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Cardiac autonomic regulation as a predictor for childhood obesity intervention success

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Abstract

Childhood obesity is a major public health concern; behavioural interventions induce weight reduction in some, but success is variable. Heart rate variability (HRV) has been associated with impulse control and extent of dieting success. This study investigated the relationship between HRV and post childhood obesity intervention weight-management success, and involved recording the frequency-domain HRV measures LF/HF and HF, and the time-domain measure PNN50. It was expected that greater LF/HF and lower HF would be associated with greater post-intervention weight gain, and that greater PNN50 would be associated with greater impulse control. Seventy-four participants aged 9-14 (M 10.7, SD 1.1) attended a weight-management camp, where HRV was recorded. Stop signal reaction time (SSRT) was also recorded as a measure of impulse control. As expected, SSRT was positively associated with pre-intervention body mass (r = .301, p = .010) and negatively associated with PNN50 (*Beta* = .29, p = .031). Post-intervention body mass change was positively associated with LF/HF (*Beta* = .34, p = .037), but was not associated with HF. Lifestyle interventions may have a greater chance of effectively supporting long-term weight-management for children with lower LF/HF; assessing HRV of obese children may be helpful in informing obesity treatment decisions.

Introduction

Childhood obesity is highly prevalent across the globe(1) and is associated with multiple long- and short-term health risks(2). Treatments typically aim to support changes in lifestyle, with the most successful tending to include exercise, diet and behavioural components(3) Community-based treatments are typically a first-line measure, but extent of weight-loss is often relatively small(3); residential weight management camps provide an alternative, more intensive intervention to support children to change their lifestyle to achieve a healthier body weight(4, 5). Weight-management camps tend to induce greater weight loss than community interventions(4), but studies have revealed considerable between-subject variability in extent of long-term post-intervention weight management success(6). This may be partly explained by variation between attendees' levels of impulsivity. An individual's impulsivity is predictive of their being unable to resist eating to excess(7, 8), and a greater level of impulsivity in obese children has been shown to be associated with eating binges(7). Furthermore, a positive association between childhood obesity and impulsivity has been demonstrated(7, 9, 10), and more impulsive participants have been found to lose less weight in obesity interventions(7, 11).

Heart rate variability (HRV), the variation in beat-to-beat intervals in an individual's cardiac rhythm(12), is associated with impulsivity, with greater HRV being predictive of increased inhibitory neural processes and impulse control(13, 14). This enables HRV to be used as a physiological marker of inhibitory capacity(15). The present study investigated whether HRV may be predictive of post-intervention weight loss success for weight-management camp attendees.

HRV is regulated by a functional unit within the central nervous system known as the Central Autonomic Network (CAN), which supports goal-directed behaviour and adaptability(16). The primary output of the CAN is mediated through sympathetic and parasympathetic neurons that innervate the heart's sinoatrial node(12, 16). HRV is increased by high-frequency parasympathetically (or vagally) mediated modulations, and decreased by low-frequency sympathetic modulations(12, 17). Time domain measures of HRV positively correlate with high frequency power (HF), which provides a measure of vagal cardiac control, and negatively correlate with the ratio between low frequency and high frequency power (LF/HF), which provides a measure of sympatho-vagal balance(17). Higher

HRV, or vagal cardiac control, is thought to indicate greater flexibility of the cardiac system, and greater ability to adapt to changing environmental conditions(18).

Research findings have indicated a trend of greater parasympathetic and decreased sympathetic modulation in anorexic participants(19); and conversely, greater sympathetic and decreased parasympathetic modulation for obese participants(20); although these trends may be partially explained by physiological factors relating to participants' body mass(12). Recent studies controlling for body mass have found greater LF/HF and lower HF to be associated with failed attempts to restrain from eating(21), and with lack of dieting success(12). The present study involved HRV and impulse control being measured in a sample of weight-management camp attendees. In accordance with findings linking frequency domain HRV measures and dieting success(12, 21), It was expected that greater LF/HF and lower HF would be predictive of greater post-intervention weight gain. It was also expected that, in accordance with previous research(13, 14), greater time domain HRV would be associated with greater impulse control.

Methods

Participants

Ethical approval was granted by the Qatar University Institutional Review Board; all participants and their parents provided informed consent. Participant eligibility criteria were to be between 9 and 14 years of age and overweight or obese, with a body mass index (BMI) on at least the 92nd percentile for their age and gender, compared to International Obesity Taskforce(22) data.

