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The relationships between self-assessed habitual physical activity and non-invasive measures of cardiac autonomic modulation in young healthy volunteers

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Abstract

Heart rate variability estimates cardiac autonomic modulation, but the relationship between habitual physical activity and heart rate variability remains unclear. The aims of this study were to compare RR-interval and heart rate variability indices in individuals of different habitual physical activity levels, and examine the relationship between habitual physical activity and heart rate variability. Ninety-two healthy volunteers (47 men, 45 women; mean age 23.1 years, $s = 2.1$) were divided into tertiles according to the Baecke Questionnaire score. Standard heart rate variability indices were derived from 5-min resting RR-interval recordings with paced respiration (0.25 Hz). Between-group differences and the relationship between habitual physical activity and heart rate variability were assessed. More active participants (tertiles 2–3) had longer RR-intervals than those in tertile 1 ($P < 0.05$). Participants in tertile 2 had higher root mean squared differences of successive normal RR-intervals than those in tertile 1 and a higher standard deviation of normal RR-intervals than those in tertiles 1 and 3. There was a positive linear relationship between habitual activity and RR-interval. Differing RR-interval lengths were found in subgroups of young individuals according to level of habitual physical activity. More active individuals showed resting bradycardia without evidence of enhanced cardiac parasympathetic modulation. The mechanism linking habitual physical activity and RR-interval length appears to be independent of physiological mechanisms that can be measured by heart rate variability.

Keywords: *Autonomic nervous system, vagal, heart rate variability*

Introduction

It is an accepted premise in exercise physiology that chronic exposure to physical activity results in a resting bradycardia (Frick, Elovainio, & Somer, 1967). Similarly, it is accepted that this bradycardia is at least partially attributable to increased activity in the parasympathetic branch of the cardiac autonomic nervous system (Maciel *et al.*, 1985). The quantification of beat-to-beat variability in heart rate (heart rate variability) is an accepted measure of cardiac autonomic, in particular parasympathetic, activity (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Many cross-sectional studies have investigated between-group differences in participants with differing levels of habitual physical activity and have provided mixed results (Aubert, Beckers, & Ramaekers, 2001; Buchheit, Simon, Piquard, Ehrhart, & Brandenberger, 2004; Davy, Miniclier, Taylor, Stevenson, & Seals, 1996; Janssen, de Bie, Swenne, & Oudhof, 1993; Jensen-Urstad, Saltin, Ericson, Storck, & Jensen-Urstad, 1997; Lazoglu, Glace, Gleim, & Coplan, 1996; Melanson, 2000). Typically, such studies use a two-group classification such as athletes versus controls. Melanson (2000) used a three-group classification and found elevated parasympathetic heart rate variability indices in both moderately and highly trained participants compared with a low-active group, suggesting a lack of dose–response between habitual physical activity and parasympathetic activity. Buchheit *et al.* (2004) found that moderate exercise was associated with higher parasympathetic

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outflow, but that extremely high habitual physical activity produced paradoxically lower values of parasympathetic indices such as high-frequency spectral power despite evidence of a distinct resting bradycardia. The was aims of this study were to identify any differences in heart rate variability indices in participants with differing habitual physical activity levels broadly within the normal population range, and to examine the relationship between heart rate variability and habitual physical activity in a larger sample of healthy young individuals than reported previously.

Methods

Participants

Ninety-two healthy volunteers (47 men, 45 women; mean age 23.1 years, $s = 2.1$, range 18–33 years) were recruited. The university ethics review board approved the study.

