Published in final edited form as:

J Appl Biobehav Res. 2010 September ; 15(3): 119–133. doi:10.1111/j.1751-9861.2010.00056.x.

Arousal and activity choice in autism: A single case assessment integrating autonomic and behavioral analysis

John Hoch, Tim Moore, Jennifer McComas, and Frank J. Symons

University of Minnesota

Abstract

Theoretical accounts of autism have hypothesized links between arousal and behavior but research translations of theory to real-world contexts have been limited. In this single-subject experimental analysis, a school-age subject chose between high and low arousing activities with real time monitoring of behavior and heart rate (HR). Time series statistical analysis showed significant changes in HR associated with activity type and no association with motor movement. Sequential analysis showed that activity choice and HR were significantly associated (i.e., activity choice sequentially dependent with the preceding level of HR). Highly arousing activities were more likely to be chosen following high HR and vice versa. Results provide evidence of the feasibility of an integrative bio-behavioral approach to understand behavior in neurodevelopmental disorders.

Early descriptions of autism contain references to over- (Hutt et al., 1964) and under- (Rimland, 1964) arousal. Arousal has been hypothesized to account for a variety of aberrant (i.e., stereotyped) and destructive (i.e., self-injurious) forms of behavior (Berkson, 1967; Edelson, 1984; Graveling & Brooke, 1978; Maisto, Baumeister, & Maisto, 1978). The basic theoretical premise relies on a homeostatic metaphor in which aberrant forms of behavior regulate chronic over- or under-arousal (Edelson, 1984; Graveling & Brooke, 1978; Guess & Carr, 1991). In either scenario, the behavior is considered to be both a response to an internal state (i.e., ‘over/under-aroused’) and as a way to regulate the internal state (i.e., reduce/increase arousal level) (Berkson, 1967). Despite these long standing speculations, there have been few empirical studies directly examining arousal in individuals with autism specifically in relation to ongoing activity levels and behavioral responses in real-world contexts.

Existing group experimental studies have attempted to show differences between those with autism and typically developing controls by arranging conditions hypothesized to be stressful and arousing compared with non-stressful stimuli and measure an array of physiological indices (heart rate, heart rate variability, skin conductance) considered to be endpoints for autonomic regulatory systems. Graveling and Brooke (1978), for example, compared heart rate (sympathetic function) and heart rate variability (parasympathetic function) between children with autism (N = 5) and children with developmental disabilities (N = 5) matched on age, gender, and IQ by creating high, medium, and low arousal classroom conditions. Results showed no difference by treatment condition, but children in the autistic group showed significantly higher heart rate variability and lower mucoprotein variability (an endocrine measure of stress indexing the hypothalamic-pituitary-adrenal axis [HPA] system) than controls. Studies with similar experimental procedures have examined heart rate and skin conductance (Palkovitz & Wiesenfeld, 1980), skin conductance alone

(Stevens & Gruzelier, 1984, van Englund, 1984, Hirstein, Iversen & Ramachadran, 2001), and heart rate alone (Sigman et al., 2003, Groden et al., 2005, Goodwin et al., 2006) with the overall findings mixed for the direction of effects (i.e., high/low arousal) in relation to diagnostic group (i.e., autism vs. comparison/controls) or treatment conditions (high/low stress). The most common outcome was increased autonomic variability among individuals with autism regardless of the specific arousal measures.

A second general strategy has been to examine physiological correlates of arousal in relation to specific behavioral features of autism, most notably stereotyped and related aberrant or destructive behavior (e.g., self-injurious behavior [SIB]). In 1965, Hutt et al. collected electroencephalogram (EEG) recordings from two individuals with autism (who were part of a larger study) while they experienced an array of relatively controlled environmental conditions that varied on the presence/absence of tasks/activities and the presence/absence of opportunities for social interaction. Irregular EEG rhythms were associated with environmental conditions that also included greater levels of stereotypy. These findings were discussed as preliminary evidence that stereotypy serves to limit additional stimulation and reduce arousal (Hutt, Hutt, Lee, & Ounsted, 1965). Similar results were published in follow up articles published in Hutt and Hutt (1968). Hutt et al (1975) compared the relationship between respiratory sinus arrhythmia (a parasympathetic measure also referred to as vagal tone) and activity context (freeplay and sorting or puzzle tasks) and stereotypy between nine children with autism and 6 younger typically developing children and six age-matched typically developing children. The authors found significant differences between typically developing children and those with autism during the task condition and the freeplay condition in respiratory sinus arrhythmia. Within child, significant decreases in HR were seen following bouts of stereotypy, accompanied by changes in RSA during bouts of stereotypy.

