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Original Article

Slow Deep Breathing Increases Pain-tolerance and Modulates Cardiac Autonomic Nervous System

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Abstract

Objective: Baroreceptor activity has been implicated in pain modulation. Baroreceptor stimulation by means of slow deep breathing (SDB) can be used as a clinically useful intervention for pain modulation. SDB is the basic component of 'Pranayama' (breath control) and 'Dhyana' (meditation). Therefore, we tested the hypothesis that SDB decreases pain perception and increases cardiovagal baroreflex sensitivity.

Methods: In 30 healthy participants, pain-threshold and pain-tolerance were assessed before and after SDB (6 breathes/minutes for 5 minutes). Exposure to cold water (5ºC) was used for pain induction. Electrocardiogram (ECG) and continuous blood pressure (BP) were recorded using Biopac MP150 (BIOPAC Systems Inc., USA). These signals were analyzed using the Nevrokard(version 6.4.0 Slovenia).

Results: Pain tolerance was high after SDB (p=0.008) as compared to spontaneous breathing. The pain-threshold showed no difference. Heart rate variability (HRV) measures of parasympathetic activity, such as standard deviation of the R–R intervals (SDNN) and root mean square of successive differences between adjacent R–R intervals (RMSSD) were higher during SDB than during spontaneous breathing (both p<0.05). Low frequency (LF) power was high (p=0.001) and high frequency (HF) power was low (p=0.003) during SDB than spontaneous breathing. LF α-index BRS was high during SDB (p=0.03).

Discussion: Our study shows that pain-tolerance increases after SDB which could be due to modulation of autonomic nervous system. However, the small magnitude of changes in pain perception suggests that factors other than autonomic control may underlie the effects of breathing techniques on pain modulation.

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Introduction

Stimulation of baroreceptors through a generalized inhibition of the central nervous system produces an antinociceptive effect (1). The modulation of baroreceptors induced by slow deep breathing may

be beneficial due to an increase in baroreflex sensitivity (BRS) (2). Slow deep breathing (SDB) is the basic component of 'Pranayama' (voluntary control of breath) and 'Dhyana' (meditation) and is increasingly being recommended as a complementary approach to standard medical care for the induction of the relaxation. SDB also reduces anxiety and stress (3, 4). Despite the popularity of this intervention, there is a lack of experimental evidences to validate the effect SDB on pain perception and understand its underlying mechanism. SDB (6 breaths/minute) increases pain-threshold, tolerance and reduces the negative 'affect' ratings following thermal pain (5, 6). Busch identified that SDB, in concert with relaxation, is an essential component in the modulation of pain perception (7). However, a recent study could not confirm the antinociceptive effects of deep-and-slow breathing (8). Pain ratings were not affected by breathing patterns but are significantly lower during inspiration as compared to expiration (9). It is still not clear whether voluntary control of respiration will affect pain perception and cardiovagal baroreflex sensitivity. Therefore, it is hypothesized that slow deep controlled breathing reduces pain perception and acutely enhances cardiac autonomic activity and baroreflex sensitivity.

Material and Methods

Study participants

The study was conducted at the All India Institute of Medical Sciences (AIIMS), Jodhpur, Rajasthan and thirty young healthy volunteers (males and females in equal numbers) aged 18 to 25 years were recruited for it. The protocol was approved by the institutional ethics committee. All the participants of the study were healthy volunteers with no prior history of any adverse health condition. They were informed about the study protocol and provided informed consent to participate in the study. They were not given any hints about the hypothesis of our study. Exclusion criteria for the study were (i) consumption of painkillers or any other medications known to interfere with the pain pathways, (ii) history of cardiovascular disease, chronic pain, diabetes, fibromyalgia, fainting, seizure, and/or Reynaud's phenomenon, (iii) frostbite or any cut, sore or fracture of the hand to be immersed in water.

