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ORIGINAL ARTICLE

Effect of deep pressure input on parasympathetic system in patients with wisdom tooth surgery

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Background/purpose: Deep pressure input is used to normalize physiological arousal due to stress. Wisdom tooth surgery is an invasive dental procedure with high stress levels, and an alleviation strategy is rarely applied during extraction. In this study, we investigated the effects of deep pressure input on autonomic responses to wisdom tooth extraction in healthy adults.
Methods: A randomized, controlled, crossover design was used for dental patients who were allocated to experimental and control groups that received treatment with or without deep pressure input, respectively. Autonomic indicators, namely the heart rate (HR), percentage of low-frequency (LF) HR variability (LF-HRV), percentage of high-frequency (HF) HRV (HF-HRV), and LF/HF HRV ratio (LF/HF-HRV), were assessed at the baseline, during wisdom tooth extraction, and in the posttreatment phase.
Results: Wisdom tooth extraction caused significant autonomic parameter changes in both groups; however, differential response patterns were observed between the two groups. In particular, deep pressure input in the experimental group was associated with higher HF-

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HRV and lower LF/HF-HRV during extraction compared with those in the control group.
Conclusion: LF/HF-HRV measurement revealed balanced sympathovagal activation in response to deep pressure application. The results suggest that the application of deep pressure alters the response of HF-HRV and facilitates maintaining sympathovagal balance during wisdom tooth extraction.

Introduction

Wisdom tooth extraction is one of the most common procedures associated with a high pain level, high stress, and anxiety regarding applying local anesthesia, and using invasive instruments.[1,2] These extraction procedures commonly lead to unpleasant sensory experiences that may complicate dental procedures,[1,3,4] resulting in inferior postoperative recovery.[5] The sensory dimension of pain is markedly suppressed by local anesthesia; however, reports on anxiety have revealed that a complex combination of cognitive, emotional, and affective factors causes wisdom tooth extraction per se to be unique to the individual.[1,2] Therefore, stress and anxiety management during tooth extraction is crucial for reducing risks and treating patients with high anxiety, particularly those with special needs.[6,7]

The autonomic nervous system (ANS) is crucial for the adaptation to anxiety.[8,9] Heart rate variability (HRV) is typically used as an index to investigate the central regulation and modulation of autonomic functions.[10,11] The ANS, comprising the sympathetic nervous system and parasympathetic nervous system, conveys information regarding autonomic influences on the rate and rhythm of the heart.[8] Although the HR levels are influenced by both sympathetic and parasympathetic activity, parasympathetic influences are pervasive over the frequency range of the HR frequency spectrum, whereas sympathetic influences "roll-off" at approximately 0.15 Hz.[12,13] Therefore, the high-frequency (HF) component (0.15–0.4 Hz) represents a marker primarily parasympathetic; influences with a low-frequency (LF) component (0.04–0.15 Hz) represent a mixture of sympathetic and parasympathetic autonomic influences;[11,13] and the LF/HF HRV ratio (LF/HF-HRV) reflects a predominance of sympathetic over parasympathetic balance.[10,11]

The parameters of HF-HRV have been hypothesized to be crucial in behavioral regulation and emotional adaptation theoretically and empirically.[14–16] Increased HF-HRV (vagally mediated) is associated with enhanced cognitive performance, particularly with the capacity for self-regulation, working memory, and psychological flexibility,[17–19] whereas the relative reduction in HF-HRV is associated with alterations in autonomic control over the cardiac function of behavioral and emotional dysregulation,[20,21] cognitive and behavioral inhibitory deficit,[15,20] and cognitive disorder.[20,22,23] Moreover, neuroimaging studies have indicated positive correlations between HF-HRV and the large number of cortical, subcortical, and brainstem structures that coordinate autonomic function.[17,24,25] In the dental environment, reduced HF-HRV in an attentional task indicates that the cognitive and behavioral regulation function might not provide an appropriate endogenous coping effect to alleviate anxiety in people with dental anxiety.[3] Therefore, exogenous stress management should be considered to be a supplement for stress and anxiety management in tooth extraction.

