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Pediatric Impedance Cardiography: Temporal Stability and Intertask Consistency

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Pediatric impedance cardiography: Temporal stability and intertask consistency

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Abstract

The pathogenic processes responsible for cardiovascular disease have their origins in childhood. Although children's measures of heart rate and blood pressure have been found to be reliable, the reliability of impedance cardiography derived measures have not been evaluated. Thirty-three children, ages 8–11 participated in two sessions. Stressors included serial subtraction, isometric handgrip, and mirror-image tracing. Results indicated the impedance measures showed moderately high temporal stability (average scores $r_{avg} = .74$; difference scores $r_{avg} = .53$) and intertask consistency (average scores $r_{avg} = .78$; difference scores $r_{avg} = .53$). Blood pressure demonstrated the lowest reliability; Heather index, preejection period, and stroke volume demonstrated the highest. These findings suggest children's cardiovascular reactivity to laboratory stressors can be reliably and consistently assessed using impedance cardiography.

Descriptors: Impedance cardiography, Cardiovascular reactivity, Children, Heart, Pediatric

Recent physiological and behavioral research suggests cardiovascular reactivity to daily stresses may be linked to a number of disorders including hypertension, coronary heart disease, atherosclerosis, and myocardial infarction (cf. Hurwitz & Schneiderman, 1998; Schneiderman et al., 2000). The pathogenic processes responsible for these cardiovascular diseases are thought to have their origins in childhood. Despite this, most cardiovascular reactivity research has been conducted using adults. Even if reliable results can be found on measures of adults' reactivity, one cannot assume that these results generalize to children. There are several reasons for this. First, the cardiovascular system of young children differs from adults and their resting blood pressure levels are lower than that of adults, whereas their resting heart rates are much higher. The underlying hemodynamic changes corresponding with these differences are not well understood. Second, pediatric electrocardiograms (ECG) differ from adult ECGs. Their T waves can be found to be inverted, which is known as a juvenile pattern (Das, Ray, Mohapatra, & Das, 1984; Sweetwood, 1989). It is unclear how these T waves may affect event waveform detection by computer software programs that measure cardiovascular variables. Third, there is less muscle and fat between the heart and the recording electrodes in children, which may produce differences in measurement accuracy and calculations of impedance cardiography (ZCG) measures.

Among children, the temporal stability of heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) has been adequately examined with findings of moderate levels of test-retest reliability across intervals ranging from 1 week to 45 years (Giordani, Manuck, & Farmer, 1981; Murphy, Alpert & Walker 1991; Taras & Sallis 1992; Wood, Sheps, Elveback, & Schirger, 1984). Together, these studies support the notion that (a) HR, SBP, and DBP are reliable over varying lengths of time, (b) HR and SBP responses are more reliable than DBP for many tasks, and (c) baseline measures are more reliable than task reactivity measures. The remaining cardiovascular measures assessed with ZCG have not been adequately examined in children, and thus, estimates of temporal stability cannot be established.

Few studies have evaluated the intertask consistency of cardiovascular measures across different types of stressors in children. Studies of HR, SBP, and DBP yielded findings of moderate correlation coefficients across different laboratory stressors (Matthews, Woodall, & Stoney, 1990; Murphy, Alpert, Willey, & Somes, 1988; Taras & Sallis 1992). Stroke volume (SV), cardiac output (CO), and total peripheral resistance (TPR) have also been examined, but only minimally, with findings of low correlational coefficients (Musante et al., 1994; Verhaaren et al., 1994). The remaining hemodynamic measures have not been evaluated in children.

The Present Study

There is a paucity of research evaluating the psychometric properties of children's cardiovascular measures as derived by ZCG. The purpose of the present evaluation was to compare the temporal stability and intertask consistency of cardiovascular responses to three stressor tasks. More specifically, the analyses were directed toward describing the changes in cardiovascular measures that

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occurred with repeated testing, the associations among the cardiovascular measures to tasks within testing sessions, and the associations among cardiovascular measures to tasks across testing situations.