To determine levels of habitual physical activity, the participants were first asked to complete the Baecke Questionnaire (Baecke, Burema, & Frijters, 1982) of habitual physical activity, which has been validated against the doubly labelled water technique (Philippaerts, Westerterp, & Lefevre, 1999) and tri-axial accelerometry (Philippaerts, Westerterp, & Lefevre, 2001). The questionnaire comprises three sections: work, sport (exercise), and non-sport leisure activity. The bulk of the questionnaire was scored on a 5-point Likert scale. Three additional questions required the participants to report the type of sporting (exercise) activity, the number of hours per week, and the number of months per year in which the respondent participated in that activity. The Baecke score was used due to its known validity and ease of application. The sample size estimate from crude *a priori* power calculations based on previous data (Buchheit *et al.*, 2004; Melanson, 2000) suggested at least 26 participants per group were necessary to detect differences in RR-interval between such homogeneous groups. Power calculations based on heart rate variability values were not possible due to heterogeneous values in the literature. Similar problems with sample size calculations in heart rate variability research have been highlighted recently (Pinna *et al.*, 2007).

All RR-interval recordings were carried out in the same quiet, temperature-controlled laboratory. Participants lay supine on a plinth with the head supported at a 15° upright angle. All measurements were made during a single visit to the laboratory. The participants reported to the laboratory between 09.00 and 12.00 h. All participants were asked not to drink alcohol or take any exercise in the 24 h prior to the test. No vigorous physical activity (such as sport-specific training) was allowed for 48 h prior to testing (Mourot, Bouhaddi, Tordi, Rouillon, & Regnard, 2004). The participants were also asked not to smoke, ingest caffeine on the day of the test, and not to eat for at least 1 h directly before the test.

After completing the questionnaire, body mass (to the nearest 0.5 kg) and stature (to the nearest 0.5 cm) were measured. The participants were then asked to lay supine, to remain still without talking, and to relax until a stable, resting heart rate could be identified. This was ascertained from a two-lead RR-interval recording (Polar® S810, Electro Ltd. Oy, Finland) with a recording frequency of 1000 Hz. This instrument shows excellent agreement with RR-interval determination from electrocardiogram (ECG) recordings in healthy patients when measured in the supine position (Gamelin, Berthoin, & Bosquet, 2006). The participants were then given standardized verbal instructions and a practice period of paced breathing. To attain a breathing frequency of 12 cycles $\cdot$ min^{-1}, the participants breathed in time with a metronome with the aid of initial verbal guidance. The experimenter watched the chest movement of the participant to check breathing rhythm and when a satisfactory rhythm was attained, the practice session was terminated. The recording phase of the testing then began. After an initial lead-in to paced breathing, the participant continued to breathe at the desired frequency and RR-intervals were recorded for at least 10 min. This information was then stored on a computer for subsequent analysis.

Data treatment

The RR-interval data were edited using the Polar® Precision Performance software 3.12 set at the moderate filtering level (6 beats $\cdot$ min^{-1}). From the 10 min or more of recorded data, stationary 300-s sections of each tachogram were selected for analysis. Filtered data were exported as a .txt file and analysed using heart rate variability analysis software (Biomedical Signal Analysis Group, University of Kuopio, Finland) (Niskanen, Tarvainen, Ranta-Aho, & Karjalainen, 2004). Standard time and frequency domain analyses were carried out to give: mean RR-interval, the standard deviation of normal RR-intervals (SDNN), and the root mean square of successive normal RR-interval differences (RMSSD). To estimate the power spectral characteristics of the time series, the data were interpolated at a rate of 4 Hz and a fast Fourier transform was performed using a non-parametric algorithm and a Welch window. The relative powers in the low-frequency (LF: 0.04–0.15 Hz) and high-frequency (HF: 0.15–0.40 Hz) bands were then determined.

The Baecke Questionnaire of habitual physical activity (Baecke *et al.*, 1982) scores were divided into tertiles, and classified as follows: lower habitual physical activity (tertile 1) ≤ 8.875, moderate habitual physical activity (tertile 2) 8.876–9.749, and higher habitual physical activity (tertile 3) ≥ 9.750.

