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The Effect of Breathing Route on Heart Rate Variability—A within Subject Comparative Study

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Abstract

Background: The effect of traffic related emissions on Heart Rate Variability (HRV) has been previously demonstrated. However, the results of different studies on the relationship between ambient pollutants and specifically carbon monoxide (CO) on HRV are inconclusive and appear to reflect personal differences. The differences in methodology including breathing style and participants under study can possibly attribute to this variability. The aim of the present study is to assess the effect of the breathing route (Nasal/Oral) on the relationship between CO concentration and HRV. **Methodology:** Forty healthy participants (25 females, 15 males) between the ages of 15 - 50 years were included in the study. The participants strolled in a central bus station, staying for 10 minutes in three designated locations alternating nasal and oral breathing. CO concentration and HRV were continuously monitored. Frequency (LnLF, LnHF, LnLF/HF) and time domain (LnSDNN, LnRMSSD) HRV indices were computed. **Analysis:** MANCOVA, with HRV indices being the dependent variables and CO, gender and age being the independent variables was employed. Results: Significant interaction effects between breathing route and CO, and breathing route and gender on HRV (LnLF/HF) were found ($p = 0.04$ and 0.01 respectively). Both CO and age were found to affect LnSDNN and LnRMSSD. **Conclusion:** Breathing route emerges as a possible modifier of the relationship between air pollution and HRV and thus contributes to interpersonal differences obtained in studies investigating the effect of environmental pollution and HRV.

Keywords

Breathing Route, Carbon-Monoxide (CO), Heart Rate Variability (HRV)

1. Introduction

Exposure to traffic-related air pollutants (TRAPs) as well as noise has been associated with a variety of health adversities [1]. Short-term exposures to TRAPs on or near roadways have also been associated with changes in heart rate variability (HRV) [2]. However, fewer studies have examined the effects of direct exposure to TRAPs on HRV, with inconsistent results [3] and the acute effects of TRAPs on HRV have also been inconsistent in controlled exposure studies [4].

A multitude of studies focuses on the risk to health posed by air pollution in cities. No study aimed at comparing the differential HRV response to ambient pollution as related to breathing rout. CO is accepted as a surrogate gas for air pollution [5]. In fact, of the different pollutants, CO was found in one ecological study related to vehicles' emitted gases to be the most consistently correlated with the rest of the emitted gases (Ranging between 0.787 - 0.84) but the correlation with PM2.5 was established at r-0.27 [6]. The lack of consistency in the reported relationship between CO and HRV in different environments has been reported previously [4]. In this aforementioned study, the analysis revealed an interpersonal difference attributing to this observed ambiguity. A recent systematic review reaffirmed this heterogeneity in the direction of this correlation and hypothesized a difference in methodology as culpable [7] [8]. Since to date the effect of the breathing route on the relationship between environmental pollution and HRV has not been investigated, it is not inconceivable that this methodological factor is partly culpable for the above cited lack of consensus.

We hypothesized that the breathing route (nasal or oral) would be associated with differences in HRV response to CO.

2. Theoretical Context

With few exceptions of highly industrialized cities, in most Israeli cities more than 90 percent of concentrations of CO are emitted from car transportation (*Statistical Abstract of Israel* 2017, *Number* 6>, 2017).

Vehicles are considered a major source of CO and thus commonly employed to represent primary vehicle emissions [9] [10].

HRV is an index of the ANS activity reflecting coping abilities of the organism to respond effectively to complex environmental challenges [11]. Studies confirm the argument that stress affects the ANS imposing risk on both mental and physiological wellbeing [12] [13]. Conventionally risk to health was found to be associated with increase in sympathetic and decrease in parasympathetic tones [14] [15] [16]. However, only few studies focus on associations between concentrations of CO and HRV, using diverse methodologies. A review by Tirosh and Schnell (2016) has shown that out of 25 articles on the effect of CO on HRV only six measured CO in situ. The rest of the articles are based on data extracted from permanent monitoring stations located at a distance from the site in which the participants' levels of HRV were tested. These studies demonstrate inconsistent results. Four of the six studies that measured concentrations of CO in close proximity to the participants found that increase in concentration of CO was associated with increased HRV. One study did not find any correlations between CO and HRV and one study found that increase in concentration of CO was associated with increase in stress as reflected by increased sympathetic tone [7].