Method

Participants

Parents and children were recruited from the community using flyers, newspaper advertisements, and electronic mail. Exclusionary criteria included reported use of medications with cardiovascular effects, a history of cardiovascular complications, serious medical conditions, or serious psychopathology. Thirty-five children (16 boys, 19 girls), in good health, aged 8 to 11 years old ($M = 9.6$, $SD = 1.1$), initially participated in the study. Nearly all of the children were Caucasian ($n = 34$, 97.1%). Two children were unable to complete the second session, resulting in an attrition rate of 5.7% and a final N of 33.

Procedure

Participants were scheduled for two 45-min appointments spaced 1 week apart, at the same time of day. Children were to abstain from eating and vigorous exercise for 3 hr prior to the experiment, as well as nonprescription medicine and caffeine for 24 hr prior to the experiment.

Upon arrival to the psychophysiology lab, a brief tour was provided. The experimenter described the procedures, demonstrated how equipment worked, and explained the informed consent form to the parent and the child. Prior to the attachment of recording devices, children were given an opportunity to hear their pulse and encouraged to ask questions in order to maximize compliance and minimize distress. The child then was seated in a comfortable chair in a temperature controlled, copper shielded room. Parents were asked to provide demographic and health history information in the waiting room, where a closed-circuit television provided constant monitoring capabilities.

Initially, participants were instructed to remain quiet and still for a 10-min baseline condition. After baseline, three stressor tasks (isometric handgrip, serial subtraction, and mirror image tracing) were presented with rest conditions between each task. Each task and rest condition was 3 min long. Task order was assigned based on a quasi-counterbalanced design, alternating serial subtraction and mirror image tracing as the first task. Isometric handgrip always was assigned last because previous research suggests the enduring effects of the handgrip may interfere with subsequent reactivity to stressors (Matthews et al., 1990). At the second session, participants were administered an identical protocol by the same experimenters. Participants received $20 as compensation for their efforts.

Stressor Tasks

Serial subtraction. Participants up to grade five were instructed to subtract backward from a two-digit number by twos at the first session and threes at the second session. Those participants grade five and above subtracted from a three-digit number by fives and sevens, respectively. Experimenters encouraged the participants to continue if they should cease reporting numbers; however, errors were not corrected.

Mirror image tracing. Participants were instructed to trace a six-sided star viewed through a mirror with a metal stylus. The star-tracing apparatus (Whipple Mirror Drawing Apparatus, Stoelting Co.), which was interfaced with a computer, beeped whenever the stylus was not on the outline.

Isometric handgrip. Prior to the attachment of the blood pressure cuff, participants initially squeezed a hand dynamometer (Lafayette Instrument Model 78010) twice with their dominant hand to assess maximal grip strength. During the experiment, participants were instructed to squeeze the hand dynamometer at 30% of their maximal grip strength level. The hand dynamometer was interfaced with a computer so that, if effort fell below the 30% maximal level, a beep was emitted and instructions were given to increase effort.

Cardiovascular Measurements

Four bands of disposable cardiograph electrode tape (Instrumentation for Medicine, Inc.) were placed circumferentially around the neck, chest, and abdomen as recommended by Sherwood and colleagues (1990). Measurements were taken to ensure that the electrodes were the appropriate distance from one another. The average electrode distance across sessions was highly correlated ($r = .89$, $p < .0001$). A Minnesota Impedance Cardiograph Model 304B recorded the ECG and ZCG signals, which were relayed to a computer software program (Cardiac Output Program, Bio-Impedance Technology, Inc.). Each signal was continuously recorded in 30-s epochs during baseline and each stressor task. Computer signal processing techniques scored the ensemble-averaged event waveforms and algorithmically derived the cardiovascular measures. Each epoch was manually checked to ensure accuracy of the event waveform scoring. Heart rate (HR), $dZ/dt_{(max)}$ (DZDT), preejection period (PEP), left ventricular ejection time (LVET), and Heather index (HI) were derived from the event waveforms. Stroke volume (SV) was calculated using the Kubicek formula (Kubicek, Karnegis, Patterson, Witsoe, & Mattson, 1966). Cardiac output (CO) was determined using the equation $CO = SV \times HR$.

