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Original Article

Stroking Stimuli to the Ear to Enhance Pleasant and Non-arousing Feelings while Listening to Sounds

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Abstract: We investigated the effects of stroking stimuli near the external auditory meatus on the emotions aroused by the experience of listening to sounds. Previous studies demonstrated that vibratory stimuli to the upper body manipulate emotions while watching videos or listening to sounds; however, none examined the effects of stroking stimuli near the external auditory meatus through which the vagus nerve extends. This study investigated the effects of stroking stimuli to the outer ear on emotions for each of six emotionally evocative sounds that arouse pleasant or unpleasant feelings. They comprised the sounds of rain, shampoo, insects' buzz, and horrifying winds. When the sound stimuli were presented with stroking stimuli at the ear, participants' emotions mostly changed to be more pleasant and sleepy, that is less arousing. These findings are expected to help in the development of haptic interfaces for more emotionally appealing content.

Keywords: Emotion, Natural sounds, Valence, Arousal

1. Introduction

Haptic stimuli to the human body affect emotions when experiencing audiovisual content (Branje et al., 2014; Fukushima et al., 2014; Giroux et al., 2019; Hasegawa et al., 2019; Karafotias et al., 2017; Lemmens et al., 2009; Makioka et al., 2022; Merchel & Altinsoy, 2014; Okazaki et al., 2015; Sakurai et al., 2014; Tara et al., 2023). For example, vibrotactile stimuli delivered through chairs to the torsos are synchronized with movie soundtracks to improve emotional impressions (Giroux et al., 2019; Merchel & Altinsoy, 2014). Furthermore, vibratory stimuli to the epigastric fossa region increase excitement and fear experienced while watching sports and horror videos, respectively (Makioka et al., 2022; Tara et al., 2023). These techniques make audiovisual content more emotionally evocative. Most extant studies have adopted vibratory stimuli to increase or decrease pleasant feelings. However, vibratory stimuli evoke the awake state and may not effectively induce non-arousal (i.e., sleepiness).

This study investigated the emotional effects of stroking stimuli on the external ear while listening to sounds. Most studies selected torsos or hands for stimulation, and few have investigated the external ears. One exception was the study by Fukushima et al. (2014) where they presented vibratory stimuli to earlobes and demonstrated their effects to increase arousing emotions. The vagus nerve monitors and controls visceral activity, and is located near the auditory meatus (Murray et al., 2016; Peuker & Filler, 2002). Mechanical stimulation of the outer ear is linked to various physiological responses (Addorisio et al., 2019; Boehmer et al., 2020; Lee et al., 2023). For example, pressure stimuli to the cymba concha were found to decrease heartbeat ratios (Lee et al., 2023). Such physiological changes are linked with emotions (Kreibig, 2010). Hence, ear stimulation may be an alternative to torso stimulation to induce the emotional effects. Furthermore, unlike earlier studies, we adopted stroking stimuli. Stroking stimuli cause pleasant feelings when presented to the arms (Essick et al., 2010; Lernial et al., 2018; Triscoli et al., 2017). For example, Triscoli et al. (2017) showed that stroking stimuli were perceived as more pleasant and relaxing and increased the variation in heartbeat ratios compared to vibratory stimuli. Hence, we expect that stroking sensations applied to the outer ear will effectively cause pleasantness and sleepiness when listening to emotionally evocative sounds.

In the present experiment, a plastic tactile contactor placed in the participants' ear was rotated by a DC motor to provide the stroking stimuli while participants listened to emotion-inducing sounds. This study is based on the authors' earlier study (Goto et al., 2023), in which only three types of sounds that were largely pleasant and relaxing were investigated. This study advances the previous study by employing six types of sounds evoking a variety of emotions. Hence, this study investigated the emotional effects of auditory stroke stimuli on various sound stimuli. The findings provide a basis for developing new interfaces for emotional haptics.

2. Methods

2.1 Apparatus

The experimental setup is shown in Figure 1. A resin rod fabricated by additive manufacturing (Form 3, Formlabs, Inc., USA; standard white resin) was used as a tactile stimulator for stroking the external acoustic meatus. The rod tip was spherical (12 mm in diameter) with an attached hemisphere (8 mm in diameter). The shape and size were determined such that the external acoustic meatus would be stimulated without damage. Additionally, the contactor tip was smoothed using fine paper. The resin rod was connected to a DC-geared motor (TG-47G-SG, Tsukasa Denko, Japan; reduction ratio: 50) via coupling (Capricorn MRG-20-6-8, Nabeya Bi-tech, Japan). The motor was given speed commands via a motor controller (SyRen 10; Dimension Engineering LLC, USA).