The differences between studies could also stem from the lack of accounting for breathing route and thus possibly introducing a measurement error bias or in other words naïve analysis [17]. Yet, only a handful of publications and mostly in a laboratory setup have addressed breathing route in their protocols demonstrating a significant effect on the ANS balance [18] [19] [20] [21]. Since our interest is in the ecological perspective, aiming at the assessment of autonomic responses in real life exposure to emitted pollution (not solely CO) this study was undertaken in a congested central bus station of one of the major cities in Israel using CO as a surrogate for TRAPs.

3. Research Method

Participants: Forty participants were included in the study. Their age ranged between fifteen and fifty years. Since age is a significant factor in modulating HRV balance participants of a young and older age range were included to enhance the statistical power related to age in a small sample size. Twenty-five of them were females and fifteen were males. All of them were healthy, un-medicated and nonsmokers. They were not consuming alcoholic drinks or drugs. They were selected by a snowball method from the people who live in the city of Ashdod. The participants signed a detailed consent form prior to their enrollment. The study was approved by the ethical committee of Tel Aviv University.

Variables: The independent variable is the concentration of Carbon Monoxide (serving as a surrogate for TRAPs) measured while the participants were walking around the bus station. CO was measured by ppm per half an hour. The intervening variables breathing style from the nose or the mouth were tested by either opening the nose or blocking it following ascertainment of nasal breathing in the nasal breathing periods. Smell was tested by a pretest prepared by us for this study. Prior to the study, each participant was tested for nasal patency and olfactory function using a field clinical procedure [22]. No participant was found anosmic.

The dependent variables were standardized HRV indices of time (LnSDNN, LnRMSSD) and frequency (LnHF, LnLF and LnLF/HF) domains. SDNN measures the absolute gap between successive heart bitts, averaging them for a given time period. It is used in order to highlight the immediate responses of the autonomic nervous system to environmental stimuli. The ratio of LF/HF is frequently used to measure the way the autonomic ANS copes with environmental nuisances, representing risk to health and stress [23]. In the analysis, low frequency (LF) values of 0.04 to 0.15 Hz are divided by high frequency (HF) of 0.15 to 0.4 Hz. While HF measures the vagal control, LF measures the mixture of parasympathetic and the sympathetic tones. Both indices were computed for cohorts of five minutes. The index has been lately validated based on reviewing large number of empirical [23] [24].

Procedure and Devices: Ten campaigns of four participants each were performed during October, 2018 in the early afternoon hours when busses activity was relatively intensive (26˚C - 29˚C). A researcher was present in each campaign during the experiments. The participants strolled outside the station for half an hour in order to adjust to the devices they wore. Following the adaptation stage, participants entered the bus station, moving slowly for half an hour around the station's platforms. The order of breathing mode was based on block randomization. At three sites, participants stood still for ten minutes, breathing five minutes from their nose and five minutes from their mouth. The data obtained from the second site was removed from the analysis since the adherence to mouth breathing was not properly maintained by some of the participants during this interval. Each interval was separated by double periods of either oral or nasal breathing, which was also excluded from the final analysis.

The participants wore a designated ambulatory monitor (Polar Electro 810i, Finland) for continuous HR recording. The monitors were calibrated prior to the study and the fidelity was reexamined following each campaign. The participants were advised by the researcher on the time to put on or take off a nasal seal (Arena Nose Clip Proii, Tolentino, Italy). To reduce noise effect, known to affect HRV [25] [26] [27], customary ear plugs were worn (3M 318 E-A-R push-inns. London, Canada).

Analysis: The CO data were processed by Gasvision 4.5 pac III program and the HRV data were processed by the Polar Protrainer 5 program. The HRV indices were produced by the Kubios HRV program (http://www.kubios.uku.fi). The data were transformed to SPSS 25 program for statistical analysis. Multivariate analyses of covariance (MANCOVA), with age, gender and CO concentration as covariates, conducted between breathing route (Nasal/Oral) in relation to HRV indices (LnLF/HF, LnLF, LnHF, LnSDNN, LnRMSSD).

4. Results

Ambient CO concentration ranged between 0 - 5 ppm throughout the experiment. There was a statistically significant difference between breathing routes on the combined dependent variables after controlling for age, gender and CO concentration ($F(5, 186) = 3.20$, $p = 0.009$, Wilks' $\Lambda = 0.921$, partial $\eta^2 = 0.079$) as shown in **Figures 1-4**.

