Comparison of the effect of increased exhalation to inhalation time with mood enhancing and exercise activities on vagal tone estimated from heart rate variability

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Abstract

Background: Vagus nerve regulates various bodily compartments and processes while the body is at rest. Heart rate variability is a trait indicator of vagal tone and psychophysiological adaptability. Lower heart rates and more heart rate variability are typically linked to increased vagal tone. This study examines the effect of different lifestyle interventions on vagal tone and to see how they can affect general well-being.

Method: Sixty participants (N=60, Nfemale =27) aged 18-25 were recruited from Birla Institute of Technology, Mesra and equally divided into experimental and control groups. The participants were put in a controlled laboratory setting in a sitting position where their ECG readings were taken. Informed written consent was taken from all participants.

Results: The fixed breathing with greater exhalation to inhalation ratio and mood enhancing interventions showed increase in RMSSD and HF Power indicating an increase in vagal tone. The exercise intervention showed decrease in RMSSD and HF Power indicating sympathetic activation. The p values for paced breathing, acute exercise and mood enhancing activity was less than 0.05 indicating the statistical significance of the hypothesis.

Conclusion: We concluded that fixed breathing with greater exhalation to inhalation ratio is one of the best ways to relax the body after stress and it is also good for the body in the long term as it shows the maximum increase in vagal tone.

Key Words*: *Heart Rate Variability, HF power, pNN50, mood enhancing activity, paced breathing, RMSSD, short term exercise, SDNN, Vagal tone

1.INTRODUCTION

Vagal tone is the activity of the vagus nerve, which is the tenth cranial nerve, and also a fundamental autonomic nervous system component of the parasympathetic branch. The fundamental role of this unconsciously managed nervous system component is to regulate various physiological compartments while the body is at rest. Vagal activity has a variety of effects, including reduced heart rate, glandular action in the heart, vasodilation of blood vessels, lungs, digestive tract, and liver, immune system regulation, and control of gastrointestinal sensitivity, motility, and inflammation [1, 2].

Vagal tone is typically not directly quantified, instead, measurements of the vagus nerve-affected processes, such as heart rate and heart rate variability (HRV), are made and used to represent vagal tone [3]. Lower heart rates and more heart rate variability are typically linked to increased vagal tone (and hence, enhanced vagal activity). Heart rate variability estimation is a recognized technique for assessing cardiac and emotional health and shows how sympathetic and parasympathetic activity in the autonomic nervous system is balanced. Heart rate variability (HRV) is the physiological occurrence of fluctuation in the time interval between heartbeats. HRV is measured by the fluctuation in the beat-to-beat interval [4].

HRV can be estimated in the time domain, frequency domain, or using non-linear measurements. Even though the root mean square of successive differences between normal heartbeats (RMSSD) categorizes the parasympathetic influences of the autonomic nervous system on cardiovagal tone, time-domain measures are pretty much exclusive variations of the standard deviation of normal to normal R-R intervals (SDNN) that reflect overall HRV [5, 6].

The frequency-domain approach, in contrast to the time-domain, calculates the heart rate's power spectral density distribution into four frequency bands (high [0.15-0.4Hz], low [0.04-0.15Hz], very-low [0.003-0.04Hz], and ultra-low [0.003 Hz] frequency power), allowing for a reasonably excellent separation of the HRV components that represent the sympathetic and parasympathetic nervous systems [7].

The parasympathetic nervous system stimulates the heart's cardiovagal activity, which in turn drives the high-frequency (HF) band of HRV, which corresponds with RMSSD [8].

Notably, therapies including mindfulness meditation and straightforward breathing pattern modification, or "paced breathing," can increase HF-HRV [9-11].

Inhalation results in vagal withdrawal and an elevated heart rate, while expiration results in an elevated vagal tone and a lowered heart rate [12, 13].

When a person believes that their adaptive capacities are being taxed or exceeded by personal or environmental pressures, they experience stress. The "fight-or-flight response," defined by sympathetic nervous system (SNS) dominance over parasympathetic nervous system (PNS) dominance, is a physiological response mechanism that tends to increase heart rate and blood pressure to promote adaptability and energy mobilization. Our mental and physical health typically benefit from this temporary adjustment that occurs after being exposed to a real stressor because it helps us cope with the circumstance [14].