Statistical analysis

Due to the skewed distributions of spectral measures, these data were naturally log transformed (ln) before parametric analysis. To assess the possible confounding effects of the participants' characteristics, differences between the sexes were assessed by independent *t*-test and correlations between heart rate variability indices, height, mass, body mass index, and age were calculated. According to the identification of appropriate covariates, either a one-way analysis of variance (ANOVA) with *post hoc* (LSD) tests or analysis of covariance (ANCOVA) with pair-wise comparisons and Bonferroni correction was used to identify between-group differences. A value of $P < 0.05$ was assumed to show statistical significance. Linear and quadratic regression was used to determine the relationship between RR-interval, heart rate variability indices, and self-reported habitual physical activity. All analyses were carried out using SPSS for Windows, version 13.0.

Results

Grouping by Baecke physical activity questionnaire score

The participants' Baecke scores ranged from 5.5 to 12.6 points, with a mean score of 9.25. None of the participants were classified as either sedentary or highly active. This was anticipated and the group mean Baecke scores shown in Table I are within the normal range for healthy volunteers (Ainsworth, Sternfeld, Richardson, & Jackson, 2000; Jacobs, Ainsworth, Hartman, & Leon, 1993) and coincidental with the range previously used to describe moderately active individuals (Buchheit *et al.*, 2004). Additional descriptive information is also displayed in Table I. All groups were extremely well matched in terms of age and anthropometric characteristics and numbers of males and females.

Table I. Descriptive characteristics by tertile of habitual physical activity (mean ± *s*).

	Tertile 1 ($n = 30$)	Tertile 2 ($n = 32$)	Tertile 3 ($n = 30$)
Sex (M/F)	13/17	17/15	17/13
Age	22.7 ± 3.5	23.1 ± 5.0	24.0 ± 5.1
Height (m)	1.72 ± 7.1	1.72 ± 9.2	1.73 ± 8.0
Mass (kg)	66.9 ± 8.7	66.4 ± 10.9	67.9 ± 10.0
BMI (kg · m^{-2})	22.7 ± 2.8	22.6 ± 2.2	23.1 ± 2.1
Baecke score	7.4 ± 1.0	9.4 ± 0.3	11.0 ± 1.0

Assessment of covariates

To assess the possible confounding effects of the participants' characteristics, differences between the sexes were assessed by independent *t*-test and correlations between heart rate variability indices, height, mass, body mass index, and age were calculated. The standard deviation of normal RR-intervals (SDNN) was found to be significantly ($P = 0.02$) higher in females than males (74 ms, $s = 22$ vs. 58 ms, $s = 18$). Age showed significant positive correlations with mean RR-interval ($r = 0.29$, $P = 0.01$) and low-frequency spectral power ($r = 0.20$, $P = 0.04$).

Heart rate variability indices

Table II shows all standard time and frequency domain measurements of heart rate variability recommended from short-term recordings (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). All heart rate variability measures were within normal ranges for values observed during short-term, resting ECG recordings in healthy volunteers (Kuo *et al.*, 1999; Leicht, Allen,

Table II. Time and frequency domain measures of heart rate variability in participants grouped according to tertile of habitual physical activity (mean ± *s*).

	Tertile 1	Tertile 2	Tertile 3
RR-interval (ms)*	852 ± 102	924 ± 141[a]	935 ± 138[a]
SDNN (ms)**	55 ± 24	75 ± 34[b]	64 ± 31
RMSSD (ms)	56 ± 28	78 ± 56[a]	60 ± 44
LF (ln ms^2)*	6.95 ± 0.42	7.26 ± 0.46	7.31 ± 0.44
HF (ln ms^2)	6.59 ± 0.79	6.95 ± 0.91	6.60 ± 0.86
LF (nu)	58 ± 18	57 ± 16	65 ± 16
HF (nu)	42 ± 18	43 ± 16	35 ± 16
LF : HF	2.0 ± 1.8	1.7 ± 1.5	2.6 ± 1.5[c]

