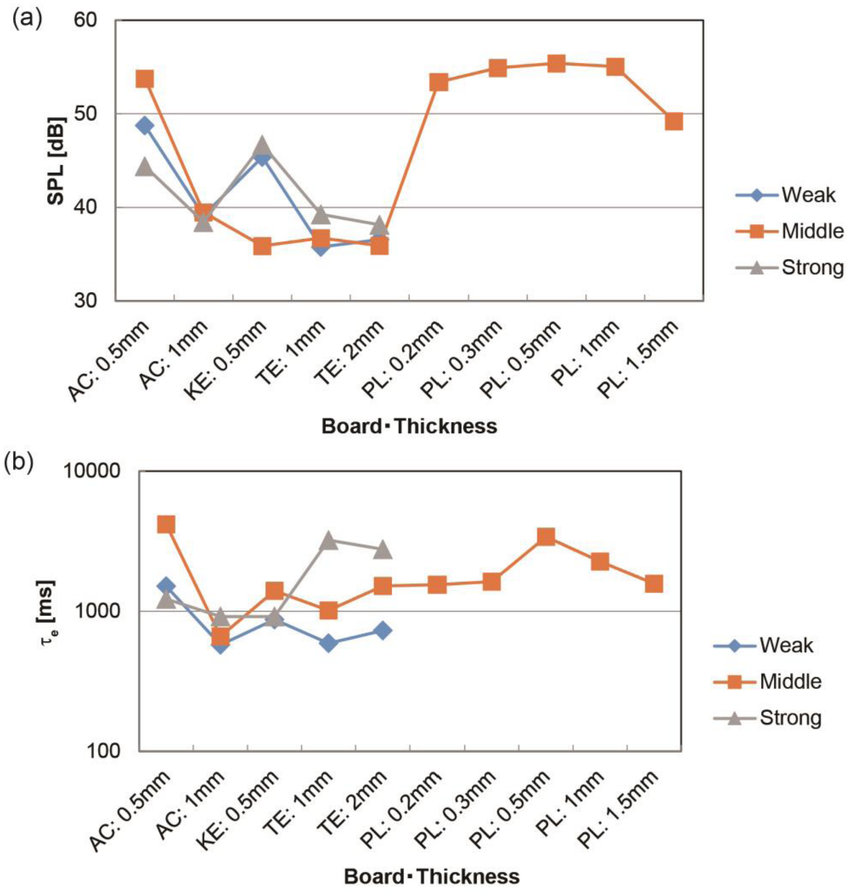

FIGURE 3. Results of (a) the A-weighted SPL and (b) τ_e for the music box

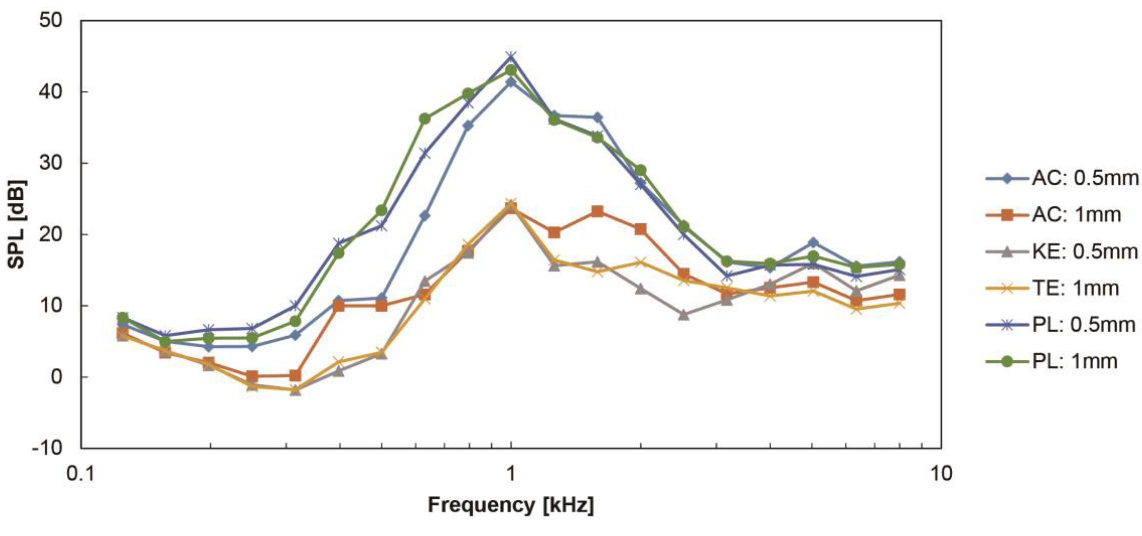

FIGURE 4. Measured SPL as a function of the 1/3 octave band center frequency for the music box

pressure condition while τ_e increased under all pressure conditions for the loudspeaker. The SPL increased but τ_e decreased for the mobile phone. The tendencies that τ_e decreases as SPL increases while τ_e increases as SPL decreases are different from tendencies previously reported [1].