A pediatric occlusion cuff attached to the medial surface of the nondominant arm over the brachial artery was used in conjunction with an IBS Model SD-700A electrosphygmomanometer to record blood pressure. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) measurements were recorded every 1.5 min during baseline and at the onset and midpoint of each stressor task. These measurements subsequently were used to calculate mean arterial pressure (MAP) using the formula $MAP = DBP + ((SBP - DBP)/3)$ and total peripheral resistance (TPR) calculated from the equation $TPR = (MAP/CO) \times 80$.

Data Reduction and Analyses

For each cardiovascular measure, a mathematical average was derived for baseline, task, and rest conditions. Only the final 5 min of the baseline condition were included. Difference scores were determined by subtracting the baseline average from each task condition average. Pearson product moment correlations were calculated for all cardiovascular measures and difference scores across tasks within sessions (i.e., intertask consistency) and within tasks across sessions (i.e., temporal stability).

Results

Global Health Functioning

Participants' height, weight, and wrist circumference were considered to be in the normal range (Height $M = 56.3$ cm ($SD = 3.6$);

Table 1. *Means and Standard Deviations of Average Scores: Session 1*

	Baseline		Drawing		Rest 1		Subtraction		Rest 2		Handgrip		Rest 3	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
HR	82.59	(11.99)	89.46	(11.45)	82.58	(12.10)	92.52	(13.08)	83.34	(11.98)	103.44	(13.77)	82.21	(13.16)
DZDT	2.23	(0.54)	2.09	(0.65)	2.23	(0.60)	2.20	(0.65)	2.21	(0.60)	1.99	(0.63)	2.31	(0.67)
PEP	97.80	(11.63)	93.63	(13.42)	96.71	(11.82)	94.53	(14.54)	97.30	(11.65)	92.25	(14.08)	93.35	(12.84)
LVET	274.01	(22.17)	271.77	(20.77)	277.50	(23.06)	264.13	(23.69)	277.25	(23.95)	262.16	(25.82)	281.97	(26.37)
HI	15.72	(4.68)	15.39	(6.24)	15.96	(5.14)	16.24	(6.59)	15.81	(5.24)	15.16	(6.31)	17.23	(6.06)
SV	63.09	(19.85)	56.21	(16.64)	63.38	(19.03)	58.76	(18.50)	63.28	(20.74)	50.64	(14.69)	67.33	(22.07)
CO	5.08	(1.32)	4.92	(1.23)	5.11	(1.30)	5.32	(1.51)	5.12	(1.38)	5.14	(1.32)	5.38	(1.52)
SBP	107.45	(7.01)	114.41	(6.86)	110.03	(7.69)	116.51	(7.24)	109.63	(6.24)	122.03	(6.71)	112.77	(7.55)
DBP	73.36	(7.77)	83.03	(7.89)	73.31	(8.74)	83.04	(8.63)	72.13	(8.80)	91.07	(9.66)	70.09	(8.81)
MAP	84.44	(6.41)	93.19	(6.07)	85.17	(7.24)	93.90	(7.04)	84.31	(7.07)	101.07	(7.30)	84.07	(6.86)
TPR	1425.64	(358.14)	1603.60	(368.83)	1424.56	(354.98)	1507.54	(407.56)	1409.47	(381.28)	1705.34	(396.40)	1332.69	(357.19)

Note: $N = 35$.

Weight $M = 37.9$ kg ($SD = 10.0$); Wrist $M = 14.3$ cm ($SD = 1.2$)). No child was found to have a hypertensive blood pressure reading (Task Force on Blood Pressure Control in Children, 1987).

Cardiovascular Characteristics

Means and standard deviations for the average scores of the cardiovascular measures during each condition are presented in Tables 1 and 2. The means and standard deviations for the difference scores are presented in Table 3. The results of the HR, SBP, and DBP average scores are comparable to those previously reported by Matthews, Rakaczky, Stoney, and Manuck (1987).