Study protocol

Since previous studies show high inter-individual differences in cold perception or tolerance, a pre-test *vs* post-test design was used. Assessments were done at the same time of the day (± 1 hour) to offset the effect of circadian rhythm. All the assessments were done atleast 2 hours after the latest meal and 4 hours after the last in take of caffeine containing beverages. To minimize the hormonal influences on pain perception, females were tested during the second week after their last menses. Participants were asked to sit on a comfortable chair and familiarize with the experimental setting. The experiment started approximately 10 minutes after the placement of electrodes and stabilization of autonomic parameters. Electrocardiogram (ECG), continuous blood pressure (BP) and chest movements were recorded during baseline and experiments. The timeline of the procedure is given in Fig. 1. For induction of pain the participants were asked to immerse his/her non-dominant hand upto the wrist in ice cold water bath (5°C) for 4 minutes. The cold water exposure was stopped as soon as the participant reported unbearable pain (pain-tolerance, minutes) and was terminated at 4 minutes in the subjects not complaining of pain. To avoid motion artefacts in signals, participants were instructed before immersion to declare when they first began to feel pain (*pain-threshold*: time from immersion) by saying 'now'. Pain tolerance was taken as the difference between the total duration of cold water exposure (time of immersion, minutes) and the pain-threshold. After a baseline experiment for exposure to cold water (CWE1) the participants were asked to take controlled slow deep (device-guided) breaths (6 breaths/min for 5 min). Finally, participants completed a second cold water exposure (CWE2) identical to the first during which the participants were again assessed for the pain-threshold and pain-tolerance (10, 11).

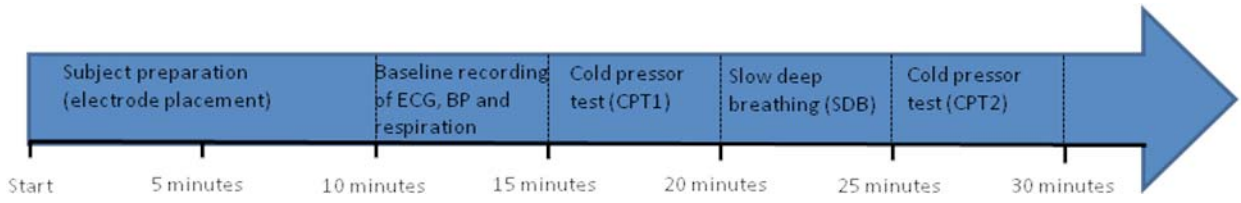

Fig. 1 : Representation of timeline of the procedures of pain stimulus and breathing trials.

Slow deep breathing (SDB)

Audio-based device guided instructions on the method of respiration were given to all participants at a fixed frequency of 6 breaths/minute for 5 minutes (5 seconds inhalation, 5 seconds exhalation).

Data acquisition

ECG and chest movements (for respiration) were acquired using the computer based digital data acquisition system Biopac MP150 (BIOPAC Systems Inc., USA). Biopac MP150 was connected to a personal computer by ethernet interfacing and signals were acquired using software Acknowledge (BIOPAC Systems Inc., USA) pre-installed on the computer. Lead II ECG and chest movements were acquired using the bio-potential amplifier ECG BIONOMADIX (BN-TX RSPEC-3.0) with the help of shielded cables and disposable Ag-AgCl electrodes. Chest movements were acquired using the sensor for recording expansion. The belt for recording chest movements was wrapped around the chest at the level of the 4th intercostal space rib. The software automatically detected QRS complexes and discarded artefacts/ abnormal beats. The distances between consecutive R waves were computed. BP was recorded using Continuous non-invasive blood pressure monitor (CNAP, CNSystems, Austria). The BP signal was fed into the same platform using DA100C amplifier for Biopac MP150 (BIOPAC Systems Inc., USA). All the biological signals were recorded in the sitting position during spontaneous breathing, CWE1, CWE2, and SDB. Sampling rates for acquiring signal was set at 1 kHz.