The analysis shown in (**Table 1**) revealed an interaction between breathing route and CO concentration on LnLF/HF. Exclusive mouth breathing was associated with a significant positive relationship between CO concentration and LnLF/HF. No Other significant interaction between breathing route and CO concentration as related to HRV indices was noted. While accounting for the covariates, CO concentration' regardless of breathing route was found to be negatively related to the time domain indices of LnSDNN and LnRMSSD as shown in **Figure 5** and **Figure 6**. No effect of CO only on the frequency domain indices was noted. Gender was related to LnLF/HF with men having an increased

LnLF/HF as compared to women and an interaction of breathing route and gender was also noted with an increased LnHF among men as compared to women. Age effect was found significant for LnLF/HF, LnLF, LnSDNN all decreasing with age.

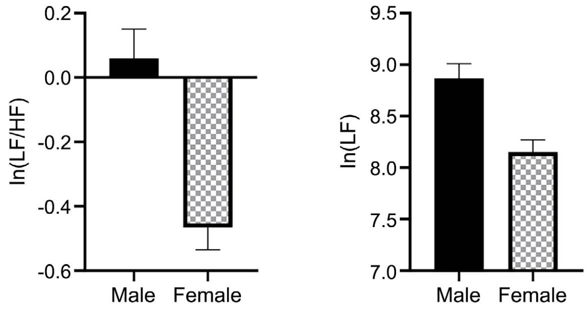

Figure 1. HRV indices by gender.

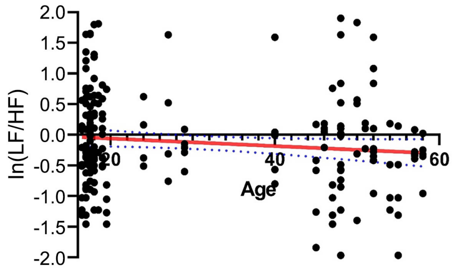

Figure 2. Regression between age and LF/HF.

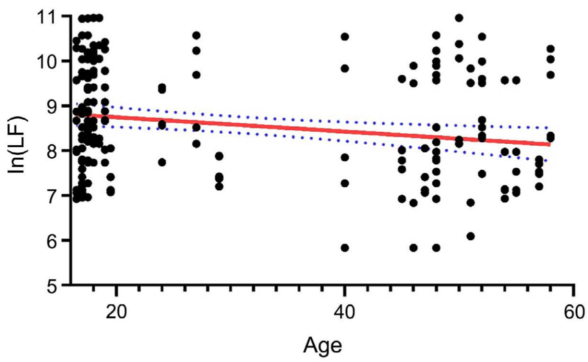

Figure 3. Regression between age and LF.

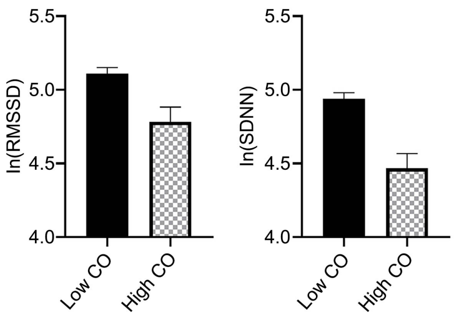

Figure 4. HRV indices by CO concentration.

Table 1. Multiple analysis of covariance (MANCOVA) for the HRV log transformed indices (LF/HF, LF, HF, SDNN, RMSSD) (age, sex, CO, breath route and interaction Sex*breath route as independent variables).

