Physiology & Behavior 159 (2016) 1–13

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/phb

Analysis of cardiorespiratory phase coupling and cardiovascular autonomic responses during food ingestion

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HIGHLIGHTS

- We analyzed the phase coherence of RSA during eating, chewing, and water intake.
- Eating, chewing, and water intake resulted in a significant decrease in coherence.
- HRV indexes did not show significant changes except for eating.
- Phase coherence was inversely correlated with the sympathovagal balance index.
- Phase coherence of RSA could provide a sensitive measure of the autonomic profile.

ARTICLE INFO

Article history:
Received 28 September 2015
Received in revised form 24 February 2016
Accepted 4 March 2016
Available online 9 March 2016

Keywords:
Mastication
Swallowing
Respiratory sinus arrhythmia
Sympathovagal balance

ABSTRACT

The present study analyzed whether the phase coherency (λ) of respiratory sinus arrhythmia (RSA) is altered by food ingestion in healthy young subjects. After 5 min of resting control, 13 healthy volunteers were asked to eat a solid meal with access to water at their own pace, followed by 5 min of the postprandial state. The R-R interval (RRI), beat-to-beat blood pressure (BP), and respiratory activity were recorded using electrocardiography, a Finapres device, and inductance plethysmography, respectively. The stroke volume was calculated by the pulse-contour method from continuous BP measurement, and the cardiac output (CO) was obtained by multiplying the stroke volume by the heart rate. From the oscillatory signals of RSA and respiration, λ was computed; additionally, frequency domain indexes of the heart rate variability (HRV) were calculated using a short-time Fourier transform. A steady-state 3-min resting period (R), food ingestion period (FOOD), and the first 2-min and the last 3-min of the post prandial period were analyzed separately. We also compared the responses to gum chewing (GUM) and water intake (WATER) using the same protocol on separate days. A shortening of RRI and increases in BP and CO were observed in FOOD compared to R, suggesting a shift of sympathovagal balance toward sympathetic activation. Similar responses but smaller magnitudes were observed in the GUM condition, whereas only transient shortening of RRI was observed in the WATER condition. The HRV indexes did not show any significant changes in response to GUM and WATER but sympathovagal balance was shifted in favor of sympathetic dominance in FOOD. λ decreased during all of the conditions. There was a significant negative correlation between λ and the indirect measure of sympathovagal balance. These results suggest that ingestion of food induces enhanced cardiac sympathetic activity and that a phase coherence of RSA could provide a sensitive measure for evaluating the cardiac autonomic profile.

1. Introduction

Changes in heart rate variability (HRV) induced by respiration are known as respiratory sinus arrhythmia (RSA), described as an acceleration and deceleration of the heart rate corresponding to the phases of the respiratory cycle. In our previous study, we found that mental stress in humans exerts an influence on the oscillations of RSA, inducing an incoherent phase lag with respect to breathing [i.e., disruption of the phase coherence (λ) between RSA and respiration] in addition to causing a decrease in the amplitude of RSA [21]. The results of the study suggested that the enhanced sympathetic nerve activity during mental stress may modulate the transduction property of the cardiac vagal efferent nerve. Interestingly, λ was not susceptible to changes in the respiratory frequency; however, such an influence is critical for evaluating the tonicity of the autonomic nervous system (ANS) from the heart rate variability (HRV) in humans [3,4,9]. Therefore, it was expected that λ could act as an alternative index that allows for standardization when measuring ANS activity. However, it remains unclear

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http://dx.doi.org/10.1016/j.physbeh.2016.03.004
0031-9384/