Cardiac autonomic activity analysis

The non-invasive measure of cardiac autonomic activity involves the analysis of heart rate variability (HRV). The short-term HRV analysis was done from the ECG signal acquired during spontaneous breathing and SDB. R–R intervals from ECG signals were detected using Nevrokard software (Nevrokard, version 6.4.0 Slovenia). HRV analysis was carried out in three standard domains for evaluating the autonomic control of the heart: time domain, frequency domain, and non-linear (Poincare) measures (12).

Cardiovascular baroreflex sensitivity (BRS) assessment

Baroreflex sensitivity was determined by the 'spontaneous method'. Spontaneous sequences were defined as three or more consecutive cycles of systolic blood pressure elevation (up-sequences) or decrease (down-sequences) coupled with RR interval changes in the same direction. The BP and RR interval change limit was set at 0.5 mmHg and 5 ms respectively for 3 heart beat and sequences with a correlation coefficient >0.85 were accepted for further analysis. Up- and down-sequences were collected and averaged separately, yielding up-sequences BRS and down-sequences BRS values. Spectral baroreflex gain was calculated using cross-spectral analysis of RR intervals and systolic arterial pressure (SAP). The low frequency (LF) range limit was set at 0.04 0.15 Hz and LF cross-spectral alpha index (β-index) was calculated as the square root of the ratios of systolic arterial pressure (SAP) and RR intervals powers (LF alpha) (13). Analysis was performed using Nevrokard software (Nevrokard, version 6.4.0 Slovenia).

Statistical analysis

The distribution of the data was assessed using the Shapiro-Wilk Test. Statistical differences between pain-thresholds and pain-tolerances during CWE1 and CWE2 were tested by paired t-test. Comparison

of cardiac autonomic activity and BRS between spontaneous breathing and SDB was calculated by using paired t-test. Results were considered as significant at p≤0.05. The statistical analyses were performed using SPSS for Windows 11.5.0 (SPSS Inc., Chicago, IL, USA).

Results

All the participants completed the experiments. No subject reported any sign of lightheadedness, dizziness, or any kind of discomfort during the experiment. Data for one participant was excluded because of poor signal quality.

Respiration

As expected, differences in respiratory rate were observed for the different breathing conditions. Compared with spontaneous breathing condition (13 breaths/minute), the respiratory rate during the SDB phase was 6 breaths/minute, which proves that all the subjects complied with the breathing instructions. The breathing depth too was greater during the SDB.

Cold Pain Threshold and Tolerance

SDB significantly affected cold pain-tolerance (p=0.008; Table I). Compared to spontaneous breathing, cold pain-tolerance values were significantly higher after SDB. Sub-group analysis showed that as compared to females, males showed significantly larger increase from the CPT1 values (p=0.01; Table I). The cold pain-threshold did not show any significant difference after SDB (p=0.9; Table I).

Effect of SDB on cardiac autonomic activityand cardiovagal baroreflex sensitivity

(i). Time domain measures

There was no significant difference in the mean R–R intervals between spontaneous and SDB (p=0.293). standard deviation of the R–R intervals (SDNN), root mean square of successive differences between adjacent R–R intervals (RMSSD) were significantly higher during SDB condition than during the spontaneous breathing (both p<0.05; Table II). Representative tracing of tachogram from a healthy control during spontaneous and SDB presented in Fig. 2a-b.

TABLE II: The effects of slow deep breathing (SDB) on cardiac autonomic activity.