Deep pressure input is a type of tactile pressure stimulation exerted by firm touching, holding, stroking, hugging, swaddling, and squeezing, and it is carried by the dorsal column-medial lemniscal system to the somatosensory cortex.[26–28] Various modes of deep pressure strategies (e.g., weight blanket, weight vest, and papoose board) have been reported to alleviate feelings of anxiety and produce a calming effect.[28–30] Although physiological evidence is relatively scarce, the application of deep pressure input plays a role in ANS modulation under dental conditions. A few studies have reported a positive increase in HF-HRV, an indicator of emotion regulation, in dental prophylactic treatment with sustained deep pressure input in healthy individuals and patients with special needs;[31,32] however, the participants in these studies underwent dental treatment without anesthetic procedures. Although parasympathetic activity is increased, dental procedure-induced pain is still confounded by deep pressure input in psychological stress alleviation. Because local anesthesia is essential for pain suppression, *in vivo* exposure to deep pressure input during wisdom tooth extraction provides an opportunity for clarifying the contribution of deep pressure input through ANS response in behavioral adaptation for stress management and a calming effect.

The aim of the present study was to evaluate the effects of deep pressure input exerted by a weight blanket during wisdom tooth extraction in healthy adults under local anesthesia. Frequency domain HRV analysis in a relatively painless dental procedure potentially leads to sympathetic and parasympathetic responses during the treatment. We hypothesized that deep pressure input is an effective intervention strategy for altering the parasympathetic response in tooth extraction. In addition, the ANS modulation pattern during tooth extraction was investigated based on the basis of the LF/HF-HRV to verify the effect of deep pressure input.

Methods

Participants

Patients requiring wisdom tooth extraction were eligible to be recruited in this single-blind, randomized, crossover control group investigation in the Division of Oral and Maxillofacial Surgery, Department of Dentistry, National Taiwan University Hospital (NTUH), Taipei, Taiwan. Patients with any one of the following criteria were not included in the study: (1) a history of systemic diseases that would contraindicate surgical treatment; (2) being pregnant or lactating, (3) smoking more than 10 cigarettes/d; (4) poor overnight sleep quality; and (5) refusal to sign the informed consent agreement. The participants signed the informed consent forms and all the procedures were approved by the Human Research Ethics Committee of NTUH. All surgeries were performed under local anesthesia (4% articaine with 1:100,000 epinephrine) by the same oral surgeon using similar techniques and sterilized surgical material. A buccal mucoperiosteal flap was raised and protected using a Minnesota retractor (Hu-Friedy Co., Chicago, Illinois, USA). Lingual flap retraction was performed only if necessary. Sterile low-speed hand pieces and sterile distilled water were used for osteotomy and crown sectioning. The wound was closed with 3—0 silk postoperation.

Deep pressure apparatus

The deep pressure apparatus, a weighted blanket (WB), was fabricated using smooth cotton fabric, 70 cm $\times$ 150 cm, to prevent annoying skin sensations (e.g., scratchy or rough) as described previously.[31] The appropriate weight load for participants was approximately 10% of the body weight,[29,33] and it was adjusted to be distributed evenly over the body of the participant from the axillaries to ankles. Only those in the experimental group received deep pressure input during wisdom tooth extraction.

Experimental design and procedures

The testing was performed in the morning to prevent physiological and physical fatigue in the participants. The temperature of the recording environment was controlled at 22 ± 2.0°C, and the relative humidity was maintained at ~40—50% to prevent artifacts in data acquisition.

Physiological measurements were acquired continually with the participants in identical supine positions to reduce posture effects throughout the treatment periods. Wisdom tooth extraction was divided into two phases. First, data acquisition in the baseline phase (T0) was performed with the individual lying on the dental chair before the dental treatment. Next, the treatment phase (Tx) of wisdom tooth extraction began following local anesthesia administration, and it proceeded with several pauses for rest if required. Two equal treatment time slots for tooth extraction were defined. In the treatment time slot (Tx1), both the control and experimental participants received regular wisdom tooth extraction. In the treatment time slot (Tx2), different treatment conditions were designed for the control and experimental groups. In Tx2, the control group underwent sustained regular tooth extraction as in Tx1. Conversely, the experimental group underwent sustained regular wisdom tooth extraction; however, an adjusted load of deep pressure input was applied simultaneously in Tx2. In the experimental group, Tx1 and Tx2 were sequenced randomly to avoid the order effects of physiological measurement. The shifting point between Tx1 and Tx2 was on a short pause during the entire period of wisdom tooth extraction, depending on the clinical estimation of its requirement. Following wisdom tooth extraction, the individual remained lying on the dental chair for data acquisition in the post-treatment (PTx) phase.