In non-experimental descriptive studies, researchers have used various analytical tools to describe the relationship between SIB and HR as well as that between stereotypy and behavior in natural and laboratory environments. Lewis et al (1989) examined the relationship between movement and HR in 17 adults with disabilities and high rates of stereotypic movement. The authors directly measured movement using wearable accelerometers and combined this data with changes in heart rate using cross spectral analysis of the cardiac and movement waveforms in a laboratory setting with no specific task demands. The authors found that the cyclical components of HR and body rocking showed shared frequency signals although body rocking and HR were not correlated and did not occur in a 1:1 ratio. In a single case experiment, Sroufe et al (1974) examined changes in HR in a single child with autism over the course of an operant treatment program for communication and during task and relaxation activities. The authors found an increase in HR associated with the onset of stereotypy (finger flicking) and a decrease in HR pre and post treatment. The authors suggest that this decrease was due to the treatment effect of decreasing arousal. Willemsen-Swinkels et al (1998) categorized stereotypic behavior observed in 26 children (typically developing, with ADHD, and with PDD) during a laboratory based mother/child play session into emotional categories (e.g. elation, distress, sensory). The authors found differing patterns of significant associations between the time course of stereotypy and HR across all children by mood ratings of individual bouts of stereotypy (e.g. a quadratic fit between the shape of the curve of HR data points was significant for 'elation', while a quartic curve fit HR associated with distress stereotypy bouts).

In a more naturalistic environment, Freeman, Horner, and Reichle (1999) collected heart rate data in BPM during daily routines for two adults with developmental disabilities to determine whether increased arousal preceded or followed episodes of SIB or aggression.

Heart rate did not reliably increase before SIB, but SIB was significantly more likely to be followed by a heart rate increase for both participants. The study provides an initial example of the use of heart rate monitoring during naturalistic examinations of severe problem behavior often associated with autism (Bodfish, Symons, Parker, & Lewis, 2000) but was limited by a coarse time scale of heart rate measurement. More recently, Barrera et al. (2007) monitored heart rate during functional behavioral assessments with three adults with developmental disabilities and SIB. The results were examined using visual inspection of raw HR data streams and plots of problem behavior. The authors observed an increase in heart rate that preceded SIB, not attributable due to movement or respiration. This study provides an initial model of integrating HR monitoring into single case behavioral designs, but lacked replicable statistical analysis of HR or quantification of the sequential dependencies between HR changes and assessment condition or SIB. In addition to the mixed substantive findings reviewed above, the studies collectively show that investigators have struggled with the degree of experimental control to employ within group and single case designs, as well as the types of statistical analyses or visual analyses that might allow conclusions to be drawn about the relationship between behavior and arousal.

Overall, despite a long history of speculating on the role of autonomic arousal in autism and related conditions as reviewed briefly above, the in situ empirical work to date has been relatively sparse. Previous studies have attempted to delineate differences between those with autism and age and IQ matched participants on a variety of neurological systems (autonomic and central) in attempts to discover the role of arousal in the disorder. A smaller body of work has examined the role of arousal in stereotypy and/or self-injury specifically. This work has been conducted, with the exception of Freeman et al., (1999) and Hutt et al., (1965), and Barrera et al (2007), using group comparison designs and static stimuli or passive exposure to selected environmental experiences. No translation-oriented biobehavioral research has examined how individuals with autism actively choose among activities (i.e., allocate behavior) based on pre-existing arousal levels or based on the arousal level associated with making choices among different activity types. One of the rate limiting steps has likely been the ability to reliably and meaningfully ‘capture’ behavior and physiology in real-world contexts.