Variables	*Spontaneous breaths (13 breaths/min)*	*Slow deep breathing (6 breaths/min)*	*p value*
Mean heart rate (BPM)	73.88 (7.35)	75.85 (7.36)	0.267
Mean RR interval (ms)	813.01 (83.85)	769.79 (158.69)	0.293
SDNN (ms)	68.12 (22.42)	109.38 (25.07)*	0.046
RMSSD (ms)	52.95 (24.69)	70.71 (25.81)*	0.000
pNN50 (%)	28.64 (18.21)	33.45 (12.81)	0.08
LF power (nu)	51.52 (15.84)	82.23 (9.09)*	0.001
HF power (nu)	40.83 (15.62)	15.93 (8.47)*	0.003
LF/HF ratio	1.69 (1.42)	8.45 (7.95)*	0.002
Total power (ms^2)	3809.82 (2846.74)	13074.57 (7014.10)	0.27
SD1	36.75 (18.51)	50.07 (18.23)*	0.000
SD2	85.19 (32.13)	146.17 (32.12)	0.36
SD1/SD2 ratio	0.42 (0.12)	0.33 (0.06)*	0.003

Data are given as means (SD); *p<0.05 vs. baseline; BPM, beats per minute; SDNN, standard deviation of the normal-to-normal interval; RMSSD, root mean square of successive differences between adjacent RR intervals; pNN50, percentage of number of RR interval with differences ≥50 ms; LF, low frequency; HR, high frequency; SD, standard deviation; ms, millisecond; nu, normalized units.

TABLE I: Mean cold pain threshold and tolerance pre and post slow deep breathing.

	Cold pain-threshold (seconds)		*p value*	*Cold pain-tolerance (seconds)*		*p value*
	CWE1	*CWE2*		*CWE1*	*CWE2*	
Participants	12.51 (5.64)	12.64 (5.59)	p = 0.9	119.35 (65.61)	151.96 (75.23)*	p = 0.008
Males	13.50 (6.09)	13.31 (5.53)	p = 0.2	126.43 (71.07)	177.00 (79.90)*	p = 0.01
Females	10.82 (5.11)	11.58 (5.47)	p = 0.54	105.47 (59.59)	121.58 (58.65)	p = 0.23

Data are given as means (SD); * p<0.05 vs. CWE1; CWE, cold water exposure.

