

Solernó, Juan I. ; Pérez Chada, Daniel ; Guinjoan, Salvador M. ; Pérez Lloret, Santiago ; Hedderwick, Alejandro ; Vidal, María Florencia ; Cardinali, Daniel P. ; Vigo, Daniel E.

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Cardiac autonomic activity predicts dominance in verbal over spatial reasoning tasks: results from a preliminary study

Juan I. Solernó ^a; Daniela Pérez Chada ^a; Salvador M. Guinjoan ^{b,c,e}; Santiago Pérez Lloret ^a; Alejandro Hedderwick ^a; María Florencia Vidal ^a; Daniel P. Cardinali ^{d,e}; Daniel E. Vigo ^{d,e}

^a Departamento de Fisiología, Facultad de Medicina, Universidad de Buenos Aires (UBA), Buenos Aires, Argentina; ^b Fundación para la Lucha contra las Enfermedades Neurológicas de la Infancia (FLENI), Buenos Aires, Argentina; ^c Departamento de Salud Mental, Facultad de Medicina y Cátedra de Neurofisiología I, Facultad de Psicología, UBA, Buenos Aires, Argentina; ^d Departamento de Docencia e Investigación, Facultad de Medicina, Universidad Católica Argentina, Buenos Aires, Argentina; ^e Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina.

Short title

Autonomic activity and reasoning tasks

Contact information

Daniel E. Vigo

Departamento de Docencia e Investigación – Facultad de Ciencias Médicas - Universidad Católica Argentina

Alicia Moreau de Justo 1550

C1107AAZ - Ciudad Autónoma de Buenos Aires

Argentina

Tel/Fax: 54 11 43490200 E-Mail: dvigo@conicet.gov.ar; dvigo1973@gmail.com

Abstract

The present study sought to determine whether autonomic activity is associated with dominance in verbal over spatial reasoning tasks. A group of 19 healthy adults who performed a verbal and spatial aptitude test was evaluated. Autonomic function was assessed by means of heart rate variability analysis, before and during the tasks. The results showed that a better relative performance in verbal over spatial reasoning tasks was associated with vagal prevalence in normal subjects.

Key Words

Autonomic nervous system; heart rate variability; laterality; verbal; spatial; aptitude tests

Introduction

There is increasing evidence on the role of areas previously implicated in cognitive and emotional behaviors (i.e., insula, cingulate cortex) in central representation of peripheral autonomic states (Critchley et al., 2000; Critchley et al., 2003). In addition, there is evidence that brain structures are asymmetrically involved in the control of sympathetic and parasympathetic activity. Activity in the right prosencephalon is associated with energy expenditure, sympathetic activity, arousal, aversive behavior and survival emotions, whereas activity in the left forebrain is associated with energy nourishment, parasympathetic activity, relaxation, appetitive behavior and affiliative emotions (Craig, 2005; Craig, 2009; Guinjoan et al., 2010).

Differential hemispheric brain activity can be explored during the performing of spatial and verbal tasks (Smith et al., 1996). Using position emission tomography, Smith and coworkers reported that verbal and spatial working memory are implemented by different neural structures, verbal memory involving mainly left-hemisphere regions while spatial memory involves predominantly right-hemisphere regions (Smith et al., 1996). Moreover, functional magnetic resonance imaging studies showed that hemispheric dominance for working memory exists in the form of quantitative differences in activation within the prefrontal cortex, with left ventral prefrontal cortex supporting preferentially verbal working memory and right dorsal prefrontal cortex supporting preferentially spatial working memory (Walter et al., 2003).

An autonomic correlate of differential hemispheric brain activity induced by time-limited spatial and verbal inductive reasoning tasks was proposed by Melis et al (Melis and

van Boxtel, 2001) who reported that the sympathetic response was relatively more important in poor performers, whereas the parasympathetic response predominated in good performers (Melis and van Boxtel, 2001). Since, in good performers, sympathetic activity was relatively more important during the spatial than during the verbal reasoning task, the findings were explained as indicating a hemispheric lateralization of the autonomic function (Melis and van Boxtel, 2001).

However, it is not known whether differential brain domain dominance, reflected by performance in inductive reasoning tasks, is also reflected in a differential resting and on-task autonomic pattern. This prompted us to carry out the present preliminary study aiming to determine whether performance in verbal and spatial cognitive tasks is associated with a particular balance of sympathovagal activity onto the heart.

