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ORIGINAL ARTICLE

Heartbeat scaling in early adolescents: Its association with anxiety symptoms and sensitivity to punishment

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Abstract *Background/Objective*: Anxiety symptoms in adolescence have been found to be associated with heart rate variability (HRV) linear features, but more basic properties of the cardiac system remain unexplored. This study focused on the fractal nature of 90 minute-long interbeat fluctuations from 24 adolescents with high anxiety and 26 with low anxiety to (a) evaluate if allometric scaling exponents and linear HRV measures allow for distinction between groups, and (b) assess the associations between these measures and sensitivity to punishment (SP), a temperamental characteristic strongly correlated with anxiety. *Method*: Cardiac functioning was recorded and allometric exponents and vagally mediated HRV as indexed by the high frequency (HF) band power were calculated. *Results*: While the exponents from the high anxiety group were significantly higher than those from low anxiety participants ($p < .05$), just marginal differences were found for the HF measure ($p = .057$). Furthermore, exponents were positively correlated with SP scores and several anxiety scale scores, but no more correlations were found. *Conclusions*: These results show that beyond parasympathetic functioning, basic properties of the cardiac system may be altered in young, anxious adolescents. These properties, therefore, can provide useful information for assessing adolescents at risk of anxiety disorders.
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PALABRAS CLAVE
Ansiedad;
adolescencia;
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fractalidad;
estudio *ex post facto*

Fractalidad cardiaca en adolescentes tempranos: sus asociaciones con la sintomatología ansiosa y la sensibilidad al castigo

Resumen *Introducción/Objetivo*: Se ha asociado la existencia de sintomatología ansiosa con algunas propiedades lineales de la variabilidad cardiaca (VC), sin prestar demasiada atención a propiedades más esenciales del sistema cardiaco, como su naturaleza fractal. En este trabajo se

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pretendía evaluar si medidas de fractalidad (exponentes alométricos) y medidas de VC (potencia en la banda de altas frecuencias, AF) permitían distinguir entre 24 adolescentes con alta sintomatología ansiosa y 26 adolescentes con baja. Además, se perseguía explorar las asociaciones de estas medidas con sensibilidad al castigo (SC), un factor de riesgo para ansiedad. *Método*: Se tomó la actividad cardiaca de los adolescentes en contexto ecológico y se calcularon dichas medidas sobre registros de 90 minutos. *Resultados*: Se encontraron exponentes alométricos significativamente mayores para los adolescentes con alta ansiedad ($p < 0,05$), sin observarse diferencias significativas en potencia de AF ($p = 0,057$). Además, sólo se encontraron correlaciones positivas significativas entre los exponentes alométricos con SC, y dichos exponentes con varias escalas de ansiedad. *Conclusiones*: Estos resultados muestran que propiedades más básicas del sistema cardiaco parecen estar alteradas en adolescentes ansiosos más allá de la mera influencia parasimpática. Estas propiedades pueden aportar información relevante para la detección y prevención de trastornos de ansiedad.
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Fluctuations in the length of successive interbeat intervals are not random but fractal-like, i.e. similar patterns of fluctuations can be seen at different temporal resolutions (Goldberger, 1996; West, 2010; West, Brown, & Enquist, 1999). In other words, there is multistability and the heart does not beat within one single time scale: different set points (at different time scales) are available to the heart system providing flexibility to respond effectively to the incoming demands. In addition, altered fractal dynamics in the heartbeat have been found to be associated with disease and aging (Goldberger et al., 2002; Sturmberg, Bennett, Picard, & Seely, 2015).

Based on these findings, West (2006) introduced the concept of allometric control. Classical explanations for heart beat fluctuations embraced homeostasis as the key control mechanism of the seemingly random deviations from the mean interbeat interval length. Homeostatic control would operate at just one single, real-time scale and the system producing those fluctuations would be memoryless. Allometric control, conversely, means that there are control mechanisms that operate at different time scales and that the system has a built-in long-term memory. West (2006) suggested that scale-free fluctuations would emerge mainly from the interaction of the two branches of the autonomous nervous system (ANS), the sympathetic and the parasympathetic branches (see also Ivanov, Chen, Hu, & Stanley, 2004; Lehrer & Eddie, 2013).

Fractal objects look the same at different spatial scales or resolutions. Similarly, fractal time series should look the same when seen at different temporal resolutions. Therefore, perhaps the most intuitive way to check if a signal shows multistability (and hence to get some evidence that it is under allometric control mechanisms) is to examine this signal at different time resolutions and test the invariance of the relationship between its mean and its variance along those resolutions. This procedure is very similar to the one introduced by B. Mandelbrot to demonstrate the fractal nature of the coast of Great Britain (Mandelbrot, 1967). The relationship between the length of the coast and the scale that we use to measure it remains invariant, so that when we plot the length obtained using each scale on log-log axes a straight line can be traced that crosses all these points, and the slope of this line (which is invariant all along the line) provides a calculation of the fractal dimension of the shape of the coast. Allometric aggregation (West, 2006) allows for testing fractality in temporal objects (i.e. time series) by plotting the means and the variances for successively aggregated values (i.e. different resolutions) from a time series on log-log axes. The slope of the straight line that fits these values on the plot is the scaling exponent that gives a quantitative measure of the scale invariance present in the data (a detailed explanation of the allometric aggregation procedure can be found in the Methods section). This procedure is more straightforward and less time-consuming than other methods like detrended fluctuation analysis (Peng, Havlin, Stanley, & Goldberger, 1995) and could be performed using any standard spreadsheet. This may seem trivial, but sophisticated mathematical procedures are not easy for most Clinical Psychology researchers, and this is probably one of the reasons that could explain why they are reluctant to use nonlinear measures based on those complex procedures. However the main reason why most research addressing the relationships between the heart system and anxiety has not taken into account the fractal-like properties of the cardiac system is the leading existence of the influential models developed by Thayer and Lane (2000, 2009) or Porges (2001).

These models emphasize the parasympathetic or vagally-mediated heart rate variability (vmHRV). In truth, there is a large body of research pointing at an association between diminished vmHRV and several anxiety disorders (see Beauchaine & Thayer, 2015; Chalmers, Quintana, Abbott, & Kemp, 2014). Furthermore, most studies on general population and clinical samples have found a positive association between the behavioral inhibition system (BIS) sensitivity or sensitivity to punishment (SP) and anxiety symptomatology (Bijttebier, Beck, Claes, & Vandereycken, 2009; Panayiotou, Karekla, & Panayiotou, 2014), and associations have also

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