Early Human Development 90 (2014) 33–38

Contents lists available at ScienceDirect

Early Human Development

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

Aerobic exercise during pregnancy influences infant heart rate variability at one month of age

Linda E. May [a], Susan A. Scholtz [b], Richard Suminski [c], Kathleen M. Gustafson [b,d,*]

[a] Division of Surgical Sciences, East Carolina University, Greenville, NC, USA
[b] Hoglund Brain Imaging Center, University of Kansas Medical Center, Kansas City, KS, USA
[c] Department of Basic Medical Sciences, KCUMB, Kansas City, MO, USA
[d] Department of Neurology, University of Kansas Medical Center, Kansas City, KS, USA

ARTICLE INFO

Article history:
Received 18 April 2013
Received in revised form 28 October 2013
Accepted 5 November 2013

Keywords:
Autonomic nervous system
Heart rate variability
Exercise
Pregnancy
Fetal programming
Magnetocardiology

ABSTRACT

Background: Previously, we reported that regular maternal aerobic exercise during pregnancy was associated with lower fetal heart rate (HR) and higher heart rate variability (HRV) at 36 weeks gestation. We now report the effect of maternal exercise on infant HR and HRV in subjects who remained active in the study at the one-month follow up visit.

Aims: We aimed to determine whether differences in fetal cardiac autonomic control related to maternal physical activity were an *in utero* phenomenon or would persist 1 month after birth.

Study design: Magnetocardiograms (MCGs) of infants born to regularly exercising (≥30 min of aerobic activity, 3 times per week; N = 16) and non-exercising (N = 27) pregnant women were recorded using a fetal biomagnetometer. Normal R-peaks were marked to derive infant HR and HRV in time and frequency domains, including the root mean square of successive differences (RMSSD), the standard deviation of normal-to-normal interbeat intervals (SDNN), and power in the low frequency (LF) and high frequency (HF) bands. Group differences were examined with Student's *t*-tests.

Results: Infants born to exercising women had significantly higher RMSSD ($P = 0.010$), LF power ($P = 0.002$), and HF power ($P = 0.004$) than those born to women who did not engage in regular physical activity while pregnant.

Conclusion: Infants born to women who participated in regular physical activity during pregnancy continued to have higher HRV in the infant period. This suggests that the developing cardiac autonomic nervous system is sensitive to the effects of maternal physical activity and is a target for fetal programming.

1. Introduction

In the absence of obstetric complications, moderate exercise during pregnancy is generally considered safe and poses no known risk to the fetus [1–8]. Epidemiological data suggest that regular physical activity throughout pregnancy improves maternal cardiovascular function [3], limits weight gain and fat retention [9], improves insulin resistance and metabolic control [9–11], prevents the onset of gestational diabetes mellitus [12,13], reduces the incidence of operative delivery [14], and decreases depressive symptoms in the postnatal period [15,16]. Maternal exercise has also been shown to benefit the fetus, improving fetal stress tolerance [17], reducing neonatal fat mass [3,18–20] and advancing neurobehavioral maturation [18,19].

We and others have demonstrated that maternal nutrition [21] and the intrauterine environment can influence fetal cardiac autonomic control [22–24]. Previous studies employing ultrasound technology have indicated that the fetal cardiovascular system is responsive to maternal exercise [25–27]. We found continuous, aerobic maternal exercise to be associated with lower fetal heart rate (HR) and higher heart rate variability (HRV) at 36 weeks gestational age (GA) [28]. Furthermore, we found fetal HR to be lower as the *intensity* of maternal physical activity increased while fetal HRV was positively associated with the *duration* of maternal physical activity [29].

The beat-to-beat variation in the duration of the R–R interval (HRV), has proven to be a useful, noninvasive tool to assess cardiac autonomic function. Reduced HRV in adults is associated with a number of cardiovascular risk factors and disease states, such as diabetes [30], obesity [31] and hypertension [32] and is a known predictor of mortality after myocardial infarct [33,34]. However, in the developing fetus and infant, metrics of HRV are more than a measure of cardiac autonomic control; they serve as a proxy for the degree of integration between central and peripheral nervous systems. The integration of autonomic function and fetal behaviors are the earliest precursors to newborn behavioral regulation [35]. For example, HRV serves as an index of attention regulation in newborns [36], orientation in neonates [37], and early life information processing [38].

* Corresponding author at: 3901 Rainbow Blvd., MS 1052, Kansas City, KS 66160, USA. Tel.: +1 913 588 0065; fax: +1 913 588 9071.
E-mail address: kgustafson@kumc.edu (K.M. Gustafson).

0378-3782/$ – see front matter © 2013 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.earlhumdev.2013.11.001

Epidemiologic studies have confirmed the observation that certain environmental or nutritional exposures during fetal development can increase the risk of developing noncommunicable diseases, such as diabetes and cardiovascular disease, in adulthood [39–44]. Because individual differences in HRV have been shown to originate before birth and persist from prenatal to postnatal life [45], we wanted to determine whether the differences we observed in fetal HR and HRV related to maternal physical activity would continue into the infant period. If this effect persists after birth, it would provide evidence of prenatal programming, suggesting that the fetal autonomic nervous system is sensitive to programming effects and that that regular maternal physical activity during pregnancy may serve as the earliest intervention to improve cardiac autonomic function. To our knowledge, no longitudinal studies have been conducted to examine the influence of prenatal maternal physical activity on measures of cardiac autonomic control in the neonate. This study aimed to determine if the maternal exercise effects observed during pregnancy continued to influence infant HR and HRV at 1 month of age.