In this preliminary case study, we developed a novel integrative biobehavioral approach to provide an initial test of the relation between arousal (i.e., heart rate) and ongoing behavior (i.e., activity choice) for a child with autism. Our specific purpose was to examine as directly as possible whether arousal level was sequentially dependent with choice of activity type. Maternal report was used to generate initial activity conditions (which were subsequently confirmed as high and low arousal) that were then compared using a modified concurrent operant design (described below). Control conditions of intermediate arousal level were interspersed between choice opportunities to allow a return to baseline levels. Across all behavioral conditions, HR was captured through wireless ambulatory recording and behavior was captured via continuous digital video recording. In this way, HR and behavior could be time locked and synchronized. Event lag sequential analyses were conducted to examine whether activity choice was sequentially related to arousal level.

Method

Participant and setting

The participant was a 7-year-old boy diagnosed with autism by a licensed psychologist (DSM IV criteria) scoring in the ‘Severely Autistic range on the Childhood Autism Rating Scale (Schopler, et al., 1992; CARS Total Score = 44). His adaptive behavior was formally assessed when he was 4 years old using the Vineland Adaptive Behavior Scales [interview form] (Sparrow et al, 1984) and was found to be at or below the .1 percentile in all subtests.

At the time of this study, his adaptive behavior repertoire included communication through the Picture Exchange Communication System (PECS). He was able to initiate and with partial independence complete a range of activities of daily living (e.g., dressing) and personal hygiene routines (e.g., tooth brushing) with moderate assistance. At the time of this study, he was not prescribed any neuroleptic or related psychotropic medications and was enrolled at an elementary school in the second grade.

His maladaptive behavior included self-injury in the form of wrist/arm biting on the left and right sides. A descriptive functional assessment for self-injury was conducted which included maternal interview (based on the Functional Analysis Interview; O'Neill et al. 1997), rating scales (Questions about Behavioral Function [QABF]; (Matson et al., 1999), and a direct observation protocol (four 15-min observation sessions). A consequent-based functional analysis was initiated (Iwata, Dorsey, Slifer, Bauman, & Richman, 1994) with conditions arranged to test putative positive and negative social reinforcers maintaining self-injury. No self-injury was observed. Based on further maternal interview there were concerns noted regarding the participant's behavioral state characterized as 'over-aroused' and possibly related to different 'high arousal' activity types and later SIB. Given this concern, this single case analysis was designed to explore the relation between arousal and activity choice for the participant.

Experimental Procedures

All procedures were conducted at the participant's home. Three conditions were developed and evaluated through a modified concurrent-operant choice procedure (Fisher et al., 1992) to study behavioral allocation and choice (Pierce & Epling, 1983). The conditions differed from a strict free-operant choice procedure in that the participant was required to remain in the chosen activity for 3 minutes after choosing before being offered another opportunity to stay with the same activity or change activities. The low-arousal (LA) condition consisted of the participant sitting on his mother's lap watching a preferred video. The high-arousal (HA) condition consisted of the participant sitting on his mother's lap being tickled. Discrete trial instruction from ongoing communication therapy sessions were used as a control condition (CC). In the control condition, the participant completed mastered tasks with his therapist while seated at a table. Picture-symbol cards were created and provided for the participant to indicate his choice of activity.

Sessions were conducted on two days one week apart. Sessions were preceded by exposure to the high- and low-arousing activities and a control condition. No other exposure to heart rate collection equipment was conducted before data collection began. After pre-exposure sessions, the participant was brought to the center of the testing area in the family's basement recreation room (a familiar environment) and presented with the choice of activities. The participant's nonverbal or verbal responses were honored with three minutes of access to the chosen activity. After approximately three minutes the participant was physically prompted to return to the center of the room and choose again. After three consecutive choice sessions a control session was conducted (see Figure 1 for schematic diagram of procedures). In total, 60 min of sessions were conducted. Condition time included 10 min of total time in pre-exposure and transition between conditions. Choice and control sessions made up a total of 33 min. These included 17 choice conditions and five control conditions.

Data Collection

To directly examine arousal, the participant was fitted with a wireless heart rate chest belt (Polar Wearlink; Polar Electro OY) which transmitted HR in beats per min to a watch placed in his pant's pocket (Polar s810i; Polar Electro OY). The reliability of polar HR monitor has

been compared to ECG has been found adequate in all cases (see Gamelin et al 2006; Kingsley et al 2005).

The HR data was downloaded from the watch after the sessions and synchronized with digital video of the session coded in PROCODER DV (Jon Tapp & Associates, 2007). HR data were visually examined for anomalous/missed beats and were filtered using the error correction techniques in the Polar Precision Performance Software (Polar Electro OY). No HR values were eliminated or corrected using either technique.