A manipulation check was performed by comparing mean task levels with the mean baseline level of cardiovascular functioning. The mean levels of cardiovascular functioning were significantly higher during the stressor tasks relative to baseline for all comparisons except: CO during handgrip and drawing, DZDT during subtraction, HI during all tasks, LVET during drawing, and PEP during subtraction.

Temporal Stability

Pearson product moment correlations were calculated using mean baseline and task levels for the two sessions. Significant correlations were observed across the test-retest interval for all measures except for DBP during handgrip and drawing and MAP during drawing (see Table 4). The test-retest interval was also evaluated using difference scores. Significant correlations were observed for all measures except for SBP during subtraction and DBP and MAP during all tasks (see Table 5).

Intertask Consistency

Intertask consistency was evaluated by computing correlations across experimental conditions within a session. All correlations among cardiovascular measures across tasks within each session were significant with the exception of DBP for the subtraction-handgrip and drawing-handgrip comparisons (see Table 6). The intertask consistency of the cardiovascular measures was also evaluated using difference scores (see Table 7). Significant correlations were observed for all measures except HR, CO, and TPR for subtraction-handgrip comparisons and DBP and TPR for subtraction-drawing comparisons.

Discussion

Impedance derived cardiovascular measures were examined under task and rest conditions to determine their reliability. Each stressor

Table 2. *Means and Standard Deviations of Average Scores: Session 2*

	Baseline		Drawing		Rest 1		Subtraction		Rest 2		Handgrip		Rest 3	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
HR	81.96	(9.76)	87.13	(10.59)	82.26	(9.87)	90.90	(11.17)	83.34	(9.99)	101.57	(13.27)	82.15	(11.14)
DZDT	2.23	(0.60)	2.12	(0.71)	2.23	(0.64)	2.27	(0.66)	2.23	(0.63)	1.98	(0.65)	2.31	(0.71)
PEP	98.41	(10.49)	93.73	(14.75)	97.68	(10.97)	94.42	(14.45)	97.19	(11.64)	92.22	(15.27)	93.12	(11.72)
LVET	274.92	(18.59)	274.37	(18.71)	277.31	(20.21)	264.35	(22.53)	275.91	(18.79)	264.03	(20.75)	283.04	(22.47)
HI	15.80	(4.82)	15.52	(6.38)	15.96	(5.41)	16.70	(6.11)	16.02	(5.40)	14.92	(6.34)	17.30	(6.39)
SV	62.61	(17.35)	57.13	(16.45)	63.35	(17.85)	59.74	(17.49)	62.92	(17.38)	50.41	(12.82)	67.52	(20.37)
CO	5.06	(1.32)	4.92	(1.23)	5.14	(1.40)	5.34	(1.44)	5.17	(1.35)	5.03	(1.12)	5.43	(1.50)
SBP	105.79	(6.67)	112.81	(8.32)	107.91	(8.66)	114.47	(9.35)	107.75	(7.20)	120.21	(7.55)	111.87	(7.36)
DBP	70.61	(7.97)	80.79	(7.89)	71.97	(7.38)	79.96	(9.51)	71.34	(6.96)	90.96	(9.65)	69.01	(8.99)
MAP	82.05	(6.35)	91.09	(6.92)	83.62	(6.89)	91.12	(7.79)	83.25	(5.99)	100.28	(7.48)	82.97	(6.95)
TPR	1382.98	(340.87)	1585.71	(470.64)	1392.31	(365.42)	1439.25	(367.70)	1367.52	(353.52)	1669.81	(354.70)	1305.26	(341.82)

Note: $N = 33$.