2. Methods

2.1. Subjects and design

We studied 19 healthy young graduate students (53 % female, mean age 21.5 ± 0.5 years) who gave their written informed consent as approved by the local review board. All of them were right-handed. Exclusion criteria were the presence of any acute medical condition reported by the subject.

Five-minute electrocardiogram recordings were obtained during rest, a verbal abilities task, and a spatial abilities task, presented in a random fashion.

2.2. Cognitive tasks

Participants were asked to perform the Bennett-Seashore-Wesman Differential Aptitude Test, with components of verbal and spatial abilities (Bennet G et al., 1999). Briefly, the test includes multiple choice questions that should be answered within a set time limit. Scaled and percentile scores are then obtained to account for age and sex differences. The verbal subtest measures the ability to find relations among words and manipulate abstract ideas. It contains incomplete sentences; each one without the first and the last word. The subject should select, from a list of five options, the two words that complete the sentence so as to make it coherent. Thirty minutes was the maximal time to complete the task. In the space relations subtest the participant is asked to analyze three dimensional characteristics of a series of figures. The subject should select, from a list of four options, the 2-dimensional figure that can be converted into the given 3-dimensional shape. Twenty five minutes was the maximal time to complete the task.

2.3. Heart Rate Variability Analysis

Autonomic nervous system activity was assessed through Heart Rate Variability analysis (HRV). HRV analysis was performed on the ECG recording of the resting period and on the initial 5-min ECG recording of each test.

Electrocardiogram signal was recorded using a digital Holter device (Holter HCAA 348, Servicios Computados S.A., Buenos Aires, Argentina). The time elapsed between R waves (RR intervals) was computed and premature and lost beats were replaced by RR intervals resulting from linear interpolation (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

Time domain HRV analysis included RRm (mean duration of RR intervals in ms), which quantifies the mean heart rate; SDNN (standard deviation of RR intervals in ms), which represents a coarse quantification of overall variability; and RMSSD (square root of the mean squared differences of successive normal RR), which measures short-term heart rate variations associated with parasympathetic activity (Seely and Macklem, 2004; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

Frequency domain (spectral) measurement of HRV were obtained by Fast Fourier Transform, and included total spectral power (TP, 0-0.4 Hz, ms²), very low frequency power (VLF, < 0.04 Hz, ms²), low frequency power (LF, 0.04-0.15 Hz, ms²), high frequency power (HF, 0.15 - 0.4 Hz, ms²) and their percentage values (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). HF is related to respiratory sinus arrhythmia and mediated solely by parasympathetic activity, whereas LF is related to baroreflex control and depends upon sympathetic and parasympathetic mechanisms (Stauss, 2003). In short term recordings, VLF rhythm is related with changes in mean heart rate (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), and depends primarily on the presence of parasympathetic outflow (Taylor et al., 1998).

2.4. Statistical analysis

Sample size was determined on the basis of a power analysis aiming at being able to identify correlations coefficients ≥ 0.6 between Spatial/Verbal subtests scores ratio with essential HRV parameters. It was determined that 17 subjects would be enough for this purpose, setting alpha and beta errors at 5% and 20% respectively.

Values were expressed as mean \pm standard error or frequency (percentage). Normality of distributions was assessed by means of a Kolmogorov-Smirnov Test. Differences between verbal and spatial scores were evaluated with a T-test for related samples. Dominance in verbal over spatial reasoning tasks was defined as the ratio between the verbal and the spatial aptitude test score. Resting HRV indexes were correlated with verbal dominance. The HRV indexes obtained during the verbal and the spatial tasks, as well as their ratio, were also correlated with verbal dominance. All correlations were assessed by means of the Pearson's correlation test.

3. Results

The score in the verbal aptitude test was of 75.6 ± 4.4 and in the spatial aptitude test of 53.5 ± 5.8 , ($T = 4.02$, $df = 18$, $p < 0.001$). The mean relation between verbal and spatial test scores was of 1.7 ± 0.2 .