When compared to 1:1 breathing, a breathing pattern with a greater exhalation to inhalation ratio (an E: I > 1) would have larger RMSSD and HF-HRV; indicators of increased parasympathetic impacts on cardiovagal tone [15].

It has been demonstrated that HRV is respiration frequency-dependent, meaning that it declines as the respiration rate rises. With each breath, the respiratory frequency is accompanied by lower trough heart rates, an increase in HRV, and a larger spectral frequency peak. According to the frequency peak data, paced breathing results in a high-frequency peak in respiratory rhythm [16].

In general, a high resting HRV indicates good health and a high tolerance for stress [17], whereas a low HRV indicates a higher chance of developing mental illness and a slower recovery process [18]. Long-term exercise training has been proven to cause resting bradycardia, as well as decreased sympathetic activity and/or increased parasympathetic activity and a significant decrease in intrinsic heart rate [19]. Furthermore, data suggests that regular exercise might reduce stress while also boosting well-being [20].

HRV measurements taken immediately after exercise in different training regiments resulted in distinct variations in HRV. When compared to interval training, HF components during the first hour after exercise were greater with constant intensity training [21]. It appears that exercise can be described as a “double-edged weapon” [22]. Indeed, frequent physical activity increases autonomic function markers such as HRV and baroreflex sensitivity [23], but it is also related to higher sympathetic tone and parasympathetic withdrawal, resulting in a drop in HRV [24]. According to this theory, regular physical activity may result in an optimized HRV for psychosomatic well-being and stress relief. Numerous researches have been conducted to investigate the effects of exercise and exercise training on HRV [25-27].

Since emotions are psychological processes, their experience, and control should be functionally dependent on the condition of the neurological system. Vagal tone is a quantifiable characteristic that contributes to individual and developmental differences in emotion expression and control. Individual differences in the neurological system may impact the expression and regulation of emotions [28].

Mood-enhancing activities or stress-relieving activities are meant to lower the heart rate and therefore elevate the vagal tone. Listening to songs is a renowned way of relieving stress and therefore can be used to test if it decreases heart rate and therefore increases vagal tone.

Most research on the autonomic correlation to emotions has focused on sympathetic activation; here we attempt to design a mood enhancing intervention to regulate emotions that will correlate to parasympathetic activation and therefore show us its relation to vagal tone and therefore the vagal modulation of the heart.

In this current study, we used three different interventions viz. modulation of respiration by changing exhalation to inhalation ratio, acute short-term exercise, and effect of mood-enhancing activity, to check which activity was the best suited to enhance parasympathetic activity and therefore increase vagal tone.

2. MATERIALS AND METHODS

2.1 Study participants

Inclusion criteria:

Healthy young adults aged between 18 to 25 years

60 Participants were recruited from the Birla Institute of Technology, Mesra. The experimental group (EG) consisted of 30 participants between 18 and 25 years of age (17 males, 13 females). The control group (CG) included 30 participants aged between 18 and 25 (16 males, 14 females).

Exclusion criteria:

For both groups included: psychiatric or neurological illnesses, significant hearing trouble that would interfere with task compliance, coronary artery disease due to the known effects of cardiac conditions on HRV [29], active breathing conditions such as chronic obstructive pulmonary disease (COPD) or asthma, and any other acute medical condition.

Informed written consent was taken from all partipipants.

2.2 Biopac Student Lab MP45 for ECG data acquisition

ECG data acquisition was done using Biopac MP 45 instrument setup.

2.3 Kubios HRV Premium (ver. 3.5.0) software for HRV parameter estimation

This software was used to extract time and frequency domain data from ECG recordings done with Biopac. Parameters useful for vagal tone estimation as described by Laborde and his team of researchers are-RMSSD, SDNN, pNN50, HF POWER and HF [30].

2.4 t-test: paired two sample for means using MS excel

The hypothesis testing was done using p- value; for an alternate hypothesis to be true p-value must be less than 0.05 ($p<0.05$) [31]. Statistical analysis includes the calculation of mean and standard deviation of pre and post ECG recordings of time domain parameters like RMSSD, SDNN, p NN50 and frequency domain parameters like High frequency component and HF power.

2.5 Procedures

2.5.1 Physiological measurements

The BIOPAC (Biopac Systems, Inc., California) MP45 system was used to collect all physiological measurements in an upright sitting position [32]. The ECG recording was done at a sampling rate of 500 Hz using a 5-35 Hz electrocardiogram (ECG) and a lead II ECG placement [33].