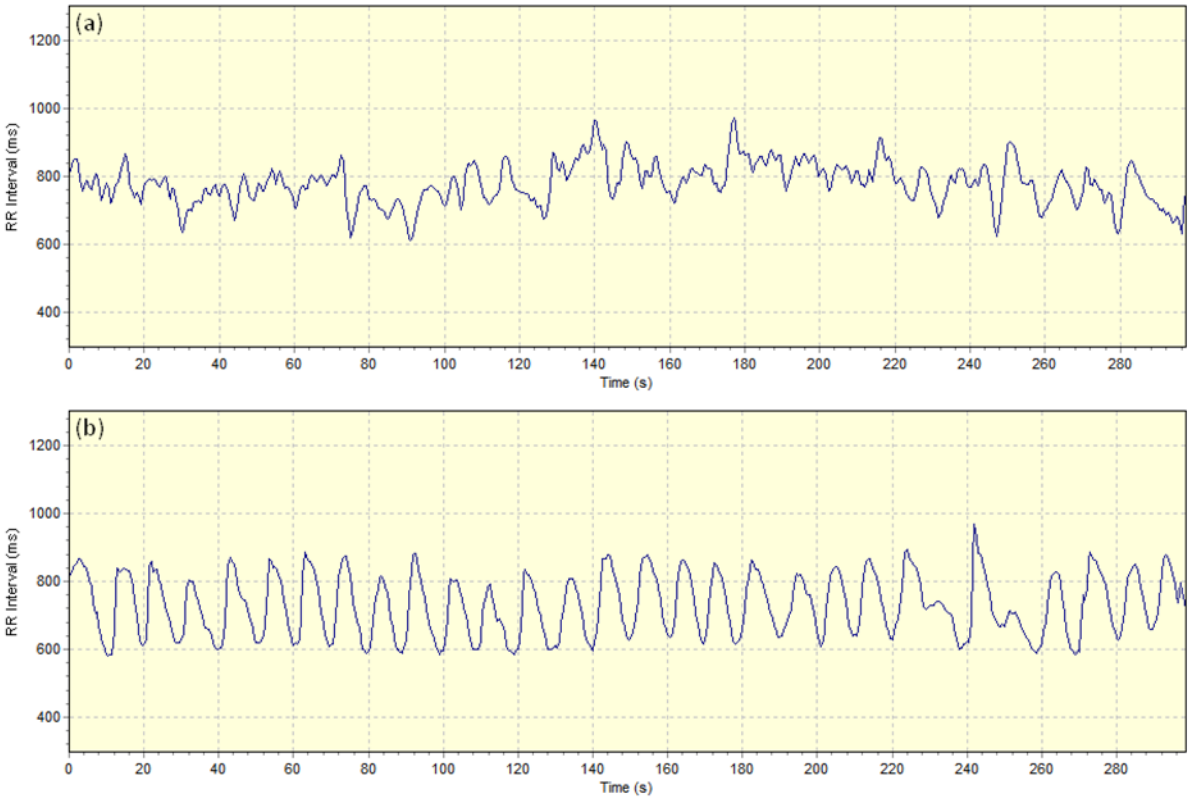

Fig. 2 : Showing the tachogram (a, b) of a representative subject during spontaneous breathing (a) and during slow deep breathing (b).

(ii). Frequency domain measures

SDB significantly affected the low frequency (LF) and high frequency (HF) component of the power spectrum (both p<0.005; Table III). LF power was significantly higher (p=0.001) and HF power was significantly lower (p=0.003) during SDB than the spontaneous breathing. LF/HF ratio was also significantly increased during the SDB than the spontaneous breathing (p=0.002). There was no significant difference in total power (p=0.27; Table II).

(iii). Non-linear (Poincare) measures

SDB significantly affected the standard deviation of the instantaneous R–R intervals (SD1) and SD1 to SD2 ratio (both p<0.05; Table III). As compared to spontaneous breathing, SD1 was significantly higher and SD1/SD2 ratio was significantly lower during slow deep breathing. The standard deviation of the continuous long-term R–R intervals (SD2) during SDB and spontaneous breathing showed no significant difference (p=0.36; Table II).

(iv). Cardiovagal baroreflex sensitivity (BRS)

From the tested cardiovagal baroreflex sensitivity indices, the average number of up- and down sequences during spontaneous breathing were about the same (Table III). However, during SDB, down-sequences outnumbered up-sequences (Table III). Moreover, the average number of down-sequences were significantly higher during SDB (Table III). Across all subjects, up-sequence BRS was increased in the systolic blood pressure (SDB), mean blood pressure (MBP) and diastolic blood pressure (DBP) during SDB compared to the spontaneous breathing (p=0.000, p=0.011, and p=0.004, respectively; Table III). As compared to the spontaneous breathing, the down-sequence BRS values showed no significant changes during SDB. The average LF α-index BRS was 26.89±14.85 ms/mmHg during spontaneous breathing and 33.48±15.14 during SDB (p=0.03; Table III).

TABLE III : The effects of slow deep breathing (SDB) on baroreflex sensitivity.

Variables	*Spontaneous breaths (13 breaths/min)*	*Slow deep breathing (6 breaths/min)*	*p value*
Up-sequences SBP	12.41 (4.84)	11.33 (6.71)	0.409
Up-sequences MBP	8.16 (4.07)	9.7 (5.33)	0.220
Up-sequences DBP	4.87 (3.16)	9.38 (5.66)*	0.001
Up-BRS SBP (ms/mmHg)	24.54 (13.65)	35.80(15.97)*	0.000
Up-BRS MBP (ms/mmHg)	26.19 (14.65)	39.25 (25.65)*	0.011
Up-BRS DBP (ms/mmHg)	19.53 (11.49)	32.46 (20.59)*	0.004
Down-sequences SBP	12.04 (6.61)	21.56 (7.13)*	0.000
Down-sequences MBP	9.41 (4.68)	19 (7.63)*	0.000
Down-sequences DBP	4.83 (3.03)	15.16 (6.92)*	0.000
Down-BRS SBP (ms/mmHg)	26.69 (18.93)	23.68 (9.59)	0.29
Down-BRS MBP (ms/mmHg)	25.73 (11.46)	27.71 (12.42)	0.40
Down-BRS DBP (ms/mmHg)	22 (13.67)	23.33 (9.31)	0.53
LF α-index BRS (ms/mmHg)	26.89 (14.85)	33.48 (15.14)*	0.03