HRV analysis

HR and HRV were determined using a monitor based on photoplethysmography connected to a Bluetooth-based telemetric bioamplifier (Nexus-10; Mind Media B.V., Roermond-Herten, The Netherlands) with a sampling rate of 128 Hz and the Biotrace^{+} software (Mind Media B. V., Roermond-Herten, The Netherlands) for frequency domain processing. The percentages of specific frequencies comprised LF (0.04—0.15 Hz) and HF (0.15—0.4 Hz) components of HRV across the entire spectrum, which were used to indicate sympathetic nervous system and parasympathetic nervous system activation, respectively. The LF/HF-HRV was calculated to yield a measure of sympathetic/parasympathetic balance during tooth extraction.

Statistical analysis

The mean and standard deviation of the data from a demographic survey were analyzed for all participants, and the results were presented as descriptive statistics. Two-way repeated measure analysis of variance (ANOVA) was used to investigate the distinct phases and main effects of HRV. All statistical tests were two-tailed, with the significance level (α) being set at 0.05, and they were performed using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA).

Results

During recruitment, 60 participants were randomized to the experimental and control groups. There was no significant difference between the groups regarding personal characteristics. The demographic characteristics are presented in Table 1. The groups were similar at the baseline.

Results from two-way repeated measure ANOVA revealed a significant effect and interaction effect involving participant groups and treatment phases on HRV indices. For HR, a significant effect was observed only during tooth extraction ($p < 0.001$, $\eta^2 = 0.499$). In HRV, significant effects were observed for response in group (LF-HRV: $p = 0.005$, $\eta^2 = 0.127$; HF-HRV: $p = 0.01$, $\eta^2 = 0.108$; LF/HF-HRV: $p = 0.002$, $\eta^2 = 0.152$), phase (LF-HRV: $p = 0.030$, $\eta^2 = 0.056$; HF-HRV: $p < 0.001$, $\eta^2 = 0.143$; LF/HF-HRV: $p < 0.001$, $\eta^2 = 0.154$), and the phase versus participant interaction (LF-HRV: $p = 0.002$, $\eta^2 = 0.094$; HF-HRV: $p < 0.001$, $\eta^2 = 0.262$; LF/HF-HRV: $p < 0.001$, $\eta^2 = 0.339$).

Figure 1A shows significant differences in HR among the treatment phases. Intragroup data revealed that phases with tooth extraction (Tx1 and Tx2) resulted in higher HR for both the control ($p < 0.001$) and experimental ($p < 0.001$) groups than the phases without tooth extraction (T0 and PTx) did, indicating that wisdom tooth extraction is the stressor to increase sympathetic activity. Moreover, no

Table 1 Characteristics and autonomic response of the study population.

Characteristics & measures	Control ($n = 30$)	Experimental ($n = 30$)	p
Gender (male/female)	15/15	12/18	0.60
Age	24.83 ± 4.62	23.60 ± 4.03	0.28
T0			
HR	74.95 ± 7.07	74.67 ± 12.58	0.92
LF-HRV	43.53 ± 8.74	43.89 ± 13.33	0.90
HF-HRV	41.90 ± 10.67	38.89 ± 13.38	0.34
LF/HF-HRV	1.15 ± 0.51	1.38 ± 0.90	0.22
Tx1			
HR	81.63 ± 8.14	84.16 ± 11.68	0.34
LF-HRV	46.21 ± 7.72	45.41 ± 7.16	0.68
HF-HRV	35.28 ± 10.96	36.83 ± 8.05	0.54
LF/HF-HRV	1.55 ± 0.88	1.28 ± 0.34	0.12
Tx2			
HR	81.22 ± 4.00	74.57 ± 7.65	0.25
LF-HRV	54.20 ± 4.47	48.40 ± 11.86	< 0.001
HF-HRV	23.44 ± 3.92	35.07 ± 12.16	< 0.001
LF/HF-HRV	2.42 ± 0.62	1.60 ± 0.83	< 0.001
PTx			
HR	83.36 ± 9.37	74.68 ± 9.73	0.96
LF-HRV	42.90 ± 6.22	43.96 ± 9.04	0.11
HF-HRV	41.89 ± 7.50	39.11 ± 12.26	0.21
LF/HF-HRV	1.07 ± 0.25	1.29 ± 0.59	0.09