Forty-nine percent of session time was coded in real time by two independent observers coding for session type (i.e., type of activity chosen) and any instances of SIB (as a duration code). Inter-observer agreement was calculated with a 5 sec window for agreement using the formula $\text{agreements} / (\text{agreements} + \text{disagreements})$ and averaged 0.99 (Range = 0.99–1.0) and using Cohen's Kappa averaged 0.91 (Range = 0.67–1.0).

The correlational, sequential, and inter-observer agreement analyses were based on all video recorded time, including time spent in transitions between activities and pre-session exposure to conditions (thus, total time does not divide by the number of conditions). As noted above, both low and high arousal conditions were provided prior to each day's choice sessions to allow the participant to sample both conditions before the first choice, but there was no relationship between the order of pre-exposure and the choices made. To better understand the sequential relationship between HR changes and activity choice, changes in HR outside of typical HR ranges (defined below) were coded as events (increase, decrease) and inserted into the data stream at their time of onset. The increased or decreased HR event was then considered in place (i.e., running) until HR returned to typical ranges from control conditions. In this way, continuous data could be statistically examined using lag sequential analysis to better understand order effects between arousal and choice.

To control for the effects of motor movement within the sessions, a research assistant blind to the study hypothesis and the experimental conditions coded motor movement across all conditions from half of the video selected quasi-randomly to include all experimental conditions. Operational definitions were developed for each body area (Torso, Arms, Legs, Overall Postural) with three levels of intensity of movement coded (no movement, moderate movement, intense movement) coded using ten second momentary time sampling. The inter-observer agreement for level of intensity averaged Cohen's Kappa of .60 and Kappas greater than .85 for presence or absence of movement for each body area. For each sample of motor movement, the sum of all body parts were entered into the ARIMA model described below and were non-significant ($t = -0.81, p < 0.42$).

Analyses & Results

Summary-Level: Confirmation of Arousal State

Sessions were examined using the General Transformation Approach (GTA; Velicer & Fava, 2003) to Auto Regressive Integrated Moving Average (ARIMA) modeling conducted using the SAS 9.3 PROC ARIMA (SAS institute, Inc). The GTA uses a standard $p = 5, q = 0$ ARIMA model to remove the autocorrelation from the data and then analyzes the adjusted data using standard General Linear Model statistical approaches. Past research has shown that this standardized model fit is adequate for removing autocorrelation for behavioral and physiological data (Hoepfner et al. 2007). Each 5 sec HR data point was coded for the type of arousal condition in effect (LA, HA) and for the presence or absence of SIB (included because of the initial concern) and these were added as predictors to the ARIMA model. Results confirmed that HR differed significantly by session type ($p < 0.0001$) (Figure 2). The mean HA condition HR was 138.10 beats per minute (BPM) ($SD = 5.23$) and was

significantly greater than the LA condition mean HR (116.43; SD = 4.56). These conditions differed significantly from the control condition mean HR (129.66; SD = 6.31). Thus, the nominal categories of high and low arousal activity derived from maternal report were confirmed via HR analysis.

Sequential Test of Relation between Arousal State and Behavioral Choice

Data were analyzed for the influence of arousal on choice using time lag sequential analysis (Figure 3). Baseline HR was defined as being within one standard deviation of the mean from the pooled control conditions, whenever this limit was exceeded an event was automatically inserted into the data stream of behavioral events using the Multiple Option Observational System for Experimental Studies (MOOSES) software (Tapp, Wehby, & Ellis, 1995; Jon Tapp & Associates, 2006). In the sequential analysis, the relation between arousal state and activity choice was thus examined as a relationship between the event of an increase or decrease in heart rate beyond the participant's normal variations and subsequent choices of activities.