[a] $P < 0.05$ compared with tertile 1; [b] $P < 0.05$ compared with tertile 1 and tertile 3; [c] $P < 0.05$ compared with tertile 2 and tertile 3.
*ANCOVA controlling for age and adjusted pair-wise comparison with Bonferroni correction; **ANCOVA controlling for sex and adjusted pair-wise comparison with Bonferroni correction.
Note: Tertile 1 = lowest level of habitual physical activity, tertile 2 = intermediate level of habitual physical activity, tertile 3 = highest level of habitual physical activity. RR-interval = the mean length of the filtered RR-intervals; SDNN = the standard deviation of all normal-to-normal RR-intervals. LF (ln ms^2) = low-frequency (0.04–0.15 Hz) spectral power in log ms^2. HF (ln ms^2) = high-frequency (0.15–0.40 Hz) power in log ms^2. LF (nu) = proportion of the spectral power from 0.04 to 0.40 Hz that is in the low-frequency band, calculated using LF/(LF + HF). HF (nu) = proportion of spectral power from 0.04 to 0.40 Hz that is in the high-frequency band, calculated using HF/(LF + HF). LF : HF = the ratio of low to high spectral power.

& Hoey, 2003; Sinnreich, Kark, Friedlander, Sapoznikov, & Luria, 1998).

Between-group differences in heart rate variability indices

One-way analysis of variance showed a significant ($P < 0.05$) main effect for RR-interval and root mean square of successive normal RR-interval differences (RMSSD). ANCOVA showed a main effect for SDNN. *Post hoc* pair-wise analyses showed longer RR-intervals in tertile 2 and tertile 3 compared with tertile 1. Both SDNN and RMSSD were elevated in tertile 2 only ($P < 0.05$). Spectral measures showed no significant between-group differences expressed either as raw (ln ms^2) or normalized units. The ratio of low to high spectral power (LF : HF ratio) was significantly elevated in tertile 3 compared with tertile 1 and tertile 2.

Relationship between heart rate variability measures and physical activity

Table III shows the linear and quadratic relationships between Baecke score, RR-interval and all heart rate variability indices. RR-interval showed significant linear relationships with SDNN, RMSSD, high-frequency spectral power, and low-frequency spectral power, none of which were significantly improved by fitting a quadratic model. There was a significant linear relationship ($R^2 = 0.21$, $P = 0.04$) between RR-interval and Baecke score but no significant relationships between Baecke score and any heart rate variability indices were observed.

Discussion

The aim of this investigation was to determine the differences in heart rate variability in a relatively homogeneous, healthy, young population grouped according to levels of self-assessed habitual physical activity that fall within commonly reported ranges for the general population.

Comparisons with previous studies

The mean RR-interval was significantly longer in the more active tertiles (2 and 3) compared with the least active group (tertile 1). In common with previous data from more diverse groups (Buchheit *et al.*, 2004; Melanson, 2000), moderate physical activity was associated with a significant bradycardia. There was no significant increment in RR-interval length in the most active group (tertile 3) compared with tertile 2, again in agreement with previous data (Melanson, 2000).

Comparing heart rate variability indices from tertile 1 with tertile 2 showed that the longer RR-intervals were accompanied by a significantly heightened RMSSD and SDNN. These are predominantly parasympathetically mediated heart rate variability indices (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). There was also a non-significant trend towards increased high-frequency spectral power. It would appear, therefore, that the longer RR-intervals in tertile 2 are associated with higher cardiac parasympathetic modulation in this group.

Previous comparisons of groups similar to tertile 2 and tertile 3 are uncommon in the literature (Buchheit *et al.*, 2004; Melanson, 2000). Melanson (2000) found longer RR-intervals in moderately active (1000–2000 kcal · week^{-1}) and highly active ($>$2000 kcal · week^{-1}) individuals compared with the least active group ($<$1000 kcal · week^{-1}). In common with our findings, Melanson (2000) also found higher parasympathetically modulated heart rate variability values (RMSSD, SDNN) in the moderate group, but found no additional increment

Table III. Linear and quadratic relationships between Baecke score, mean RR-interval, and selected heart rate variability indices.