2. Subjects and methods

2.1. Subjects

The study population consisted of a subset of infants born to women enrolled in a prospective, longitudinal pilot study designed to determine the influence of maternal exercise on fetal cardiac autonomic nervous system development [28] (Fig. 1). Sixty-seven women enrolled in the primary study. Women were eligible for enrollment if they were 20 to 35 years of age and less than 28 weeks' gestation. Subjects were excluded if they were expecting multiple infants or considered to have a high-risk pregnancy. All subjects were non-smokers with no history of alcohol or illicit drug use. Women were invited to return for a postnatal magnetocardiogram (MCG) when their infant was one-month of age. Of the original cohort, 46 agreed to participate in the follow-up study. Informed consent was obtained prior to study participation. The research protocol and informed consent forms adhered to the Declaration of Helsinki (including the October 1996 amendment) and were approved by the Institutional Review Boards at the University of Kansas Medical Center and Kansas City University of Medicine and Biosciences.

2.2. Group classification

As detailed in previous publications, physical activity was assessed at 28 and 36 weeks' gestation using the Modifiable Physical Activity Questionnaire (MPAQ). Briefly, women were assigned to the exercise group if they engaged in moderate to vigorous aerobic exercise for a minimum of 30 min, three times per week throughout pregnancy [28]. Those who did not meet this criterion were assigned to the control group.

2.3. Data acquisition

A continuous, 18-minute MCG recording was obtained in infants at one month of age using an investigational 83-channel fetal biomagnetometer (CTF Systems Inc., subsidiary of VSM MedTech Ltd., Vancouver, Canada) housed in a magnetically shielded room to eliminate the influence of electromagnetic artifacts. Infants were placed in a foam support chair approximately 10 cm from the sensor array (Fig. 2). Recordings were made when the infants were in a quiet, but alert state. If the infant became fussy or started to cry, the recording was aborted and restarted after the infant was soothed. If the infant could not be consoled, the mother cradled the infant in front of the sensor array. Data were sampled at 300 Hz. Digital filtering between 1 and 40 Hz (bidirectional fourth-order Butterworth filters) was applied offline.

2.4. Data pre-processing

Multivariate data were subjected to an Infomax independent component analysis algorithm implemented in EEGLAB [46]. Fiducial QRS points were automatically detected using a template-matching algorithm. False-positive and false-negative detections were manually corrected and abnormal beats removed from the subsequent analysis [47,48]. Infant HRV was analyzed in both time and frequency domains. The time domain measures included the root mean square of successive differences (RMSSD) and the standard deviation of normal-to-normal interbeat intervals (SDNN). These serve as measures of short-term and overall HRV, respectively. For frequency domain measures, a Fast Fourier Transform was applied to the HR plot and derived power in the low frequency (LF, 0.04–0.2 Hz) and high frequency (HF, 0.2–1.5 Hz) bands. The LF band is thought to contain contributions from both sympathetic and parasympathetic arms of the autonomic nervous system, while the HF band is considered to serve as a measure of parasympathetic (vagal) control. Respiratory sinus arrhythmia is captured in the HF band, reflecting the sinusoidal increase and decrease in HR from cardiac vagal efferent effects on the sinoatrial node. The strength of the signal within these frequency ranges is described in terms of power in milliseconds squared. The LF/HF ratio was calculated as a measure of sympatho-vagal balance.

2.5. Statistical analysis

Descriptive statistics were computed for maternal subject characteristics, including age, resting heart rate, pre-pregnancy BMI, and gestational weight gain (pre-pregnancy weight to 36 weeks GA) (Table 1). Pearson's correlation coefficients (two-tailed) were used to identify potential covariates of infant HR and measures of HRV, including maternal characteristics (maternal age, maternal resting HR, gestational weight gain, pre-pregnancy BMI) and infant sex. As no significant correlations were identified, Student's *t*-tests were used to compare infant HR, RMSSD, SDNN, LF power, HF power, and LF/HF between the exercise and control groups. RMSSD, LF power, and HF power were positively skewed. Thus, a log transformation was employed to normalize the distributions before group comparison. Model assumptions were examined using the Kolmogorov–Smirnov test, Shapiro–Wilk test, and Levene's Test of Equality of Error Variances. All data were analyzed with IBM SPSS Statistics 20.0 software (SPSS, Chicago, IL), and P-values ≤ 0.05 were considered significant.

3. Results

Of the 46 postnatal MCGs recorded, 3 were rejected due to an excessively fussy infant state, resulting in a final sample size of 43 ($N = 23$ females and 20 males). Infant HR, SDNN, RMSSD, LF power, HF power, and LF/HF did not vary by infant sex and were not significantly correlated with maternal age, maternal resting heart rate, gestational weight gain, or pre-pregnancy BMI (data not shown).

Log transformation normalized the distributions of RMSSD, LF power and HF power (Fig. 3). Similar to our findings during the fetal period, infants born to women who engaged in moderate to vigorous aerobic exercise had significantly higher short-term HRV (RMSSD; $P = 0.010$), LF power ($P = 0.002$), and HF power ($P = 0.004$) at one month of age than those born to women in the control group (Table 2).

Infant HR was lower (147 *vs.* 153 beats per minute) and overall HRV (SDNN) was higher (38.8 ms *vs.* 34.8 ms) in the exercise group when compared to control, but neither variable reached significance: HR ($P = 0.185$), SDNN ($P = 0.342$). Maternal exercise was not significantly related to sympatho-vagal balance (LF/HF ratio; $P = 0.763$) (Table 2).