Data are presented as mean ± standard deviation.
HF-HRV = percentage of the high-frequency component of heart rate variability; HR = heart rate; LF/HF-HRV = low-frequency to high-frequency heart rate variability ratio; LF-HRV = percentage of the low-frequency component of heart rate variability; PTx = post wisdom tooth extraction treatment condition; T0 = baseline condition; Tx1 = first treatment phase, regular wisdom tooth extraction without deep pressure input in both the experimental and control groups; Tx2 = second treatment phase, regular wisdom tooth extraction with deep pressure input in the experimental group and without deep pressure input in the control group.

significant difference was observed between the control and experimental groups in all phases of the present study.

Intragroup data indicated significantly higher LF-HRV only for the control group in T0 versus Tx1 ($p < 0.001$) and Tx1 versus Tx2 comparisons ($p < 0.001$; Figure 1B). Intergroup data showed significantly higher LF-HRV in the control group than in the experimental group only in Tx2 ($p < 0.001$), indicating that applying a WB significantly reduced LF-HRV in the experimental group during wisdom tooth extraction.

For HF-HRV, Figure 1C illustrates significant intragroup and intergroup differences in the control and experimental groups. In the control group, HF-HRV was significantly lower in Tx2 than in Tx1 ($p < 0.001$). Conversely, HF-HRV was significantly higher in Tx2 than in Tx1 in the experimental group ($p < 0.001$). Furthermore, intergroup data revealed that HF-HRV was significantly higher in Tx2 in the experimental group than in the control groups ($p < 0.001$). The results indicated that deep pressure input is associated with higher HF-HRV in wisdom tooth extraction, even over a sustained tooth extraction period.

In LF/HF-HRV, significant intragroup and intergroup differences were observed (Figure 1D). In the control group, LF/HF-HRV was significantly higher in Tx2 than in Tx1 ($p < 0.001$), indicating that sustained tooth extraction was accompanied by increasing LF-HRV and decreasing HF-HRV in the control group. Furthermore, LF/HF-HRV was significantly higher in PTx than in T0 ($p < 0.001$), indicating that the tooth extraction-induced effect on LF-HRV was prolonged to the post tooth extraction period in the control group. In the experimental group, LF/HF-HRV was significantly higher in Tx1 than in Tx2 ($p = 0.001$). The intergroup data of the experimental group revealed that LF/HF-HRV was significantly lower than that of the control group only in Tx2 ($p < 0.001$). The results indicated that the effect of deep pressure is accompanied by decreasing LF-HRV and increasing HF-HRV in tooth extraction, even in a phase with a longer intervention period.

In summary, our data revealed that applying a WB alters the autonomic response to wisdom tooth extraction by maintaining LF-HRV, increasing HF-HRV, and reducing LF/HF-HRV.

Discussion

This study investigated HRV in healthy adults undergoing wisdom tooth extraction in response to deep pressure input, to more clearly understand the interrelation of sympathetic activity, parasympathetic activity, and ANS. According to our review of relevant literature, this is the first study investigating the effect of deep pressure stimulation during wisdom tooth extraction. The results from the present study revealed increased HF-HRV, particularly during the application of deep pressure during wisdom tooth extraction. These findings may indicate that deep pressure input increases flexibility/regulation in parasympathetic activity and ANS modulation to alleviate the stress experienced during tooth extraction.