Figure 6 shows the increase in the 1/3 octave band SPL when applying pressure using the 1-mm-thick PL to the loudspeaker and mobile phone. The increase fell to 5 dB or

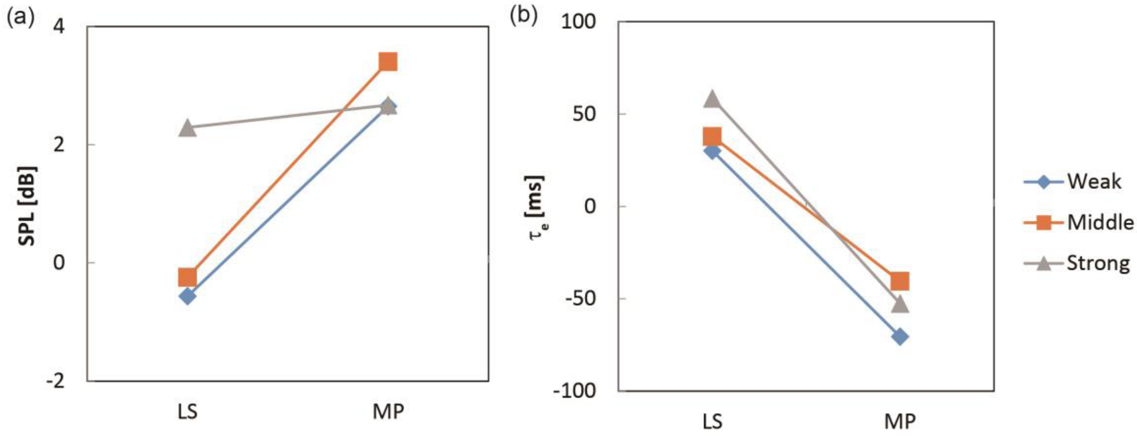

Figure 5. Measured (a) SPL and (b) τ_e for the loudspeaker (LS) and mobile phone (MP) with different strengths of pressurization

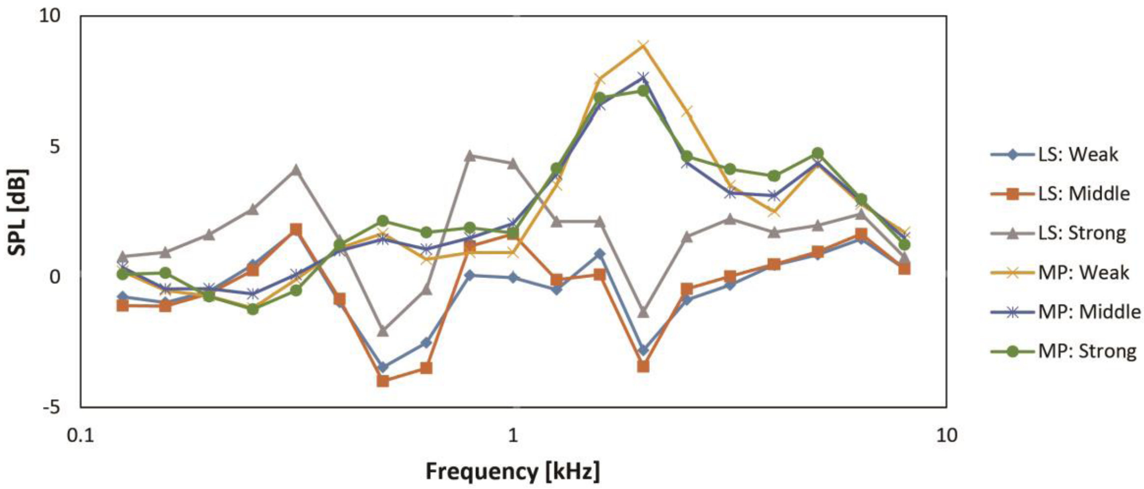

Figure 6. Measured SPL as a function of the 1/3 octave band center frequency for the loudspeaker (LS) and mobile phone (MP) with different strengths of pressurization

less around 500 Hz and 1000 Hz for the loudspeaker. There was a pronounced increase in the SPL around 2000 Hz for the mobile phone.

4. **Discussion and Conclusions.** The present study reproduced the phenomenon of an increase in the sound pressure level (SPL) and the repetitive component when applying pressure using a board near the sound source. Experiments have been carried out under limited conditions in a previous study [1], while the effects of the material and thickness of the board, the strength of the pressure, and the sound sources were investigated in detail in the present study. It was found that acrylic and plastic boards with thickness of 0.5 mm and a mid-range bending strength produced a higher SPL and longer τ_e. It seems that a board with appropriate flexibility (i.e., it is not too soft or hard) can increase the SPL and repetitive components.

In experiments conducted using the loudspeaker and mobile phone, it was possible to confirm the phenomenon of the SPL and the repeating component increase by applying pressure near the sound source in the same way that a music box does. This indicates that it is possible to improve the SPL and clarity of sound generated by the loudspeaker simply by applying pressure near the sound source using a kind of board. However, the increase in the SPL was not as large as that for the music box. This is attributed to the weak contact between the board and the vibration part of the sound source.

In summary, the present study found that the SPL and repetitive components can be increased by applying pressure near the sound source using a flexible board with thickness of about 0.5 mm. This method is applicable to existing loudspeakers. However, there is room for improvement in how to create the pressure. How to apply pressure to the vibration part of the loudspeaker and thus increase the SPL and repetitive components effectively will be examined in future work.

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