The transitional probability of the participant's making a choice of HA or LA activities following the occurrence of heart rate above or below the participant's typical limits was examined using a transformed score because of the variation in base rates of both heart rate and choice events. Yule's Q is an adjusted odds ratio bound by -1 and $+1$ that allows probabilities to be compared between events of differing base rates (Yoder & Feurer, 2000). Yule's Q probability values were calculated for the participant choosing high or low arousal activities within 5-sec following any HR increase or decrease (> 1 SD). The Yule's Q difference was calculated between the probability of choosing LA activities and choosing HA activities following increases or decreases in HR. These differences were tested using a re-sampling procedure providing an exact probability estimate (Yoder, Bruce, & Tapp, 2001). Results showed that the participant was significantly more likely to choose LA activities following a decrease in HR than to choose HA activities following a decrease in HR ($p = 0.01$). Conversely, the participant was significantly more likely to choose HA activities following an increase in HR than to choose LA activities following HR increase ($p = 0.04$).

Post-Hoc Analysis of SIB and Arousal State

Observed rates of SIB were too low in the sessions to allow the use of time lag sequential analysis to examine the transitional probability of SIB occurring on a moment-by-moment basis in high/low arousal activities. Overall conditional probabilities were calculated for the occurrence of SIB given high or low arousal conditions and these were tested using a McNemar test for significance (Siegel, 1956). The conditional probability of SIB during HA conditions was 0.33 and the conditional probability of SIB given LA conditions was 0.06. The McNemar test for significance (related samples) was $2.4_{(1)}$ and marginally significant ($p < 0.10$). All but one of the occurrences of SIB occurred during HA activities.

Discussion

Given the long series of claims regarding arousal and autism but relatively limited data specific to ongoing patterns of behavior in real-world contexts, the purpose of this case study was to test the feasibility of an integrative biobehavioral analysis approach to examine the role that arousal played in choice of activities for a young boy with autism. We leveraged technology advances such that our acquisition of autonomic (HR) and behavioral (allocation) data could be accomplished in real time in a real-world context to ensure a high level of ecological validity (e.g., all sessions conducted in the home [not lab], all activities selected based on maternal report). The arousing nature of the activities was then verified by

testing the actual arousal levels during the activities by examining HR during each activity. The influence of changes in arousal on choice of activities was then evaluated using lag sequential analysis. The results showed that the participant tended to choose an activity that maintained the level of arousal occurring in the previous condition. In other words, the participant was more likely to choose a highly arousing activity following an increase in arousal as measured by HR and he was more likely to choose low arousing activity following a decrease in HR. Secondary analyses showed a tendency for SIB to be more likely during highly arousing activities.

As with other single case demonstrations, this study provides a proof of concept and an initial test of the experimental procedures rather than a test of any particular theoretical model of arousal or SIB in autism. There are a number of key issues that limit the conclusions that can be drawn from our results including external validity and selection bias. Clearly, there are many potential indices of autonomic arousal of which HR is only one measure. Future work could help delineate the relative influence of sympathetic and parasympathetic activity to modulate overall arousal. Measurement of other systems would also be important in future work such as the activity of the HPA axis in relation to environmental challenge and stressors.

Limitations notwithstanding, given the limited empirical work in this area, our approach and preliminary findings do relate to and extend prior work in this area (e.g., Barrera et al 2007; Freeman, et al., 1999). Because physiological data are known to be highly variable and inherently auto-correlated they are often a poor candidate for visual analysis (Jones, Weinrott, & Vaught, 1978). Thus, we extended the work of Barrera et al and Freeman et al by using quantitative analyses of HR data instead of relying of visual analysis. The sequential methods used here also extend the approach by quantifying the magnitude of the relationship between HR and behavior while taking into account the base rates of all the coded events. Previously, Graveling and Brooke (1978) modified arousal level by increasing or decreasing ambient lighting, noise levels, and amount of physical and verbal interactions between teachers and students. Their results showed no difference by treatment condition, but children with autism showed significantly higher heart rate variability and lower mucoprotein variability than the controls. In the current demonstration, the participant self-selected between the two arousal conditions and reliable differences were found between changes in arousal and choice of activity. One issue, then, for further investigations of physiological arousal is to consider possible differences in passive exposure to versus active selection of environmental experiences.

Overall, our results, although not confirmatory of any one model of arousal within autism, provide an initial examination of the role of arousal in relation to behavioral allocation among activities and provide a model of an integrative biobehavioral methodology to test the hypothesis that individuals with developmental disorders may modulate arousal by activity choice. The use of a concurrent-like operant choice procedure allowed quantification of choice making behavior within the sessions while alternation with control conditions provided a return to baseline arousal levels to assess the effects of high and low arousal choices. The use of sequential analysis as implemented here allows the testing of specific hypotheses about whether arousal preceded or followed choice of activities which has not been explored in previous work. Clinically, future work should explore the role arousal may play in treatment outcome particularly for participants for whom state of the art functional behavioral assessments are inconclusive or treatments are ineffective.