HRV is a quantitative measure that has been used as a marker to characterize autonomic influences (particularly parasympathetic) on the heart, and it has been widely used in understanding cardiac and emotional regulation and their relative associations.[20,21,34] Negative emotions, such as stress and fear, result in parasympathetic withdrawal and sympathetic activity, as represented by a relative decrease in HF-HRV associated with an HR increase. Conversely, positive emotions, such as happiness and calm, result in altered ANS activity, which is characterized by an increase in HF-HRV associated with a decreasing HR.[17,35] Therefore, HRV is commonly used in investigating physiological responses to stress and threats. The results of our cardiac autonomic measurement are consistent with the typical physiological response associated with negative emotions experienced in wisdom tooth extraction (Tx1), namely an increase in HR and a decrease in HF-HRV responses compared with the baseline phase,[21,35] in both the control and experimental groups. Our results indicated that tooth extraction induced psychological stress in the patients, even if local anesthesia was administered. By contrast, alternative, typical, and physiological responses associated with positive emotion significantly reduced HR and increased HF-HRV, demonstrating the effect of

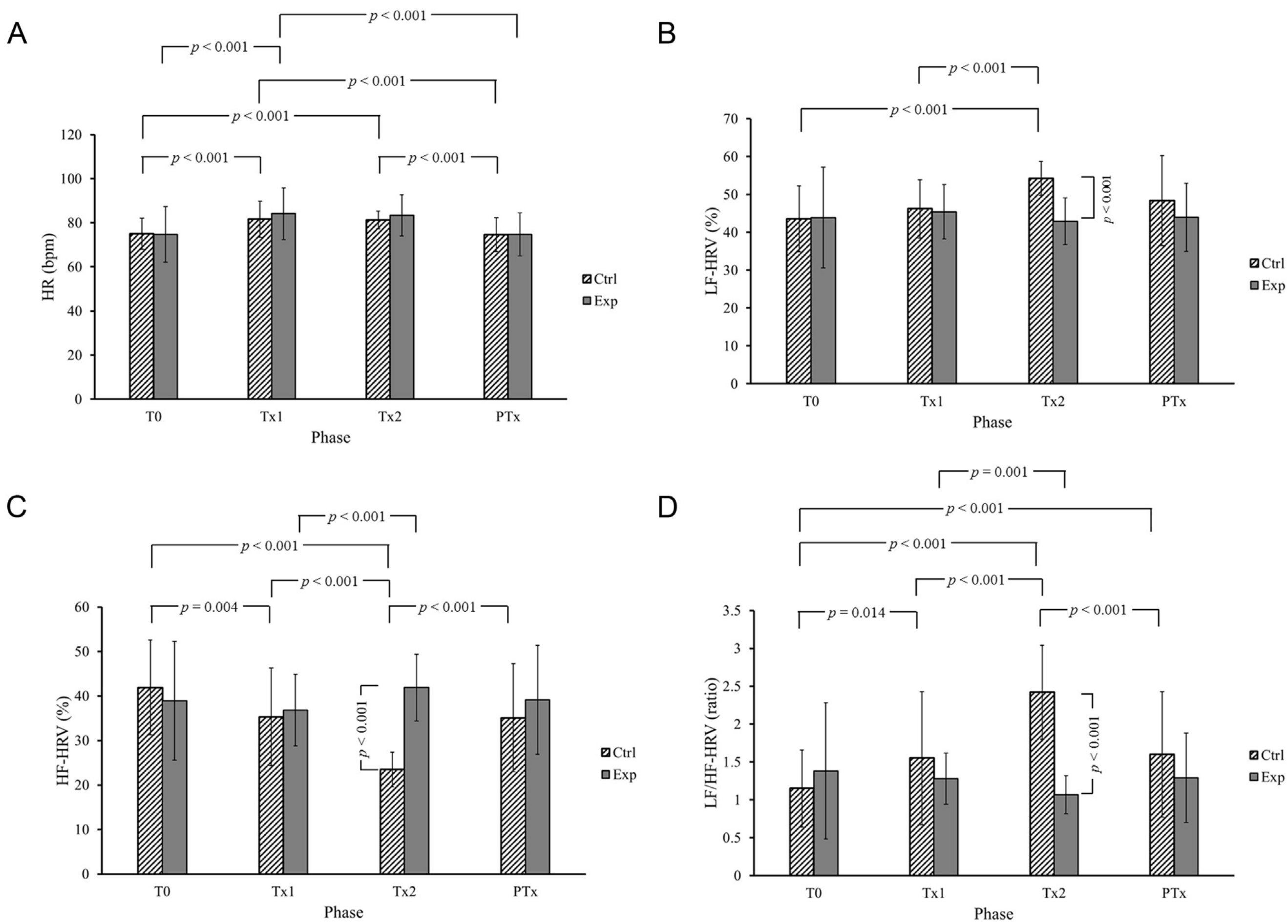

Figure 1 Comparison of heart rate variability parameters between the control and experimental groups during wisdom tooth extraction at the baseline (T0), in the first treatment phase (Tx1) for both the control and experimental groups, in the second treatment phase (Tx2) with deep pressure input in the experimental group and without deep pressure input in the control group, and during posttreatment (PTx). Error bars depict the standard deviation of the mean. Significance according to two-way repeated measurement ANOVA with group and phase entered as within-individual variables and phase and group entered as between-individual variables. bpm = beats per minute; Ctrl = control; Exp = experimental; HF-HRV = percentage of high-frequency component; HR = heart rate; LF/HF-HRV = low-frequency component to high-frequency heart rate; LF-HRV = percentage of low-frequency component.

parasympathetic modulation in the patients in the experimental group. The present findings provide some of the first data clarifying the HF-HRV differences in dental procedure-induced stress between patients receiving and those not receiving deep pressure input.

It is axiomatic by biomedical definition that the ANS contributes to maintenance of homeostasis and proper functioning of the body. Significant correlations were observed between the neural activity of brain regions, such as the anterior cingulate cortex (ACC), insula, amygdala, and hippocampus, and the parasympathetically linked HF-HRV.[13,15,36] According to neuroimaging observations, the areas of the ACC are involved predominantly in cognitive and emotional processes.[36] Dorsal ACC activation is related to cognitive interference tasks, and a study emphasized its role in mediating cognitive processes such as error processing and response inhibition.[24] Therefore, increased dorsal ACC activation is related to response inhibition, affirming its role in processing cognitive information. Contrary to the dorsal ACC, neuroimaging studies have indicated a positive correlation between HF-HRV and ventral ACC activation, which provides evidence of the role of the ventral ACC in parasympathetic nervous system modulation.