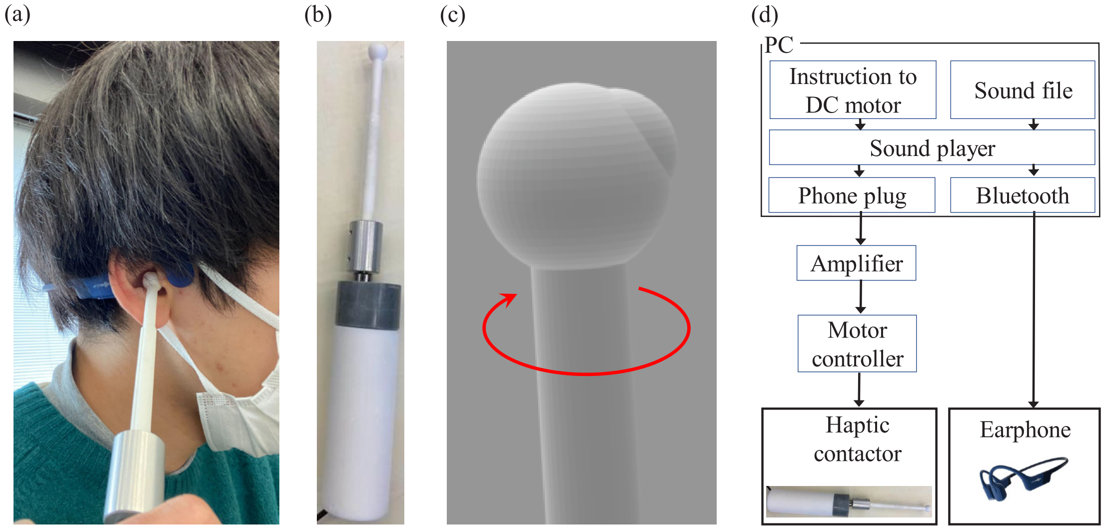

Figure 1: Experimental apparatus: (a) Experimental scene, (b) tactile stimulator, (c) tip of the stimulator, (d) configuration of apparatus.

Figure 2 shows the configuration of the apparatus. The command value of the DC motor was provided through the earphone jack of a personal computer. It was then passed through a non-inverting amplifier circuit using an operational amplifier and input. The motor controller applied a pulse-width modulation signal of 12 V tailored to a sound waveform, as described in Section 2.3.

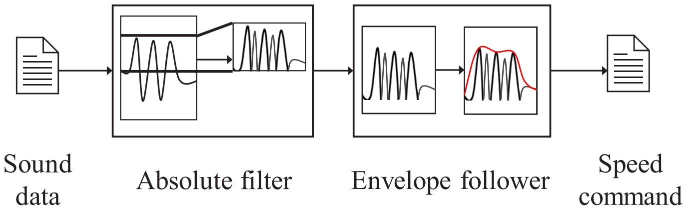

Figure 2: Voltage-speed instruction to the DC motor generated from sound waves.

In addition to tactile stimuli, participants were presented with sound stimuli using bone-conducting earphones (Aeropex, Shokz, USA). We did not use inner ear or canal-type earphones as they would block the external acoustic meatus where the stroking stimulus was applied.

2.2 Sound stimuli

Table 1 lists the six sounds used in the study. Two were from the IADS-E database of emotional sounds (Yang et al., 2018), and four were from YouTube (Google, LLC., USA). Each sound was clipped at a sampling frequency of 44,100 Hz for 30 s. We selected sounds that evoke specific emotions, either pleasant or unpleasant.