Dependent Variable	Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared
						Lower Bound	Upper Bound	
LnLF/HF	Intercept	0.204	0.238	0.855	0.394	−0.266	0.674	0.004
	Female#	−0.526	0.149	−3.536	**0.001**	−0.820	−0.233	0.062
	Mouth$	0.258	0.302	0.855	0.394	−0.338	0.854	0.004
	Low CO@	0.199	0.230	0.864	0.389	−0.255	0.653	0.004
	Age	−0.007	0.003	−1.952	**0.052**	−0.014	7.33-5	0.020
	Mouth*low CO	−0.659	0.332	−1.984	**0.049**	−1.314	−0.004	0.021
	Female*mouth	0.588	0.237	2.481	**0.014**	0.121	1.056	0.032
LnLF	Intercept	9.017	0.376	23.970	0.000	8.275	9.759	0.753
	Female#	−0.720	0.235	−3.065	**0.002**	−1.183	−0.256	0.048
	Mouth$	0.291	0.477	0.610	0.543	−0.650	1.232	0.002
	Low CO@	0.284	0.363	0.781	0.436	−0.433	1.001	0.003
	Age	−0.013	0.005	−2.337	**0.020**	−0.024	−0.002	0.028
	Mouth*low CO	0.009	0.524	0.017	0.987	−1.025	1.043	0.000
	Female*mouth	0.349	0.374	0.933	0.352	−0.389	1.087	0.005
LnHF	Intercept	8.812	0.296	29.766	0.000	8.228	9.396	0.825
	Female#	−0.193	0.185	−1.045	0.298	−0.558	0.172	0.006
	Mouth$	0.035	0.375	0.094	0.925	−0.705	0.776	0.000
	Low CO@	0.085	0.286	0.299	0.765	−0.479	0.650	0.000
	Age	−0.006	0.004	−1.397	0.164	−0.015	0.002	0.010
	Mouth*low CO	0.667	0.412	1.617	0.108	−0.147	1.480	0.014
	Female*mouth	−0.241	0.294	−0.818	0.414	−0.822	0.340	0.004
LnSDNN	Intercept	4.679	0.165	28.428	0.000	4.354	5.004	0.811
	Female#	−0.098	0.103	−0.951	0.343	−0.300	0.105	0.005
	Mouth$	0.060	0.209	0.287	0.775	−0.352	0.471	0.000
	Low CO@	0.472	0.159	2.972	**0.003**	0.159	0.786	0.045
	Age	−0.006	0.002	−2.670	**0.008**	−0.011	−0.002	0.037
	Mouth*low CO	0.112	0.229	0.488	0.626	−0.340	0.564	0.001
	Female*mouth	−0.058	0.164	−0.352	0.725	−0.381	0.265	0.001
LnRMSSD	Intercept	4.977	0.165	30.089	0.000	4.651	5.303	0.828
	Female#	−0.128	0.103	−1.235	0.218	−0.331	0.076	0.008
	Mouth$	0.041	0.210	0.197	0.844	−0.372	0.455	0.000
	Low CO@	0.327	0.160	2.047	**0.042**	0.012	0.642	0.022
	Age	−0.005	0.002	−2.011	**0.046**	−0.010	−9.1E−5	0.021
	Mouth*low CO	0.111	0.230	0.482	0.631	−0.344	0.565	0.001
	Female*mouth	−0.065	0.165	−0.398	0.691	−0.390	0.259	0.001

male reference group, $nose reference, @high level reference.

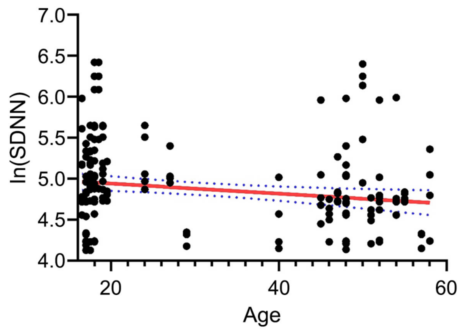

Figure 5. Regression between age and HRV indices.

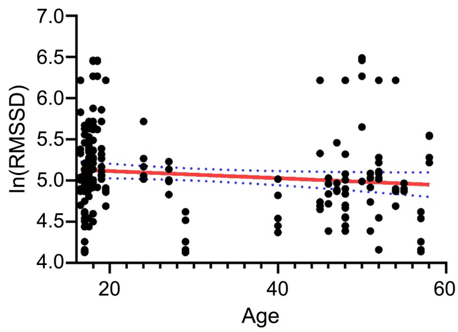

Figure 6. Regression of RMSSD and age.

5. Discussion

The relationship between air pollution and HRV has been extensively studied. Yet, a systematic reviews failed to reach a consensus as for the validity of such relationship and point out that the lack of repeatability and heterogeneity of results possibly reflect the complexity of ambient pollution on one hand and the diversity in methodology on the other [7] [28] [29] [30] [31].

The study of the ANS balance is commonly employed to assess the wellbeing, either physiological or mental in a variety of contexts [11] [23] [32] [33] [34]. The respiratory system has a well-known critical effect on HRV and indeed breathing rate is also often measured in these studies [35] [36] [37] [38]. However, the mode of breathing, either nasal or oral has gained almost no attention in these studies. The relationship between olfaction, a nasally located sense and the ANS activity has also been investigated [39]. Hence, breathing route is a potential intervening variable affecting the relationship between CO and HRV.