Correlation between HRV and aptitude tests scores is shown in table 1. Verbal dominance was positively correlated with RRm, SDNN and RMSSD at rest; with RRm, RMSSD and HF during the verbal task; and with RRm, global HRV (TP, SDNN) and all HRV frequency components (HF, LF, VLF) during the spatial task (table 1).

When considering the HRV verbal / spatial ratios, lower TP and higher HF% were associated with verbal dominance. The negative correlation of TP appears because TP in the spatial test (but not TP in the verbal test) correlates positively with verbal dominance. The positive correlation of HF% appears because HF% is the quotient between HF (positively correlated with verbal dominance during the verbal test) and HF+LF+VLF (positively correlated with verbal dominance during the spatial test) (table 1).

4. Discussion

The main result of this preliminary study is that parasympathetic predominance was associated with a better performance in the verbal test as compared to performance in the spatial test.

Verbal dominance was positively correlated with different HRV indexes, depending on whether it was measured at rest, during the verbal test, during the spatial test, or when considering the HRV verbal / spatial ratios. Although these indexes were not consistently correlated in every stage, they all reflect different degrees of parasympathetic predominance, as seen when passing from stand to supine (higher values of RRm, SDNN, RMSSD and all absolute frequency domain indexes) (Task Force of the European Society

of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), when going from wake to NREM sleep (higher values of RRM and HF%) (Vigo et al., 2010) or in endurance trained athletes (higher values of RRM and HF) (Dixon et al., 1992).

This observation pointing out that subjects with vagal predominance performed relatively better in verbal tasks agrees with the fact that the left prefrontal cortex supports preferentially both verbal working memory (Walter et al., 2003) and parasympathetic activity (Craig, 2005; Craig, 2009). Conversely, subjects with sympathetic predominance performed relatively better in spatial tasks, in line with observations that the right prefrontal cortex supports preferentially both spatial working memory (Walter et al., 2003) and sympathetic activity (Craig, 2005; Craig, 2009).

Alternative interpretations for the present observations can be entertained. The poor results in the spatial task could reflect a higher relative difficulty in its resolution. Subjective task difficulties impose higher cognitive loads that mobilize physiological reserves as part of a natural response to such tasks (Hoyland et al., 2008; Kennedy and Scholey, 2000). In this regard, the vagal withdrawal associated with the increase in performance in spatial tasks reported herein could reflect the activation of the 'sympathetic' right forebrain, reacting to a higher cognitive load imposed by the difficulty of the task, to fully accomplish an extended energy expenditure (Craig, 2005).

The main limitation of our study is the small sample size. It is thus possible that important correlations with coefficients lower than 0.6 (i.e. the predefined threshold of interest), could have been missed in the present study due to insufficient power. However,

our preliminary results suggest a clear relationship between parasympathetic activity and verbal efficacy, which will have to be confirmed in larger studies.

It is clear that the interpretations hereby entertained require fMRI studies to determine whether the autonomic asymmetries correlate with differential hemispheric activation during the execution of the tasks. Nonetheless, the data presented contribute to the characterization of the pattern of autonomic response associated with the performance of differential aptitude tests.

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Table 1. Correlation coefficients between HRV and verbal dominance.

	Resting	On-task verbal	On-task spatial	On-task verbal / spatial
RRm (ms)	0.573 *	0.548 *	0.576 **	0.048
SDNN (ms)	0.498 *	0.440	0.699 **	-0.445
RMSSD (ms)	0.613 **	0.591**	0.657 **	-0.289
ln TP (ms ²)	0.403	0.367	0.655 **	-0.472 *
ln VLF (ms ²)	0.389	0.226	0.473 *	-0.432
ln LF (ms ²)	0.393	0.400	0.670 **	-0.314
ln HF (ms ²)	0.301	0.502 *	0.625 **	-0.024
VLF (%)	0.072	-0.295	-0.249	-0.074
LF (%)	0.015	0.158	0.251	-0.027
HF (%)	-0.099	0.191	-0.020	0.574 *

Shown are Pearson's r correlation coefficients of HRV measurements during rest and tasks with verbal/spatial aptitude test score. * p < 0.05, ** p < 0.01. RRm, mean RR interval; SDNN, standard deviation of all normal RR intervals; RMSSD, square root of the mean squared differences of successive normal RR; TP, total spectral power; VLF, very low frequency power; LF, low frequency power; HF, high frequency power.

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