Table 1: Audio clips used in the study

Sound name	Description	Reference
Fear 1	Sounds recorded in a windy cave	IADS-E 0209
Fear 2	Monsters' crying sounds	IADS-E 0777
Rain	Sounds of moderate rain	https://www.youtube.com/watch?v=NNLIC0bMdPE
Shampoo	Shampoo sounds recorded at ear positions	https://www.youtube.com/watch?v=RCT8hGGnTjw
Marker pen	Scratch sounds by a felt pen	https://www.youtube.com/watch?v=d_pWifU5hes
Mosquito	Buzzing of the mosquito	https://www.youtube.com/watch?v=mMYGkwiZkXI

2.3 Stroking stimuli to the ear

The plastic rod attached to the DC motor rotated in response to the sound volume. Voltage commands to the motor were generated from the waveform of the audio stimuli using the process shown in Figure 2. First, the audio channel corresponding to the ear to be stroked was extracted from stereo audio channels. Subsequently, the absolute values of the sound output voltage were calculated. Hence, the DC motor continually rotated in a single direction. Finally, the waveform envelope was computed using the *envelope* function in MATLAB (MathWorks, Inc., USA), following the local peaks of the sound signal at 22.7 ms intervals. This value determined envelope smoothness. That is, the DC motor trembled only slightly when the value was small, whereas the motor rotated the rod smoothly when the interval was large. This study did not aim to optimize the stroking pattern; hence, the interval value was adjusted for comfort. The same interval was used for all sounds and participants in the experiment.

2.4 Participants

Twelve healthy participants (nine males and three females) in their early 20s participated in the experiment after providing written informed consent. None of the participants had any experience with the apparatus or knew the purpose of the experiment.

2.5 Procedures and tasks

The experiment comprised two sessions. In the first, the emotional characteristics of each sound were investigated. In the second, we investigated the effects of the stroking stimuli while listening to each sound.

During the first session, individual participants listened to each sound for 30 s and rated eight adjective items representing different emotional states: joyful (*yorokobi* in Japanese), pleasant (*kokochiyoi*), relaxed (*kutsurogeru*), sleepy (*nemukunaru*), depressed (*ochikomu*), unpleasant (*fukaina*), afraid (*kowai*), and awake (*megasameru*), referring to Russell's circumplex model of emotion (Russell, 1980). English and Japanese words were presented simultaneously. The ratings were graded from 1 to 9, ranging from little to very much. The sounds were presented in random order among the participants. One minute of interval was set between two sounds.

In the second session, the participants experienced two successive conditions for each of the six sounds. In the first condition, only the sound was played. In the second, both sound and tactile stimuli were provided as the participants held the stimulator by the grip and maintained contact with the auditory meatus using the tip of the rod. The participants set the contact load and angle between the rod and their ear for comfort, as individual differences in pain and discomfort levels were significant. They were instructed to maintain the same contact condition throughout the experiment while keeping their eyes closed. For a given sound, the sound was played for 30 s under one condition and repeated for another 30 s after a 1 min interval for the second condition. The order in which the two conditions and six sounds were presented was randomized. Participants closed their eyes during the presentation of the audio stimuli. After experiencing an audio stimulus under the two conditions, participants selected the most applicable condition for each of the eight emotional items in a two-alternative forced-choice manner.

2.6 Data analysis

For the 9-graded scores obtained in the first session, the average values among the participants were calculated for each emotional item and the six sounds. From the results in the second session, we calculated the proportion of participants who selected the audio-tactile stimulus conditions for each emotional item across the six sounds. A binomial test was then performed to determine whether each of the eight types of proportions was significantly different from chance, i.e., 0.5 with a Bonferroni correction of factor eight.

3. Results

Figure 3 shows the mean intensities of the emotions reported by the participants for the individual sounds. Fears 1 and 2 were largely judged as horrifying, unpleasant, and depressed. Rain was judged as pleasant, relaxed, and sleepy. The Marker pen and Mosquito were unpleasant and awake. The shampoo did not show salience for any type of emotion. Hence, the six sound types tested in this study exhibited varied emotional features.