Our objective in this research was to identify the difference in the ANS as measured with HRV between oral and nasal breathing and to assess whether breathing route affects the ANS response to ambient CO as a surrogate for TRAPs in an urban setup. Previous studies addressed differences in HRV response to nasal/oral breathing. However, with no reference to ambient pollutants, using different methodologies and mostly laboratory stationary procedures [40], the present study investigated the effect of exclusive oral breathing as compared to nasal breathing on the relationship between HRV and CO using an ecological approach with participants strolling in a central bus station and thus reflecting the real effect of TRAPs on HRV. The frequency domain index of LnLF/HF reflecting the general autonomic balance, commonly employed in environmental studies was affected significantly by the interaction between CO and breathing route. No relationship between short term breathing route alone and HRV was found in our study (BuSha and colleagues, 2009). In their study of 12 young males and 12 females tested for their R-R interval for 15 minutes in a laboratory setup, randomly alternating nasal and oral breathing found an increased R-R interval in oral as compared to nasal breathing. A previous study among athletes performing the Wingate Anaerobic Exercise Test found an increased heart rate while using nasal breathing as compared to oral breathing yet the respiratory rate declined. Albeit HRV was not analyzed it is conceivable that the increased heart rate was associated with reduced variability [41]. Furthermore, in this study oral breathing was associated with increased respiratory exchange rate. Such increase is also expected to change HRV regardless of breathing rate. The more sensitive response detected by the frequency domain index possibly originates from the frequency domain being more sensitive to short intervals such as the five minutes' intervals used in the present study [23]. Our results suggest that both HRV time domain indices of LnSDNN and LnRMSSD are sensitive to CO. Both indices declined in response to increased CO regardless of breathing route. This finding while being in line with other studies investigating traffic emitted pollution and autonomic functions [6] [42] is not in line with our previous findings of increased HRV in response to low concentrations of CO. Yet this later study took place in urban non-polluted locations. One may speculate that the observed changes in HRV result from the effects of a variety of other pollutants typically emitted from buses. These pollutants were previously documented to decrease HRV as observed in the present study. The HRV measurements obtained in a close vicinity to the buses, unlike those obtained in a more distanced location probably reflect the general TRAPs effect on HRV rather than CO alone.

The HRV difference as related to gender is in line with previous studies concluding a significant gender effect on HRV response to stress with males activating more their sympathetic system than females [43] [44] [45]. More specifically, as evident in our results, the study by Sookan *et al.* [46] suggests that gender related differences in HRV are more evident using frequency domain indices than time domain indices. A similar gender-breathing route interaction found in LnLF/HF reflecting the total ANS balance found in the present study was also demonstrated in a laboratory setup [19]. The gender distribution in our study reflects volunteering bias that should be accounted for. The significant gender effect would have been enhanced once an equal number of men and women were included. The age effect has also been consistently documented in previous studies [47] [48]. Due to the small sample size two separate age groups were recruited and a larger sample size would allow a more representative age distribution.

6. Conclusion

In conclusion, we suggest that following the results of the present study, investigators should be aware of breathing routes, oral or nasal, in the study of HRV as related to ambient pollutants. It is conceivable that the difference in breathing route of participants results in type 1 or 2 errors and thus contributes to interpersonal differences in ANS reactivity as reflected by HRV results. This methodological aspect is of relevance to the ecological environment as well as laboratory studies. It would be advisable to screen participants for their breathing route and their nasal patency. Studies investigating the relationship between emitted pollutants and HRV may also account for the probable complex effect of the pollutants and acknowledge that while selecting a surrogate gas such as CO, the resulting relationship may in fact reflect the latent effect of other pollutants in addition to CO. Finally, it appears that due to the different sensitivity of time and frequency domain indices to ambient pollutants, the analysis of both is warranted in environmental studies.

7. Limitations

Our study used a wide age range and a type 2 error related to the time domain indices should be considered. In an attempt to account for the age effect, we included two groups representing young and older participants rather than a narrow age range. Furthermore, our results pertain to complete rather than partial nasal breathing. However, it appears that ANS balance is similarly affected by the two procedures. We did not record breathing rate and therefore cannot account for the effect of this variable on the difference between oral and nasal breathing. The information to date, specifically addresses the difference between the two breathing routes relates to intensive exercise and thus cannot be of relevance to our study [41]. It would be advisable to include this factor in a future study. We also did not account for other environmental factors. However, the single experimental location, the use of the same participant as her/his own control and the use of ear plugs to minimize the noise effect, makes this problem redundant. The lack of this information does not invalidate the value of our findings to the research in the field of HRV analysis. The five minutes breathing mode intervals may also affect our results. Yet, this time period suffices for short time responses expected in HRV. In addition, the observed gender and age effect in the present study similar to that observed in previous studies lends support to the validity of the results obtained while using these time periods and the employed conservative statistical analysis.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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