Data are given as means (SD); * $p<0.05$ vs. baseline; SAP, systolic arterial pressure; DAP, diastolic arterial pressure; MAP, mean arterial pressure; LF alpha, low frequency cross spectral baroreflex gain;ms, millisecond.

Discussion

The present study assessed the effects of SDB on pain-threshold and tolerance to cold, cardiac autonomic activity, and cardiovagal baroreflex sensitivity. Results indicated that SDB increases cold pain-tolerance in males but does not affect the pain-threshold. Our study could not substantiate the hypothesis that SDB affects the pain perception, which is in contrast to the two previous studies that demonstrated the effect of SDB on experimental thermal pain perception using paced breathing (5, 6); It might be due to the different modalities of eliciting pain in our study. Hence, unlike previous studies that used heat to induce pain, the present study assessed the effect of SDB on cold pain perception. It is reasonable to posit that a common link underlines both breathing-induced modulation in pain perception and breathing-induced changes in cardiovagal baroreflex sensitivity. The study was not designed to address this issue; however, it was hypothesized that SDB leads to increased autonomic tone (high HRV measures such as SDNN and RMSSD) and BRS (LF α-index BRS) and also responsible for the decrease in cold pain perception. On the basis of animal experiments using cholinergic and beta-adrenergic blockade, an increase in SDNN is interpreted as parasympathetic activation and/or sympathetic withdrawal (14). Thus, it seems that SDB moderately affected the cardiovagal autonomic regulation. These findings are not in agreement with a recent study by Zannin et al., (2015) (15). Who observed that SDB (6 breaths/min) for 5 min had no significant effect on R-R interval and RMSSD. The HF component, which is a marker of cardiac vagal activity, was low while LF component, which represents sympathetic tone, was high during SDB. During SDB at 6 breaths/minute, RR fluctuations merge with the rate of respiration and their amplitude increases relative to BP changes, enhancing the vagal arm of baroreflex. Additionally, high values of LF-to-HF ratio were observed during SDB, which estimates the sympatovagal balance (12).

In line with previous observations, SDB increased the BRS (2). It is not clear whether the observed phenomenon represents 'real increase' in BRS, or simply represents a merging of the frequency-dependent components of baroreflex and non-baroreflex respiratory responses (16). In line with the observations of Tzeng et al., slow breathing was associated with an increase in α-index and up-sequence BRS. However, down-sequence BRS showed no changes. They argued that if the 'increase' in BRS is due to breathing, it should also be reflected in the down-sequence BRS. Moreover, SDB (6 breaths/minute) does not augment BRS when assessed from the drug-induced fluctuations in the BP evoked during the modified Oxford method (17). Therefore, these discrepancies have not yet been resolved and further studies are required to unravel the influence of slowdeep breathing on the baroreflex loop and understand the influence of non-baroreceptor influences (e.g. myocardial stretch mechanism) during slow breathing on BRS.

These reports strengthen the speculation that non-pharmacological interventions such as SDB may serve as a therapeutic modality in ameliorating depressed cardiovascular autonomic tone and baroreflex sensitivity function in conditions with

depressed autonomic variability. Thus, our study proves that pain-tolerance increases after SDB which could be due to modulation of autonomic nervous system. However, the small magnitude of changes in pain perception suggests that factors other than autonomic control may underlie the effects of breathing techniques on pain modulation.