Figure 1: ECG Recording in LEAD II configuration

2.5.2 Breathing task

Normal breathing

The task began with a 6-minute ECG recording of the participant at normal breathing pattern to adjust the participant to the lab environment and to determine the participants' baseline breathing rate. Participants were told to sit quietly and relax for six minutes while their breathing was recorded. The 6-minute baseline recording was used to calculate the mean duration of inhalation and exhalation phases, the mean number of entire breathing cycles per minute, and the E: I ratio. The control task design block is described in Figure 2.

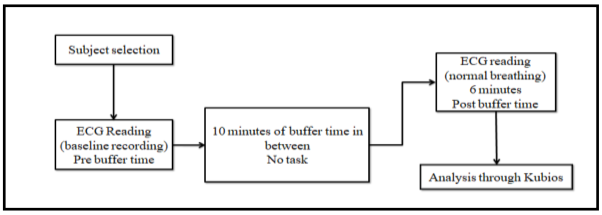

Figure 2: Workflow for control (normal breathing)

Respiration rate

The chest belt provided to measure the respiration rate of the participants was found to be uncomfortable and restricting so the respiration rate was measured manually with the help of manual observation with a stopwatch. The respiration rate for the experimental procedure was taken as 6 bpm which was determined as the most comfortable breathing rate among the participants.

Task design

The experimental fixed breathing task consisted of breathing with an exhalation rate that was higher than the inhalation rate. The participants were asked to listen to an audio that included auditory cues according to the task design. The sound cues consisted of 4 seconds of inhalation and 6 seconds of exhalation. This was designed for 6 breaths per minute and we recorded for 6 minutes to achieve a sufficient length of time for proper analysis through Kubios. The experimental task design is illustrated in Figure 3.

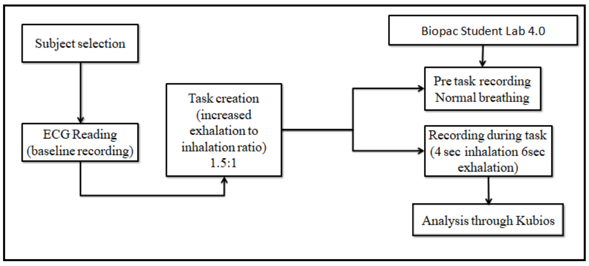

Figure 3: Workflow for the experimental task (breathing at a fixed E: I ratio)

Experimental procedure

During the fixed breathing task, the participants listened to the auditory cues using earplugs to minimize distractions from other sounds in the environment. To prevent motion artifacts from affecting the ECG data, they were instructed to unwind, keep calm, and limit movement. The participants were asked to remove any electronic gadgets on them like smartwatches and mobile phones and were told to stay away from laptops to minimize the effect of electromagnetic field on the ECG.

2.5.3 Physical exercise task

To get the subject used to the lab setting and determine their baseline breathing rate, the task started with a 6-minute recording of their normal breathing pattern. For six minutes, participants were advised to sit still and decompress while their ECG was recorded.

The participants were given instructions to walk for 10 minutes at a speed of 3 on the treadmill that was set up in the lab as part of the experiment. The ECG recording was then done for 6 minutes at a fixed E: I ratio (1:1- 4 seconds exhalation and 4 seconds inhalation) after the initial 10 minutes had passed. To prevent introducing distortions into the ECG data, they were urged to relax, be quiet, and move as little as possible. The experimental task block is shown in Figure 4.

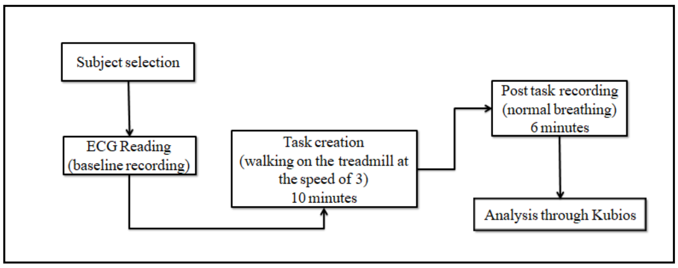

Figure 4: Workflow for the experimental task (short-term exercise)

2.5.4 Mood-enhancing activity task

A survey was conducted to find out the most relaxing activity in young healthy adults. 100 participants filled up the survey which concluded working out was the most preferable activity 33%) followed closely by listening to songs 28%), watching funny videos (18%), watching a movie (7%) and cooking (5%). This survey was used as a base for creating the third task. As working out has already been used as one of the experimental tasks we chose to go with the second most relaxing activity according to the survey.