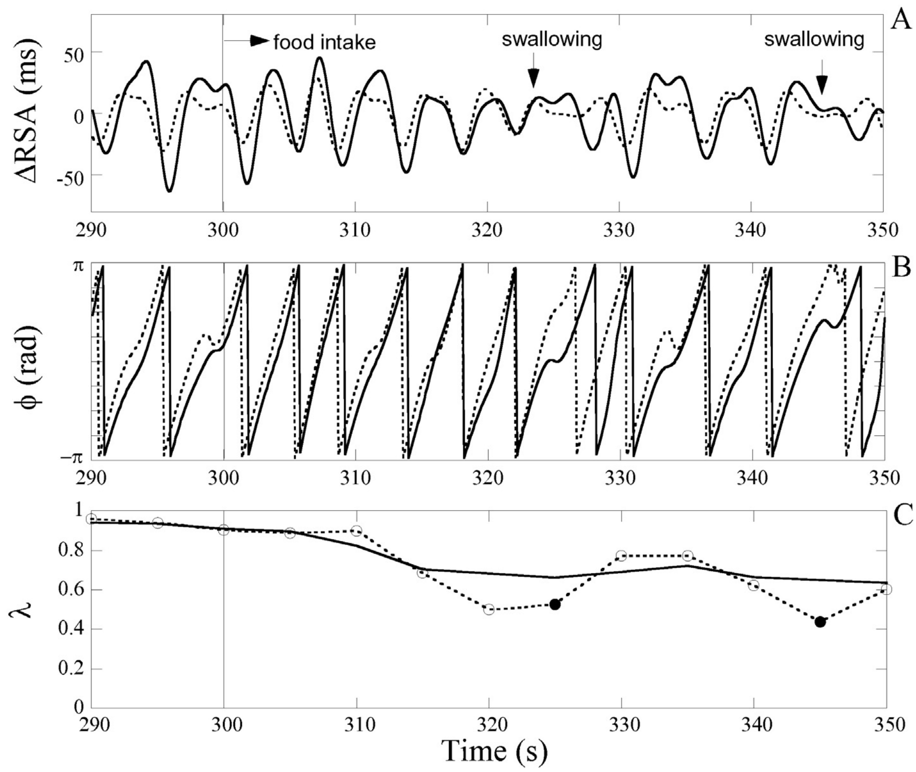

Fig. 1. A: Data segment showing effect of swallowing on changes in RSA (i.e., bandpass filtered RRI, solid trace) and breathing trace (dotted trace) for 1-min portion around beginning of food intake. Breathing trace was plotted in arbitrary units. Upward deflections denote expiration. Vertical line indicates the beginning of food intake. B: Instantaneous phases for RSA (solid trace) and breathing (dotted trace). C: phase synchronization index λ calculated from 10-s windows with a sliding window of 5-s (dotted curve). Closed circles shown are λ values calculated from data segment containing swallowing activity; these were removed from the analysis. Solid curve indicates interpolated λ values after removing λ values indicated by closed circles. Note that instantaneous phase for breathing precedes that for RSA, and that during swallowing, both breathing and RSA oscillations are briefly interrupted. Thereby the phase-lag between RSA and breathing is influenced.

how changes in λ may relate to ANS activity under situations other than mental stress. It would also be of interest to examine whether λ is altered by natural interventions during activities of daily life, depending on changes in ANS tonicity.

One such primary activity of humans that affects hemodynamic changes and ANS activity is eating. Eating behavior has been documented to increase the heart rate (HR), cardiac output (CO), and systolic blood pressure (SBP) [8,12,16], but at the same time feeding activity is known to induce vasodilation in the visceral arteries by increasing gastrointestinal parasympathetic activity [7,24]. These cardiovascular responses are mediated through the ANS to meet the requirement of greater energy utilization associated with the digestion, absorption, and storage of food in gastrointestinal tracts. Studies conducted using the spectral analysis of HRV to evaluate cardiac autonomic reactions to meal ingestion in the case of young adults showed that high-frequency (HF) power decreased [29] and low-frequency (LF) power increased [28] after a meal, suggesting a suppression of cardiac parasympathetic tone and sympathetic excitation. During mental stress conditions (mental arithmetic task), the decrease in λ has been found to be accompanied by enhanced sympathetic activity and/or decreased

Table 1
Meal duration, number of breaths, and number of swallowings during each condition.

Subj.	Meal duration (s)	Number of breaths during food ingestion	Number of breaths during gum chewing	Number of breaths during water intake	Number of swallowings during food ingestion	Number of swallowings during gum chewing	Number of swallowings during water intake
1	274	68 (0.25)	54 (0.20)	58 (0.21)	8	3	3
2	174	55 (0.32)	53 (0.30)	47 (0.27)	9	3	3
3	172	34 (0.20)	44 (0.26)	48 (0.28)	7	2	2
4	145	30 (0.21)	26 (0.18)	33 (0.23)	7	2	2
5	133	25 (0.19)	47 (0.35)	47 (0.35)	6	4	3
6	152	48 (0.32)	48 (0.32)	49 (0.32)	8	1	3
7	156	44 (0.28)	40 (0.26)	43 (0.28)	7	3	3
8	187	66 (0.35)	44 (0.24)	54 (0.29)	7	2	3
9	149	32 (0.21)	33 (0.22)	30 (0.20)	6	2	3
10	177	42 (0.24)	51 (0.29)	64 (0.36)	9	3	3
11	264	80 (0.30)	94 (0.36)	67 (0.25)	8	3	3
12	182	50 (0.27)	49 (0.27)	52 (0.29)	7	3	3
13	405	39 (0.10)	34 (0.08)	41 (0.10)	6	5	3
Mean	198 ± 22	47.2 ± 4.7	47.5 ± 4.7	48.7 ± 3.1	7.3 ± 0.3[a,b]	2.7 ± 0.3	3.0 ± 0

Values are mean ± SE.
Values in parentheses are respiratory frequency in Hz.
[a] $P < 0.01$ food ingestion vs. gum chewing.
[b] $P < 0.01$ food ingestion vs. water intake.