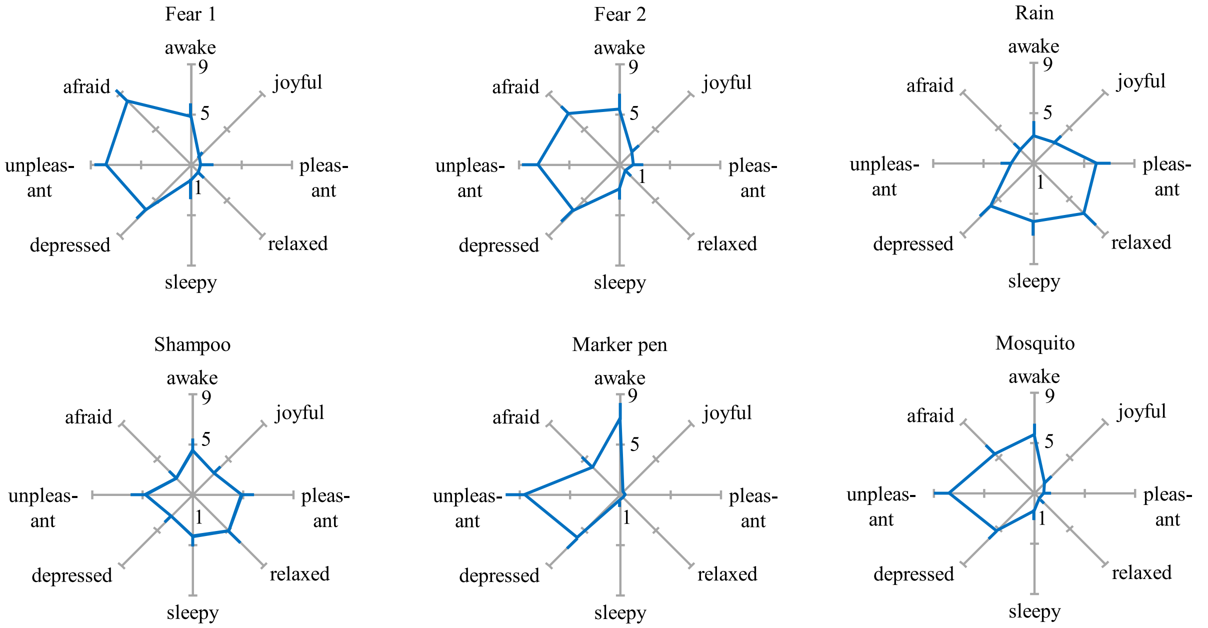

Figure 3: Feelings felt for each sound with no tactile stimuli. Mean values and standard errors among the 12 participants.

Figure 4 shows the proportion of audio-tactile conditions selected as more suitable than the audio-only conditions for each of the eight types of feelings and six sounds. Across the six sounds, similar trends were observed. For example, for Fears 1 and 2 and Mosquito, the audio-tactile condition seemed more relaxing and sleepier, while the audio-only condition seemed to cause fear. For Rain, Shampoo, and Marker pen, the audio-tactile condition seemed more relaxing and pleasant than the audio condition.

Figure 5 shows the average proportion across the six sounds for each emotional item. The audio-tactile condition was judged as more relaxing ($z = 4.01$, $p = 0.0005$), pleasant ($z = 3.77$, $p = 0.0013$), sleepy ($z = 3.06$, $p = 0.0175$), and joyful ($z = 3.30$, $p = 0.0077$) than the audio condition. The audio condition was judged as more unpleasant ($z = 3.77$, $p = 0.0013$), depressed ($z = 3.06$, $p = 0.0175$), and afraid ($z = 4.01$, $p = 0.0005$) than the audio-tactile condition. Apart from awake, one of the two conditions was more frequently selected than the other condition.

4. Discussion

As shown in Figure 5, the stroking stimuli on the auditory meatus influenced the subjectively reported emotions. Figure 6 shows the six types of sounds in Russell's emotional plane (Russell, 1980; Tseng et al., 2014). The coordinates of each sound were determined using the centroid of the radar chart of the corresponding sound, as shown in Figure 3. All sound stimuli were placed in the awake–unpleasant or sleepy–pleasant quadrants. The arrows indicate how the stroking stimuli changed the emotional responses to the sounds. The directions and lengths of the arrows in Figure 6 were determined