The participants were told to sit and relax while their baseline ECG was recorded as in the previous tasks. All the participants were asked to plug in the headphones and listen to the songs which are relaxing to them for 10 minutes. After that the ECG recording was done again for 6 minutes at a fixed E:I ratio (1:1- 4 seconds exhalation and 4 seconds inhalation). To avoid distortions and noise in the ECG data they were told to relax, be quiet and move as little as possible. The experimental task block is shown in Figure 5.

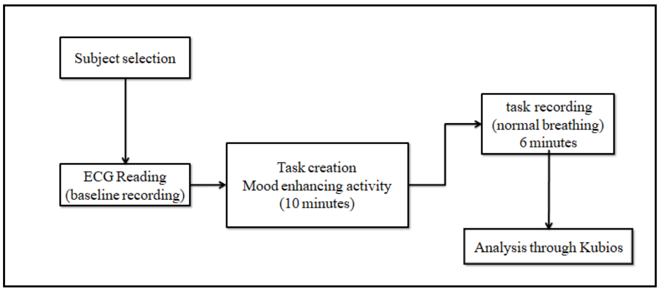

Figure 5: Workflow for the experimental task (Mood enhancing activity)

3. ANALYSIS

Analysis was performed on the Kubios premium software where the standard HRV analysis was used to visualize the R-R time series, the time domain results, the frequency domain results, and the non-linear results. We have used the time domain results and the frequency domain results to assess the HRV parameters which are the best indicators of vagal tone according to the guidelines of Laborde et al., 2017 and the Task Force guidelines of Malik 1996. The time domain parameters taken for this study are SDNN, RMSSD, and pNN50 and the frequency domain parameters are HF power and LF/HF ratio. The analysis feature on the Biopac student software gives a variety of options where we chose the Heart Rate Variability analysis option. The HRV analysis options show us the R-R interval, raw tachogram, interpolated tachogram, and the spectrum of the graph; we used the R-R intervals in the ECG to analyze the HRV parameters. To test the hypothesis that an increased E: I ratio in the 2:1 task condition would be linked with larger HRV than a 1:1 breathing condition, mean RMSSD, SDNN, and HF-HRV values in the 2:1 task block were compared to a control group of participants with a 1:1 E: I ratio. The values of each participant's pre and post paced breathing were also compared and then compared to the control group with normal breathing. The post-exercise task breathing was compared to the 1:1 pre-task normal breathing and then to the control group to compare the acute effect of exercise on HRV parameters.

For the third intervention; the post mood enhancer task 1:1 breathing was compared to the pre-task 1:1 breathing and then with the control group to check if the hypothesis about relaxing activity is valid.

Statistical analysis was done in MS Excel with the help of the data analysis option. We did the t-test: Paired Two Sample for Means and found the p-value for both the one-tailed test and the two-tailed test. Since we assumed the confidence rate for our hypothesis is 95%, therefore, our α value is 0.05.

4. RESULTS

Based on the data collected and analyzed as shown in Table 1, it was found that there was a significant difference between the control and experimental group in terms of heart rate variability.

This indicates that the intervention implemented in the experimental group, had a modulating effect on the participants' autonomic nervous system.

Vagal tone refers to the activity of the vagus nerve, which plays an important role in regulating the parasympathetic nervous system. The parasympathetic nervous system is responsible for the "rest and digest" response, which helps the body to relax and recover. An increase in vagal tone suggests that the parasympathetic nervous system is more active, which is associated with improved health outcomes, including reduced stress levels and improved immune function.

The results showed that for the first intervention the experimental group had a significant increase in the vagal tone parameters, as compared to the control group. Specifically, the experimental group showed an increase in SDNN, RMSSD, pNN50, and HF power, which are indicators of increased vagal tone. The LF/HF ratio, which is an indicator of sympathetic-parasympathetic balance, showed a decrease in the experimental group, indicating a shift towards parasympathetic dominance.