Conflict of Interest

The authors have no conflict of Interest (COI) to declare.

References

1. Dworkin BR, Elbert T, Rau H, Birbaumer N, Pauli P, Droste C, Brunia CH. Central effects of baroreceptor activation in humans: attenuation of skeletal reflexes and pain perception. *Proc Natl Acad Sci USA* 1994; 91(14): 6329–6333.
2. Bernardi L, Porta C, Spicuzza L, Bellwon J, Spadacini G, Frey AW, Yeung LY, Sanderson JE, Pedretti R, Tramarin R. Slow breathing increases arterial baroreflex sensitivity in patients with chronic heart failure. *Circulation* 2002; 105(2): 143–145.
3. Kitko J. Rhythmic breathing as a nursing intervention. *Holist Nurs Pract* 2007; 21(2): 85–88.
4. Skoglund L, Josephson M, Wahlstedt K, Lampa E, Norback D. Qigong training and effects on stress, neck-shoulder pain and life quality in a computerised office environment. *Complement Ther Clin Pract* 2011; 17(1): 54–57.
5. Chalaye P, Goffaux P, Lafrenaye S, Marchand S. Respiratory effects on experimental heat pain and cardiac activity. *Pain Med Malden Mass* 2009; 10(8): 1334–1340.
6. Zautra AJ, Fasman R, Davis MC, Craiq AD. The effects of slow breathing on affective responses to pain stimuli: an experimental study. *Pain* 2010; 149(1): 12–18.
7. Busch V, Magerl W, Kern U, Haas J, Hajak G, Eichhammer P. The effect of deep and slow breathing on pain perception, autonomic activity, and mood processing—an experimental study. *Pain Med Malden Mass* 2012; 13(2): 215–228.
8. Zunhammer M, Eichhammer P, Busch V. Do cardiorespiratory variables predict the antinociceptive effects of deep and slow breathing? *Pain Med Malden Mass* 2013; 14(6): 843–854.
9. Arsenault M, Ladouceur A, Lehmann A, Rainville P, Piche M. Pain modulation induced by respiration: phase and frequency effects. *Neuroscience* 2013; 252: 501–511.
10. Bieri D, Reeve RA, Champion GD, Addicoat L, Ziegler JB. The Faces Pain Scale for the self-assessment of the severity of pain experienced by children: development, initial validation, and preliminary investigation for ratio scale properties. *Pain* 1990 May; 41(2): 139–150.
11. Rutchick AM, Slepian ML. Handling Ibuprofen increases pain tolerance and decreases perceived pain intensity in a cold pressor test. *PloS One* 2013; 8(3): e56175.
12. Sharma P, Makharia GK, Ahuja V, Dwivedi SN, Deepak KK. Autonomic dysfunctions in patients with inflammatory bowel disease in clinical remission. *Dig Dis Sci* 2009; 54(4): 853–861.
13. Zöllei E, Paprika D, Makra P, Gingl Z, Vezendi K, Rudas L. Human autonomic responses to blood donation. *Auton Neurosci Basic Clin* 2004; 110(2): 114–120.
14. Berntson GG, Cacioppo JT, Quigley KS. Respiratory sinus arrhythmia: autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology* 1993; 30(2): 183–196.
15. Zannin E, Pellegrino R, Di Toro A, Antonelli A Dellaca RL, Bernardi L. Parasympathetic Stimuli on Bronchial and Cardiovascular Systems in Humans. *PloS One.* 2015; 10(6): e0127697.
16. Tzeng YC, Sin PYW, Lucas SJE, Ainslie PN. Respiratory modulation of cardiovagal baroreflex sensitivity. *J Appl Physiol* (1985). 2009; 107(3): 718–724.
17. Horsman HM, Peebles KC, Tzeng YC. Interactions between breathing rate and low-frequency fluctuations in blood pressure and cardiac intervals. *J Appl Physiol* (1985). 2015; 119(7): 793–798.