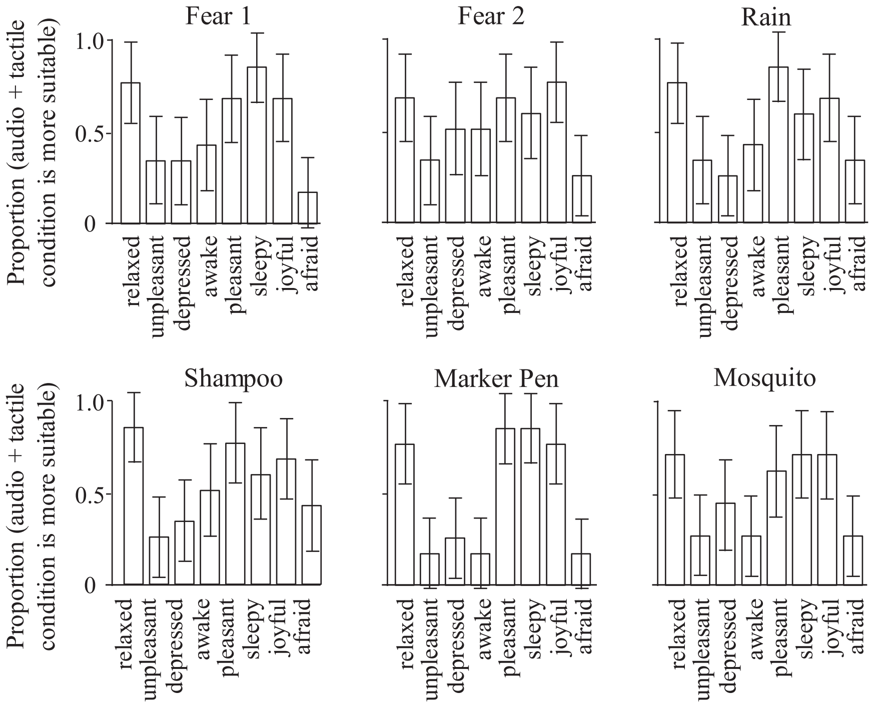

Figure 4: Proportions at which the audio + tactile condition was selected as more suitable to each of the eight emotional attributes. Error bars indicate 95% confidence intervals.

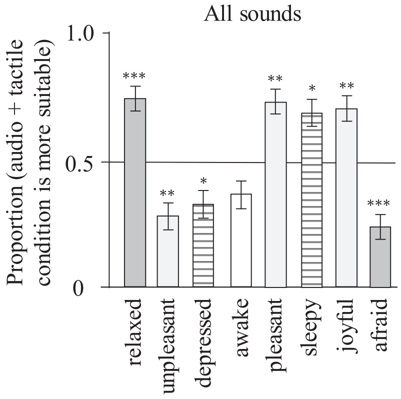

Figure 5: Proportions at which the audio + tactile condition was selected as more suitable for each emotional evaluation item across the six sounds. ***, **, and * indicate significant differences from the 0.5 chance level at $p<0.001$, 0.01, and 0.05, respectively, with a Bonferroni correction of factor eight. Error bars indicate 95% confidence intervals.

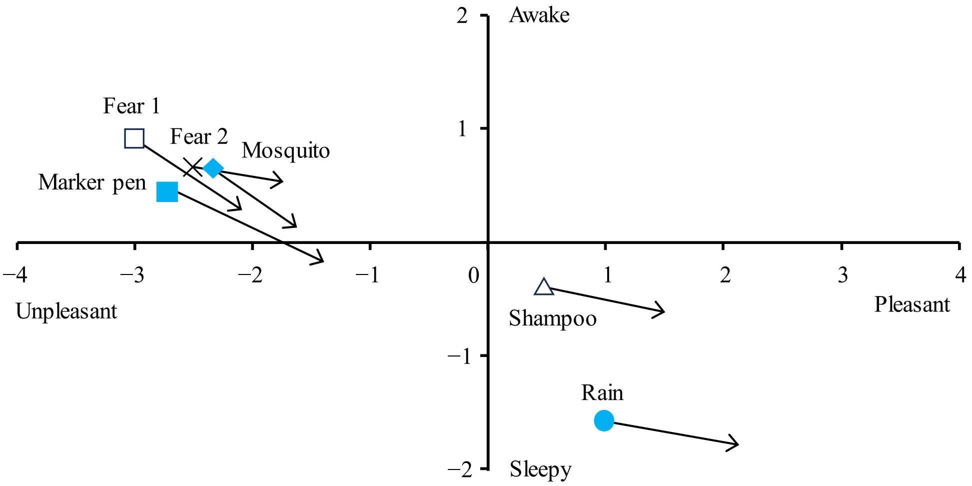

Figure 6: Sound ratings and the amount of change in emotion caused by the presentation of tactile stimuli for each sound clip.

by the results shown in Figure 4. The centroid of the octagonal radar chart, based on the proportions of the eight types of emotions, was calculated for individual sounds. The vector connecting the origin of the chart, at which the eight proportions were zero, to the centroid was considered the effect of the tactile stimuli.