[13,24] In association with neural modulation, this suggests that enhanced AAC activity may be associated with a reduction in stress-related responses and increased cardiovagal activity under stress. In the present study, deep pressure input resulted in increasing HF-HRV during wisdom tooth extraction, which might reflect the contributions of specific brain regions in stress modulation.

The WB is an apparatus that provides deep pressure input by evenly distributing the load on the torso of the individual. Our results demonstrated significantly higher HF-HRV in the experimental group than in the control group. This result is consistent with previous deep pressure studies, which have reported that deep pressure input alleviates feelings of anxiety and produces a calming effect through the influence of parasympathetic activity in clinical practice.[31,32,37] The use of a WB, having the same conduction pathways as deep pressure massage does, may provide its benefits by shifting the ANS from a state of sympathetic response to a state of parasympathetic response.[29,38] Studies have postulated that, when the pressure receptors beneath the skin are stimulated, the vagal tone increases and the cortisol and skin conductance level decrease.[29,37,39] Therefore, deep pressure input is suggested to lead to homeostasis, which results in improving arousal modulation that is consistent with a state of calmness.[38] In the present study, we observed that higher HF-HRV, the index of inhibitory function, resulting from deep pressure input, is associated with enhanced behavioral regulation and modulation of calming processes, inducing stress management in wisdom tooth extraction.[17] When accompanied by increased HF-HRV, ascending inputs from deep pressure input might function in association with the brain areas having functional neurovisceral activity. Although the mechanism of deep pressure input in increasing HF-HRV is still unclear, cortical interaction between deep pressure input and brain areas with neurovisceral activity is believed to be critical in the processes of ANS modulation in wisdom tooth extraction.

In conclusion, this study investigated the physiological correlations of HF-HRV with the application of deep pressure input under stress during wisdom tooth extraction. We observed substantial consistence between the main effect of deep pressure input and its correlation with ANS modulation, particularly in HF-HRV. The type of physiological measures in HRV is a feasible strategy for objectively assessing ANS responses. Our findings provide empirical evidence that deep pressure input can influence autonomic arousal through enhancement of parasympathetic activation during stress, such as that induced by wisdom tooth extraction. Our results further suggest that deep pressure input may be an appropriate therapeutic modality for use in people with special needs with arousal regulation during or in preparation for stress conditions, such as wisdom tooth extraction and regular dental procedures. Future studies are necessary to further investigate its underlying mechanism and correlation with ANS modulation for application in clinical practice.

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