The second intervention which was based on the acute effects of exercise showed sympathetic activation and therefore parasympathetic withdrawal. It showed a decrease in SDNN, RMSSD, pNN50 and HF Power which shows sympathetic activation and the LF/HF ratio showed an increase suggesting the same.

The third intervention, mood enhancing activity showed significant changes; it showed an increase in the SDNN, RMSSD, pNN50, and HF power indicating parasympathetic activation. The increase in the values was not as good as paced breathing but it still proves the hypothesis that mood-enhancing activities like listening to songs can actually modulate vagal tone and therefore heart rate variability.

Therefore, the results suggest that the interventions 'paced breathing' and 'listening to music' implemented in the experimental group were effective in improving the participants' autonomic nervous system functioning, which may have important implications for their overall health and well-being.

Table 1: HRV parameters (mean values) in young adults (N=30)

Intervention	SDNN (ms) ±SD	RMSSD (ms) ±SD	pNN50 (%) ±SD	HF Power (n.u) ±SD	LF/HF ratio ±SD
Pre control breathing	45.82±3.72	38.63±3.85	15.77±2.45	34.65±3.48	3.12±0.53
Post control breathing	47.78±3.36	39.42±3.92	16.12±2.74	33.4±3.6	3.11±0.43
Normal respiration	47.02±4.0	42.3±5.3	18.14±3.3	16.08±1.54	8.38±1.44
E: I (1.5:1) respiration	77.11±6.13	50.35±5.42	20.77±2.65	36.1±3.82	3.11±0.58
Pre-exercise breathing	47.02±4.0	42.3±5.3	18.14±3.3	35.7±3.57	3.7±0.63
Post-exercise breathing	37.58±2.48	29.1±2.55	9.63±1.96	29.55±2.65	3.11±0.58
Pre activity Breathing	38.19±3.06	32.72±3.67	11.84±2.55	30.88±3.07	3.39±0.51
Post activity Breathing	44.71±4.11	37.65±3.93	17.93±3.45	37.23±3.52	3.14±0.58

Based on the p values given in Table 2 it was found that for the first intervention i.e. with fixed high E: I ratio (1.5:1) breathing; the p values in the both one-tailed and two-tailed test was less than the α values showing a significant rise in the HRV parameters which verified the proposed hypothesis that paced breathing or increased exhalation time to inhalation time can increase vagal tone.

For the second intervention i.e. acute short-term exercise, the p values for both the tests were less than the α values indicating that the hypothesis saying that acute exercise increases heart rate and therefore decreases vagal tone is statistically correct.

Table 2: p values for one-tailed and two-tailed tests for all the interventions

	SDNN (ms)	RMSSD (ms)	pNN50 (%)	HF Power (n.u)	LF /HF Ratio
Respiration	P(T<=t) one tail=1.22E-080.0000000122 P(T<=t) two tail=2.43E080.0000000243	P(T<=t) one tail=0.0055 P(T<=t) two tail=0.011	P(T<=t) one tail=0.091 P(T<=t) two tail=0.18	P(T<=t) one tail=3.79E-060.00000379 P(T<=t) two tail=7.57E060.00000757	P(T<=t) one tail=0.000227 P(T<=t) two tail=0.000454
Exercise	P(T<=t) one tail=0.0013 P(T<=t) two tail=0.0026	P(T<=t) one tail=0.00129 P(T<=t) two tail=0.00257	P(T<=t) one tail=0.00018 P(T<=t) two tail=0.00036	P(T<=t) one tail=0.014 P(T<=t) two tail=0.029	P(T<=t) one tail=0.0816 P(T<=t) two tail=0.163
Mood enhancing activity	P(T<=t) one tail=0.054 P(T<=t) two tail=0.108	P(T<=t) one tail=0.116 P(T<=t) two tail=0.233	P(T<=t) one tail=0.019 P(T<=t) two tail=0.039	P(T<=t) one tail=0.022 P(T<=t) two tail=0.044	P(T<=t) one tail=0.334 P(T<=t) two tail=0.669

For the third intervention i.e. mood-enhancing activity the HRV parameters like SDNN, pNN50, and HF power showed p values less than α but RMSSD and LF/HF ratio was a bit higher than α, indicating that parameters which are most efficient for showing changes in vagal tone were following the theory of alternate hypothesis.