The stroking stimuli made the four sounds in the unpleasant–awake quadrant feel more pleasant and less arousing. Regarding the evaluation of sounds perceived as pleasant and sleepy in the audio-only condition, Shampoo and Rain sounds were judged as more pleasant and sleepy when the stroking stimuli were applied. Thus, tactile stimulation made ordinarily pleasant and unpleasant sounds to become more sleepy and pleasant. As shown in previous studies (Lernial et al., 2018; Triscoli et al., 2017), soft stroking evokes pleasant and non-arousing feelings. The results of this experiment are consistent with those reports. However, as mentioned, no previous studies have examined the effects of stroking stimuli on the ear.

We tested whether the participants' responses were similar for all sounds in an ad hoc manner. For each sound, we applied a goodness-of-fit test using the χ^2 distribution to confirm that the number of participants who selected the audio + tactile condition for the eight items agreed with the expected values. When testing the goodness of one sound, the expected values were calculated based on the responses to the five remaining sounds. None of the sounds were significantly different from the others, suggesting that participants' responses did not depend much on the type of sound (Fear 1 ($\chi^2(7) = 1.59$, $p = 0.98$), Fear 2 ($\chi^2(7) = 2.75$, $p = 0.91$), Rain ($\chi^2(7) = 1.62$, $p = 0.98$), Shampoo ($\chi^2(7) = 3.01$, $p = 0.88$), Marker Pen ($\chi^2(7) = 4.54$, $p = 0.72$), Mosquito ($\chi^2(7) = 1.56$, $p = 0.98$)).

We found some limitations in the study method using Russell's circumplex model. Some sounds could not be localized in the emotional plane. For example, as shown in Figure 3, although Fear 1 gave rise to fear and feelings of depression, they contradicted Russell's emotional plane. Fear is the combination of unpleasantness and arousal whereas depression is that of unpleasantness and sleepiness. Hence, in our experiment, the sound of Fear 1 was judged to be arousal and sleepy that do not coexist in the Russell's circumplex model. Such problems or limitations of the circumplex model have occasionally been pointed out by earlier researchers. For example, vector models may express affect systems in which the axes of arousal and pleasantness are not perpendicular (Rubin and Talarico, 2009; Verschuere et al., 2001). In order to generalize the effects of stroking stimuli to the ear, the experiments need to involve a variety of sounds including music and human voices, although this study did not examine such sounds. Our experiments did not include sounds in the pleasant-arousal and unpleasant-sleepy quadrants. The effects of stroking stimuli on the sounds in such quadrants are unclear. Furthermore, the stimulation method, including the shape of the contactor rod and motor command for the DC motor employed in this study, can be improved in the future. One challenge is the optimization of the stroking stimuli to individual sounds and emotion types. For example, a specific arm-stroking velocity has been found to create comfort sensations (Essick et al., 2010). For the ear, the frequency of mechanical stimulation may be similarly fine-tuned. Nonetheless, Lee et al. (2023) reported a minor impact of frequency on the relaxation effects caused by ear stimulation. The emotional dependencies of various stimuli remain study items for future work.

5. Conclusion

We investigated the emotional effects of stroking stimuli presented to the external auditory meatus while listening to sounds. Six sounds evoking pleasant and unpleasant emotions were used. In a user study involving 12 participants, the stroking stimuli were found to change the emotions evoked by the sounds to more pleasant and sleepy. However, for the generalization of the emotional effects of the stroking stimuli, a variety of sounds should be tested in the future. Our current findings highlight new avenues for research in emotional haptics. We plan to optimize the stimulation method to achieve more intensive effects.

Ethics Statement

This study was approved by the Institutional Review Board of the Hino Campus of Tokyo Metropolitan University (H23-11).

Author Contributions

Y.G.: conceptualization, apparatus, experiment, statistical analysis, and writing of the manuscript. S.O.: conceptualization, supervision, statistical analysis, and review and editing of the manuscript. All authors contributed to the manuscript revision and have read and approved the submitted version.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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