Table 3. *Means and Standard Deviations of Difference Scores*

	Session 1						Session 2					
	Drawing		Subtraction		Handgrip		Drawing		Subtraction		Handgrip	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
HR	6.87	5.83	9.92	6.18	20.85	10.63	5.02	6.82	8.68	5.87	19.05	11.20
DZDT	−0.13	0.29	−0.02	0.26	−0.23	0.29	−0.11	0.25	0.04	0.21	−0.24	0.25
PEP	−4.17	8.80	−3.27	10.92	−5.55	10.84	−4.55	7.55	−3.87	8.64	−6.01	9.71
LVET	−2.23	10.10	−9.87	13.58	−11.84	18.30	−0.53	10.79	−10.26	13.73	−10.58	15.54
HI	−0.33	2.54	−0.52	2.78	−0.56	2.92	−0.27	2.28	0.87	2.06	−0.86	2.42
SV	−6.87	7.08	−4.33	6.76	−12.45	11.38	−5.32	8.41	−2.79	6.42	−11.85	10.60
CO	−0.15	0.51	0.25	0.61	0.06	0.62	−0.14	0.52	0.28	0.39	−0.02	0.63
SBP	6.97	5.97	9.07	4.98	14.58	7.49	6.81	6.91	8.43	6.23	14.00	7.45
DBP	9.67	7.49	9.68	7.78	17.71	10.43	9.89	8.12	9.08	6.88	19.76	9.11
MAP	8.75	6.02	9.46	5.97	16.63	7.87	8.78	7.35	8.80	5.95	17.70	7.86
TPR	177.96	169.89	81.90	200.30	292.96	251.04	196.94	275.15	54.67	138.98	278.64	219.67

Note: Session 1 $N = 35$; Session 2 $N = 33$.

task elicited significant levels of reactivity. The impedance measures were stable and reliable across time and across tasks, yielding moderately high correlation coefficients. In contrast, blood pressure measures were less stable and reliable. Additionally, average scores of the cardiovascular measures were consistently more reliable than difference scores.

The BP and HR findings were consistent with those reported in the adult literature (Kasprowicz, Manuck, Malkoff, & Krantz, 1990; Saab et al., 1992). Specifically, HR was more reliable than BP and SBP measurements were more reliable than DBP measurements. In general, impedance-derived measures tended to be more reliable than BP measurements, both across time and task.

There are several reasons why BP measurements yielded less adequate reliability. First, the average BP measurement was based on fewer numbers of observations relative to impedance measures for each task. Simply increasing the number of observations alone may help to increase the stability of BP measurements. Second, BP measures may contain more error due to the cuff deflation rate. Additionally, participants exhibited some movement during the tasks, particularly handgrip and mirror-image tracing. This movement in combination with the cuff deflation rate may have made the Korotkoff sounds difficult to detect and thus more variable. Finally, the BP recordings may reflect a more variable physiological process.

The impedance results suggest that children are consistent in their hemodynamic cardiovascular responses exhibited during stressful and challenging conditions. In addition to documenting the stability over time, these results demonstrate the generalization of such responses across tasks requiring qualitatively different responses. Taken together, the findings support the notion that cardiovascular measures assessed with ZCG are stable among children.

Limitations

Several limitations should be noted including power, sample representation, and ecological validity. First, the sample size introduces limitations with respect to power. The decision to use the sample size was based on the expectation that reliable response patterns would be detected in a complex protocol involving more

Table 4. *Temporal Stability of Average Scores: Correlations Across Sessions*

	Task			
	Baseline	Subtraction	Handgrip	Drawing
HR	.85	.85	.81	.86
DZDT	.82	.86	.88	.90
PEP	.89	.88	.93	.90
LVET	.83	.78	.85	.77
HI	.79	.83	.86	.89
SV	.84	.82	.86	.83
CO	.77	.79	.80	.81
SBP	.75	.68	.60	.69
DBP	.61	.47	.13	.17
MAP	.67	.55	.43	.28
TPR	.74	.78	.78	.69

Note: The values represent Pearson product moment correlations across sessions. $N = 33$. All values significant at $p < .01$ except MAP during drawing task and DBP during handgrip and drawing tasks.

Table 5. *Temporal Stability of Difference Scores: Correlations Across Sessions*

	Task		
	Subtraction	Handgrip	Drawing
HR	.49	.67	.72
DZDT	.68	.60	.67
PEP	.71	.76	.63
LVET	.46	.61	.60
HI	.74	.70	.70
SV	.54	.70	.64
CO	.54	.51	.45
SBP	.35	.67	.54
DBP	.21	.10	.23
MAP	.29	.31	.36
TPR	.44	.52	.47

Note: The values represent Pearson product moment correlations across sessions. $N = 33$. All values significant at $p < .01$ except SBP during the subtraction task and MAP and DBP during all tasks.