Acknowledgments

We gratefully acknowledge the support and patience of our participating family and help from Alexandra Schmidt. This research was supported, in part, by a pre-doctoral fellowship from the Center for Neurobehavioral Development at the University of Minnesota to John Hoch and NIH Grant No.'s 44763, 47201.

References

- Barrera, et al. On the form and function of severe self-injurious behavior. *Behavioral Interventions*. 2007; 22:5–33.10.1002/bin.228
- Berkson G. Abnormal stereotyped motor acts. *Proceedings of the annual meeting of the American Psychopathological Association*. 1967; 55:76–94. [PubMed: 4963340]
- Bodfish JW, Symons FJ, Parker DE, Lewis MH. Varieties of repetitive behavior in autism: Comparisons to mental retardation. *Journal of Autism and Developmental Disorders*. 2000; 30(3): 237–243. [PubMed: 11055459]
- Edelson SM. Implications of sensory stimulation in self-destructive behavior. *American Journal of Mental Deficiency*. 1984; 89(2):140–145. [PubMed: 6486177]
- Fisher W, Piazza CC, Bowman LG, Hagopian LP, Owens JC, Slevin I. A comparison of two approaches for identifying reinforcers for persons with severe and profound disabilities. *Journal of Applied Behavior Analysis*. 1992; 25(2):491–498.10.1901/jaba.1992.25–491 [PubMed: 1634435]
- Freeman RL, Horner RH, Reichle J. Relation between heart rate and problem behaviors. *American Journal on Mental Retardation*. 1999; 104(4):330–345.10.1352/0895–8017(1999)104<0330:RBHRAP>2.0.CO;2 [PubMed: 10450460]
- Gamelin FX, Berthoin S, Bosquet L. Validity of the polar S810 heart rate monitor to measure R-R intervals at rest. *Medicine and Science in Sports and Exercise*. 2006; 38(5):887–893.10.1249/01.mss.0000218135.79476.9c [PubMed: 16672842]
- Graveling RA, Brooke JD. Hormonal and cardiac response of autistic children to changes in environmental stimulation. *Journal of Autism and Childhood Schizophrenia*. 1978b; 8(4):441–455.10.1007/BF01538049 [PubMed: 730667]
- Groden J, Goodwin MS, Baron MG, Groden G, Velicer WF, Lipsitt LP, et al. Assessing cardiovascular responses to stressors in individuals with autism spectrum disorders. *Focus on Autism and Other Developmental Disabilities*. 2005; 20(4):244–252.10.1177/10883576050200040601
- Guess D, Carr E. Emergence and maintenance of stereotypy and self-injury. *American Journal of Mental Retardation*. 1991; 96(3):299–319. [PubMed: 1756034]
- Hoepfner BB, Goodwin MS, Velicer WF, Heltshe J. An applied example of pooled time series analysis: Cardiovascular reactivity to stressors in children with autism. *Multivariate Behavioral Research*. 2007; 42(4):707–727.10.1080/00273170701755291
- Hutt C, Hutt SJ, Lee D, Ounsted C. Arousal and childhood autism. *Nature*. 1964; 204:908–909.10.1038/204908a0 [PubMed: 14235732]
- Hutt SJ, Hutt C, Lee D, Ounsted C. A behavioural and electroencephalographic study of autistic children. *Journal of Psychiatric Research*. 1965; 3(3):181–197.10.1016/0022–3956(65)90028–2 [PubMed: 5860627]
- Iwata BA, Dorsey MF, Slifer KJ, Bauman KE, Richman GS. Toward a functional analysis of self-injury. *Journal of Applied Behavior Analysis*. 1994; 27(2):197–209.10.1901/jaba.1994.27–197 [PubMed: 8063622]
- Jones RR, Weinrott MR, Vaught RS. Effects of serial dependency on the agreement between visual and statistical inference. *Journal of Applied Behavior Analysis*. 1978; 11(2):277. [PubMed: 16795592]
- Jon Tapp & Associates. ProCoderDV. Computer software and manual. 2010. Retrieved from <http://procoder.vueinnovations.com/>
- Kingsley M, Lewis MJ, Marson RE. Comparison of polar 810s and an ambulatory ECG system for RR interval measurement during progressive exercise. *International Journal of Sports Medicine*. 2005; 26(1):39–44.10.1055/s-2004–817878 [PubMed: 15643533]