A power calculation that predicted, using data from previous research(7, 12), inhibitory capacity as measured by frequency domain HRV variables and SSRT would predict at least 20% of the variance in weight management success, indicated that a minimum sample size of 36 would be required to achieve an alpha of 0.05 and a 1-Beta of 0.80. A greater number of participants were recruited to account for potential attrition.

Seventy-four participants (37 female) aged 9-14 (M = 10.7, SD = 1.1) were recruited from a weight-management camp in Qatar.

Materials

Participants' height and weight were measured using a wall-mounted stadiometer and calibrated SECA scale (SECA, Ohio, USA). These measures were used to calculate body mass index (BMI). BMI Standard deviation scores (SDS) were calculated by comparing BMI measures to United Kingdom population data(23).

HRV was measured using a Polar H7 Bluetooth 4.0 Heart Rate Sensor set. The sensor was strapped to participants' chests and recordings were transmitted by Bluetooth to a smartphone using the "Heart Rate Variability Logger" app(24). The HRV values measured were SDNN, PNN50, HF (measured in absolute units) and LF/HF. SDNN is the standard deviation of beat-to-beat intervals; PNN50 is the percentage of successive beat-to-beat (R-R) intervals that differ by more than 50ms; LF is low frequency power (0.04-0.15 Hz); and HF is high frequency power (0.15-0.40 Hz)(24).

Inhibitory control was measured using the CANTAB (Cambridge Cognition, Cambridge, UK) Stop Signal Task to measure stop signal reaction time (SSRT); this task has been validated(25, 26) and subsequently used extensively to measure impulse control in both children and adolescents(27). The task equipment consisted of a tablet and a connected controller, which had two buttons, and was used with headphones to enable participants to hear noise stimuli.

Procedure

Participants attended a 2-week weight management camp, which was immediately followed by ten 2-hour weekly after-school club sessions. The camp and the clubs involved the children taking part in physical activities and lifestyle education about healthy diet and exercise behaviours. Participants' height and weight were measured at the beginning and end of the camp, at the end of the after-school club stage, and a subset of participants (n = 44) attended height and weight measurement sessions 1 year after the end of the club phase. HRV and SSRT were measured during the 2-week camp.

HRV measurements and SSRT were collected in quiet rooms with at least one researcher present. HRV was measured whilst participants were sitting; recordings were of 5 minutes duration, as previous research has shown this to be appropriate(28).

The stop signal task procedure was adapted from the method described by Logan et al(9, 29) and involved participants sitting, facing the tablet screen, wearing headphones, with their index fingers resting on the two buttons of the controller. Arrows that pointed either left or right appeared on the screen and participants were instructed to press the corresponding button as quickly as possible, unless they heard a noise, in which case they were instructed to refrain from pressing any button. For each participant, the first noise stimulus occurred 250ms after the appearance of an arrow; the timing of this delay was then adjusted throughout the task, depending upon the participant's performance. The outcome variable, SSRT, is a calculation of the time the individual requires to inhibit a response following the noise stimulus. Lower SSRT indicates better impulse control.

Results

Table 1 displays descriptive statistics for HRV, SSRT and body mass outcome variables. Weight change was analysed using Wilcoxen Signed Rank tests, and relationships between variables were analysed using Pearson correlation and linear regression analysis; the experimental data met the assumptions of these tests. A significant reduction in participants' BMI SDS during the camp phase was observed (M -.22 SD .10 [$Z = -6.40$, $p < .001$]). No significant BMI SDS change was observed during the club phase (M .03 SD .22 [$Z = -1.35$, $p = .178$]) or between the end of the club phase and 1-year follow-up (M .07 SD .37 [$Z = -.96$, $p = .336$]).

BMI SDS at the start of the camp was positively correlated with SSRT ($r = .30$, $p = .010$). Negative correlations were revealed between BMI SDS at the start of camp and HF ($r = -.44$, $p = <.001$), SDNN ($r = -.72$, $p < .001$) and PNN50 ($r = -.47$, $p < .001$); SSRT was also negatively correlated with SDNN ($r = -.30$, $p = .010$) and PNN50 ($r = -.36$, $p = .002$). A regression analysis that controlled for BMI SDS at the start of camp found PNN50 to have a significant negative association with SSRT ($t(72) = -2.21$, *Beta* = -.29, $p = .031$). When BMI SDS was controlled for, SDNN was not found to have any significant independent association with SSRT scores ($t(72) = -.96$, *Beta* = -.17, $p = .339$).