	RR-interval		Baecke score	
Measure	Linear	Quadratic	Linear	Quadratic
Baecke score	$^\star R^2 = 0.21$ $P = 0.04$	$R^2 = 0.22$ $P = 0.10$		
SDNN (ms)	$^\star R^2 = 0.20$ $P < 0.001$	$^\star R^2 = 0.22$ $P < 0.001$	$R^2 = 0.005$ $P = 0.49$	$R^2 = 0.05$ $P = 0.09$
RMSSD (ms)	$^\star R^2 = 0.26$ $P < 0.001$	$^\star R^2 = 0.27$ $P < 0.001$	$R^2 = 0.001$ $P = 0.78$	$R^2 = 0.05$ $P = 0.10$
HF (ln ms^2)	$^\star R^2 = 0.24$ $P < 0.001$	$^\star R^2 = 0.24$ $P < 0.001$	$R^2 = 0.001$ $P = 0.73$	$R^2 = 0.010$ $P = 0.59$
LF (ln ms^2)	$^\star R^2 = 0.11$ $P = 0.001$	$^\star R^2 = 0.11$ $P = 0.005$	$R^2 = 0.01$ $P = 0.34$	$R^2 = 0.02$ $P = 0.49$
LF (nu)	$R^2 = 0.01$ $P = 0.28$	$R^2 = 0.01$ $P = 0.60$	$R^2 = 0.02$ $P = 0.14$	$R^2 = 0.06$ $P = 0.05$
LF : HF	$R^2 = 0.02$ $P = 0.19$	$R^2 = 0.02$ $P = 0.42$	$R^2 = 0.03$ $P = 0.11$	$R^2 = 0.05$ $P = 0.90$

Note: RR interval = the mean length of the filtered RR-intervals. SDNN = the standard deviation of all normal-to-normal RR intervals. LF (ln ms^2) = low-frequency (0.04–0.15 Hz) spectral power in log ms^2. HF (ln ms^2) = high-frequency (0.15–0.40 Hz) power in log ms^2. LF (nu) = proportion of the spectral power from 0.04 to 0.40 Hz that is in the low-frequency band, calculated using LF/(LF + HF). LF : HF = the ratio of low to high spectral power. Please note that HF (nu) is not included as it is the inverse of LF (nu).

in these indices between the moderate and the high groups. Using groups ranging from sedentary to highly trained athletes, Buchheit *et al.* (2004) found longer RR-intervals and higher parasympathetic modulation (high-frequency power) in moderately active compared with less active individuals. Despite possessing the longest mean RR-intervals, the most active participants had lower parasympathetic modulation than the moderately active and sedentary participants.

Our findings agree with those of Melanson (2000). We found no additional difference in RR-interval length in tertile 2 compared with tertile 3, and found the highest values for all parasympathetic heart rate variability indices in tertile 2. In contrast to the findings of Melanson (2000), SDNN was significantly elevated in tertile 2 compared with tertile 3. Our findings also agree with those of Buchheit *et al.* (2004), in that the longest RR-intervals were observed for the participants in the most active group. We do not, however, concur with their results showing significantly decreased parasympathetic indices in the most active volunteers. Differences in results between the work of Buchheit *et al.* (2004) and the present study are likely to be due to group allocation methodologies. Buchheit *et al.* (2004) hypothesized that the significant reduction in high-frequency power in the highly active group showed a negative dose–response. There is no comparable group in our study to either support or refute this statement, as all of our participants would fall into the "moderate" classification used previously. Our data demonstrate some agreement with previous studies (Buchheit *et al.*, 2004; Melanson, 2000) but do not agree fully with either. Direct between-study comparisons should only be made with caution due to methodological differences.