Table 6. *Average Intertask Consistency of Average Scores: Sessions 1 and 2*

	Task pairs					
	Subtraction & drawing		Subtraction & handgrip		Drawing & handgrip	
	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
HR	.91	.85	.76	.62	.72	.64
DZDT	.92	.94	.95	.94	.91	.93
PEP	.87	.86	.91	.90	.88	.83
LVET	.91	.81	.87	.71	.85	.77
HI	.92	.96	.94	.96	.93	.94
SV	.93	.89	.91	.82	.85	.86
CO	.90	.93	.96	.90	.92	.90
SBP	.64	.83	.45	.59	.59	.70
DBP	.70	.39	.32	.53	.29	.55
MAP	.69	.48	.46	.49	.40	.54
TPR	.88	.82	.92	.81	.85	.78

Note: Values represent Pearson Product Moment Correlations across tasks. Session 1 $N = 35$. Session 2 $N = 33$. All values significant at $p < .05$ except DBP during Session 1 for subtraction & handgrip and drawing & handgrip comparisons.

Table 7. *Average Intertask Consistency of Difference Scores: Sessions 1 and 2*

	Task pairs					
	Subtraction & drawing		Subtraction & handgrip		Drawing & handgrip	
	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
HR	.60	.59	.50	.33	.44	.39
DZDT	.57	.48	.75	.47	.56	.48
PEP	.76	.56	.84	.76	.79	.51
LVET	.71	.44	.71	.38	.68	.54
HI	.56	.65	.70	.68	.65	.60
SV	.49	.45	.72	.37	.64	.61
CO	.32	.39	.75	.27	.59	.49
SBP	.41	.69	.36	.37	.60	.62
DBP	.64	.20	.34	.34	.34	.52
MAP	.62	.39	.45	.40	.46	.58
TPR	.46	.31	.78	.31	.59	.34

Note: Values represent Pearson Product Moment Correlations across tasks. Session 1 $N = 35$. Session 2 $N = 33$. All values significant at $p < .05$ except HR, CO, and TPR for subtraction & handgrip and DBP and TPR for subtraction & drawing comparisons.

than one experimental session and the use of multiple tasks. Consistent with expectation, the impedance parameters yielded replicable findings.

Second, participants were predominantly Caucasian. Other researchers have demonstrated racial differences in cardiovascular reactivity; therefore, the present results may only extend to Caucasian populations (e.g., Murphy, Stoney, Alpert, & Walker, 1995). Future research should evaluate whether racial differences exist when impedance measures are used to measure cardiovascular reactivity in children.

Finally, the ecological validity of the findings is constrained by the rigor of the experimental design. Participants were carefully screened and asked to abstain from vigorous activity, eating, medications, and caffeine prior to the cardiovascular assessment. Although such rigor is beneficial from a methodological standpoint, it may cloud the results, having them appear to be more stable than one would find from naturalistic observation. The field could benefit from both the establishment and incorporation of standardized tasks and protocols to use when evaluating cardiovascular functioning in children as well as validation studies to demonstrate the extent to which laboratory measures of ZCG represent cardiovascular responses that occur in real-world environments.

Implications

The results suggest that ZCG is a reliable measurement method that can be used to assess cardiovascular reactivity with children. High levels of reliability occurred across a 1-week time interval and across cognitive, motor, and psychomotor stressors. This is an important preliminary step in the process of demonstrating that exaggerated cardiovascular response patterns to behavioral stress are either a marker for, or part of, a pathogenic process that leads to the development of atherosclerosis, hypertension, and cardiovascular disease. Given the contribution to the thorough understanding of underlying cardiovascular functioning, it is recommended that the assessment of the additional impedance measures be incorporated whenever possible. Additionally, the results underscore the need for measuring blood pressure in multiple settings on several occasions.

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