5. DISCUSSION

The purpose of this study was to compare different interventions to assess their effect on breathing and heart rate variability which could indicate the increase or decrease in the vagal tone. We specifically compared the effects of cued 1.5:1 (exhale 1.5 times as long as inhale) and cued 1:1 (equal exhale and inhale) breathing.

In line with our theory, vagal tone indicators such as RMSSD and HF power increased significantly in the 1.5:1 task block compared to 1:1 normal breathing. These findings show that prolonged exhalation time compared to inhalation time affects central cardiac autonomic control rather than being a result of the longer time window during exhalation that maximizes the capacity to observe the effects of cardiac vagal control. Our findings are consistent with the fact that paced breathing or E: I>1 increases HRV parameters showing an increase in vagal tone [15] but the breathing pattern used there is not comfortable with everyone, therefore we have used a more comfortable ratio which is 1.5:1 (4-second inhalation and 6-second exhalation). Deep breathing or paced breathing affects all the HRV parameters suggesting an increase in vagal tone [34] and not only in one or two parameters from which deduction is hard. Paced breathing at a cardiovascular system resonance frequency results in a significant rise in HRV, as observed in a study by [35, 36]. Paced breathing and respiratory interval do not affect the spectral components of HRV and support the concept that increasing respiratory interval amplifies the respiratory-related vagal modulation of heart rate [37].

These results suggest that paced breathing, with a specific exhalation-inhalation ratio, may be an effective technique for increasing vagal tone and promoting parasympathetic activity. However, it should be noted that the study design was limited by the relatively small sample size and the use of only one type of breathing pattern for the experimental group. Future research with larger sample sizes and different breathing patterns may provide further insights into the effects of paced breathing on HRV parameters.

Heart rate variability, on the other hand, refers to the variation in time between successive heartbeats. Higher heart rate variability is connected with better health outcomes, such as better cardiovascular health and a lower risk of chronic diseases. The quick increase in heart rate at the start of exercise is caused by a decrease in cardiac vagal tone [38] which is established in this current study using the HRV parameters showing a decrease in their values from the pre-exercise values.

The acute effect of exercise can be seen as an increase in sympathetic activity; however regular physical activity and exercise may increase parasympathetic dominance in the long run [39]. Moderate-intensity exercise training hastens post-exercise vagal reactivation [40]. Hence continuous exercise training is important in maintaining a higher vagal tone.

Several studies indicate that HRV measures are important in analyzing the stress that the body experiences during training and in gaining insight into physiological recovery after training [41]. Future research can be done based on this hypothesis and its effect on long-term exercise.

The relationship between vagal tone and emotions has not been widely hypothesized previously, but some studies show that baseline levels of cardiac vagal tone and vagal tone reactivity abilities are associated with behavioral measures of reactivity and emotional expression [28], so we hypothesized that vagal tone can serve as an indicator of emotional regulation.

Higher HRV would be associated with improved subjective well-being, as shown by improved mood and higher life satisfaction [42] but the limitation of the study was they didn't know if HRV was giving a positive effect or a positive effect was increasing HRV but in this hypothesis, we are creating a positive mood which is related to increase in HRV which is later shown in the HRV parameters showing an increase in vagal tone. Vagal activation appears to be crucial for good emotional response control [43], our hypothesis shows parasympathetic activation and therefore an increase in vagal tone due to positive mood-enhancing activity.

6. CONCLUSION

In summary, we demonstrated three interventions related to vagal tone and its corresponding parasympathetic or sympathetic activation. Out of these three, breathing at higher E: I ratio and mood-enhancing intervention works well for parasympathetic activation and therefore in increasing vagal tone and indicating that it can relax your body after stress.

Our second intervention about acute short-term exercise indicates sympathetic activation but after a long period of exercise can help in parasympathetic dominance and can improve stress and body function over time. Out of our two interventions that increase vagal tone paced breathing has shown significant changes as compared to the mood-enhancing activity, therefore we can conclude that fixed breathing at higher E: I ratio is one of the best ways to relax your body after stress and it is also good got your body in the long term as it shows the maximum increase in vagal tone.

Declarations

Ethical approval and consent to participate
Informed consent forms were signed by participants

Consent for publication
The authors consent to their work being published

Data availability
All the data has been included in the manuscript

Competing interest
On behalf of the authors, the corresponding author declares that there is no conflict of interest

Funding source
None

Clinical trial registration
Not applicable

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