Relationship between habitual physical activity, mean RR-interval, and heart rate variability

Few studies have examined the relationship between habitual physical activity and RR-interval length in young volunteers. In middle-aged volunteers, a standard dose–response (Rennie *et al.*, 2003) and a negative dose–response relationship (Buchheit *et al.*, 2005, 2006) have both been reported. It is of note that the latter studies recruited highly active individuals to the most active group. In our study, we found significant, positive linear relationships between all raw heart rate variability indices (SDNN, RMSSD, high-frequency spectral power, low-frequency spectral power) and RR-interval length as expected (Bigger *et al.*, 1992). Habitual physical activity correlated only with mean RR-interval length and no relationships between habitual physical activity and heart rate variability were observed. Heart rate variability measures showed no dose–response between the more fit groups in our study and other cross-sectional data show a negative dose–response (Buchheit *et al.*, 2005, 2006). Longitudinal studies have shown that 3 months of moderate exercise is sufficient to increase heart rate variability indices and that longer-term, more intense training results in no further gains (Iwasaki, Zhang, Zuckerman, & Levine, 2003; Okazaki *et al.*, 2005). The lack of a dose–response between exercise levels and heart rate variability indices appears to be a reproducible physiological phenomenon.

Physiological explanations for differences in RR-interval and parasympathetic heart rate variability

The present findings seem to create something of a paradox. Tertiles 2 and 3 represent groups of young, healthy individuals who are moderately active, with similar resting heart rates. The less active individuals (tertile 2), however, have higher values for parasympathetic heart rate variability indices (high-frequency spectral power, RMSSD, SDNN) compared with tertile 3. This suggests greater cardiac parasympathetic modulation in tertile 2 than in tertile 3 but with a shorter resultant RR-interval. In addition, raw heart rate variability measures correlate positively with RR-interval length, RR-interval length correlates positively with habitual physical activity, but raw heart rate variability measures show no relationship with physical activity. The association between habitual physical activity and RR-interval appears to be modulated by mechanisms not measured by heart rate variability. Heart rate variability is a good indicator of cardiac parasympathetic modulation, whereas RR-interval length is determined by: parasympathetic activity, sympathetic activity and the intrinsic firing rate of the sino artrial node. Habitual physical activity may, therefore, be linked to RR-interval via differences in sympathetic activity or non-autonomic mechanisms not measured in this study, such as intrinsic heart rate or left ventricular hypertrophy.

Conclusions

Even within relatively homogeneous individuals, habitual physical activity is associated with differing amounts of cardiac parasympathetic modulation and RR-interval length. Within the normal range of habitual physical activity, less active individuals have lower cardiac parasympathetic modulation and a shorter mean RR-interval than their more active counterparts.

Subgroups of more active individuals also show differences in cardiac parasympathetic modulation measured by heart rate variability not associated with differing RR-interval length. The present methodologies cannot provide physiological reasons for such findings. Similarly, the relationship between mean RR-interval length and self-reported habitual physical activity appears to be linear, but no significant relationships between habitual physical activity and heart rate variability appear to exist. The association between habitual physical activity and RR-interval length may be mediated via mechanisms not measured by heart rate variability.

Limitations and recommendations

The use of self-reported physical activity remains a limitation. The Baecke Questionnaire may have lacked the discriminative power necessary to subclassify all groups correctly. Participants in tertile 3 may have falsely assigned themselves by overestimating physical activity but in reality were very similar to those in tertile 2. It is also possible that the additional physical activity carried out by participants in tertile 3 was not aerobic in nature (e.g. resistance training). Whereas aerobic exercise significantly influences heart rate variability, mixed aerobic and anaerobic activities have a less pronounced effect (Aubert *et al.*, 2001). It may be of interest to repeat the analysis with individuals classified according to an objective variable, closely linked to aerobic training, such as anaerobic threshold or maximal oxygen consumption. In the present study, however, the variable of interest was habitual physical activity, not physical fitness. A questionnaire-based assessment was chosen to reduce recruitment bias as much as possible. The requirement for an exercise test may have reduced the external validity of the sample used by "pre-selecting" more physically active individuals.

Further research using combinations of accelerometry and indices of aerobic capacity may provide an objective score with which to classify individuals, and may be able to bridge the gap in data between the "general population" sample used here and findings from highly trained athletes reported previously. Objective measurements will provide values that may be regressed against RR-interval and heart rate variability to better quantify the magnitude, direction, and nature of the relationship between these measures.

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