A linear regression controlling for BMI SDS at the end of the club phase found LF/HF to be a significant predictor of BMI SDS change between the end of the club phase, and at 1-year post-intervention follow-up ($t(38) = 2.17$, *Beta* = .34, $p = .037$), with body mass increases being positively associated with LF/HF. No significant relationship between post-intervention weight change and HF ($t(38) = .70$, *Beta* = .13, $p = .484$) or SSRT ($t(38) = .22$, *Beta* = .04, $p = .824$) was revealed.

INSERT TABLE 1 HERE

Discussion

LF/HF was found to be predictive of weight management success in the year following the weight management camp intervention. This is consistent with previous findings of LF/HF being negatively associated with dieting success(12) and, as far as we are aware, this is the first study to demonstrate an association between LF/HF and obesity intervention success. HF was inversely associated with body mass at the start of the intervention, but was not predictive of weight-management.

A negative association between HRV and body mass was observed, which is consistent with previous research(28). When body mass was controlled for, HRV, as measured by PNN50, was found to be negatively associated with SSRT. This is consistent with previous findings of HRV being inversely associated with impulse control(13, 14), and may help to explain the link between HRV and dieting success.

A limitation of the present study is the small sample size, and it is possible that with larger numbers, HF would also have been predictive of weight-management; future research could investigate this possibility. A further limitation is that it was not recorded whether participants were taking any medications that can affect HRV(30). Respiratory rate was not recorded, and this can affect R-R intervals(30) and the HF recordings(31, 32). It would be beneficial in future studies measuring HRV to record respiratory rate and medication so that these factors can be controlled for in analysis. HRV data collected by Polar sensor sets can be affected by artefacts and no artefact correction was performed.

LF/HF can be affected by variables other than sympatho-vagal balance, and LF itself has been shown to be potentially affected by both parasympathetic and sympathetic nervous system modulation, as well as other confounding factors such as baroreceptor reflex activity(30, 31). The findings reported here of the relationship between weight-management success and LF/HF are consistent with previous research that has found a negative association between LF/HF and dietary control(12). However, the finding that neither HF nor SSRT predicted weight management success indicates that the results might have been influenced by factors other than the CAN and inhibitory capacity. SSRT not being predictive of long-term weight management may be partially due to the stop signal task, unlike the HRV variables, relying high levels of focus and attention from participants, and variations in this may have led to measurement errors. LF/HF might have been influenced by psychological stress, which can independently affect LF and HF(31, 33), and can cause both activation of sympathetic, and inhibition of vagal, activity(33). Negative stressors such as tension and fear(34), increased effort when conducting tasks(31), and a deficit in positive social relationships, or having negative social experiences despite making affiliative efforts, can all result in increased sympathetic activity, and potentially lead to greater LF and LF/HF(31, 35). It may be possible, therefore, that children with poorer social relationships and greater psychological stress were more likely to have a higher LF/HF and gain more weight post-intervention for reasons linked, not only to their inhibitory capacity, but also to their psychological wellbeing. We suggest that it would be beneficial for future research to further investigate the relationship between weight management, impulsivity, HRV measures including LF/HF, and factors that can affect frequency domain HRV measures, including stress. Possibilities for new types of intervention could also be explored. There is evidence that HRV can be altered through exercise, changes in diet, and stress reduction techniques such as meditation(18, 36); future obesity interventions could aim to increase HRV in order to reduce impulsivity and thereby improve weight management.

Weight management camp interventions may have a greater chance of successfully inducing long-term weight management for children with lower LF/HF. Assessing characteristics, such as impulsivity and HRV, of overweight children may help to infer the type of obesity treatment most likely to be effective.

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Table 1: Body mass, heart rate variability, and stop signal task data

	N	Mean	Std. Deviation
BMI SDS scores			
BMI SDS at the start of camp	74	2.35	.81
BMI SDS at the end of camp	54	2.04	.87
BMI SDS at the end of the after-school club phase	57	2.26	.80
BMI SDS at 1-year follow-up	44	2.36	.88
BMI SDS change between the end of clubs and 1-year follow-up	39	.07	.37
HRV scores			
AVNN	74	728.94	117.18
SDNN	74	65.35	21.07
PNN50	74	43.18	13.14
HF	73	.26	.07
LF/HF	74	1.24	.73
Impulsivity score			
Stop signal reaction time (SSRT)	73	251.5	103.13