- Maisto C, Baumeister A, Maisto A. An analysis of variables related to self-injurious behavior among institutionalized retarded persons. *Journal of Mental Deficiency Research*. 1978; 22(1):27–36. [PubMed: 682181]
- Matson JL, Bamburg JW, Cherry KE, Paclawskyj TR. A validity study on the questions about behavioral function (QABF) scale: Predicting treatment success for self-injury, aggression, and stereotypies. *Research in Developmental Disabilities*. 1999; 20(2):163–175.10.1016/S0891–4222(98)00039–0 [PubMed: 10198945]
- O’Neil, RE.; Horner, RH.; Albin, RW.; Sprague, JR.; Storey, K.; Newton, JS. *Functional assessment and program development for problems behavior: A practical handbook*. Pacific Grove, CA: Brooks/Cole Publishing Company; 1997.
- Palkovitz RJ, Wiesenfeld AR. Differential autonomic responses of autistic and normal children. *Journal of Autism and Developmental Disorders*. 1980; 10(3):347–360.10.1007/BF02408294 [PubMed: 6927661]
- Pierce WD, Epling WF. Choice, matching, and human behavior: A review of the literature. *The Behavior Analyst*. 1983; 6:57–76.
- Rimland, B. *Infantile autism: The syndrome and its implications for a neural theory of behavior*. Appleton-Century-Crofts; 1964.
- Schopler, E.; Reichler, RJ.; Renner, B. *The childhood autism rating scale*. Test Corp of America; 1992.
- Siegel, S. *Nonparametric statistics for the behavioral sciences*. NY: McGraw-Hill; 1956.
- Sparrow, SS.; Balla, DA.; Cicchetti, DV. *Vineland adaptive behavior scales*. Circle Pines, MN: American Guidance Service; 1984.
- Sroufe LA, Struecher HU, Strutzer W. The functional significance of autistic behaviors for the psychotic child. *Journal of Abnormal Child Psychology*. 1973; 1:225–240.10.1007/BF00917733
- Stevens S, Gruzelier J. Electrodermal activity to auditory stimuli in autistic, retarded, and normal children. *Journal of Autism and Developmental Disorders*. 1984; 14(3):245–260.10.1007/BF02409577 [PubMed: 6480545]
- Tapp J, Wehby JH, Ellis N. A multiple observation system for experimental studies: MOOSES. *Behavior Research Method, Instruments, & Computers*. 1995; 27:25–31.
- Velicer, W.; Fava, J. *Research Methods in Psychology*. 1. Vol. 2. New York: Wiley; 2003. Time series analysis; p. 581–606.
- Yoder PJ, Bruce P, Tapp J. Comparing sequential associations within a single dyad. *Behavior Research, Methods, Instruments, & Computers*. 2001; 33:331–338.
- Yoder, PJ.; Feurer, ID. Quantifying the magnitude of sequential association between events or behaviors. In: Thompson, T.; Felce, D.; Symons, FJ., editors. *Behavioral observation: Technology and applications in developmental disabilities*. Baltimore: Paul H. Brookes Publishing; 2000. p. 335–348.

Figure 1.
Schematic diagram of choice procedures.

Figure 2.

Summary level comparison of HR between the three conditions. Data points indicate means (beats per min [BPM]) for each condition; bars represent 95% confidence interval for means. LA = low arousal; CC = control condition; HA = high arousal.

Figure 3.

Probability of choosing high (HA) or low (LA) arousal activity following heart rate (HR) increases or decreases greater than 1 SD from mean of pooled control conditions. Yule's Q values on Y axis at 0 represent observed values at chance probabilities; positive Yule's Q values indicate occurrence at greater than expected from chance levels; negative values represent observed values less than expected from chance estimates. P values are for comparison of congruent (e.g., increase in arousal (HR) followed by choice of HA) vs. noncongruent (e.g., decrease in arousal followed by choice of HA) patterns for both high arousal and low arousal test conditions.