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Heart rate and skin conductance in four-year-old children with aggressive behavior

J.A. Posthumus [a,*], K.B.E. Böcker [b], M.A.J. Raaijmakers [a], H. Van Engeland [a], W. Matthys [a]

[a] Department of Child and Adolescent Psychiatry, Rudolf Magnus Institute of Neuroscience, University Medical Center Utrecht, The Netherlands
[b] Departments of Psychopharmacology and Experimental Psychology, Utrecht Institute of Pharmaceutical Studies, Rudolf Magnus Institute of Neuroscience and Helmholtz Institute, Utrecht University, The Netherlands

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ABSTRACT

Autonomic underarousal, indicated by low heart rate (HR) and skin conductance level (SCL), is related to childhood aggression. However, results are inconsistent in preschoolers. We assessed HR, SCL, heart rate reactivity and skin conductance reactivity in four-year-old children. Comparisons were made between children with a high level and with a low level of aggressive behavior according to the Child Behavior Checklist 1½–5 as well as between children who were diagnosed with Oppositional Defiant Disorder or Conduct Disorder (ODD/CD) and children with a low level of aggression. Preschool children with a high level of aggressive behavior showed lower SCL and SCR and children with ODD/CD showed lower SCL. In contrast, we did not find lower HR and HRR in preschool children with a high level of aggressive behavior or ODD/CD. Thus, results suggest that decreased SCL, but not HR, is a characteristic of preschool children with aggressive behavior or ODD/CD.

1. Introduction

Autonomic underarousal is one of the neurobiological correlates of aggressive behavior (Raine, 2002), i.e., behavior deliberately aimed at harming people (Parke and Slaby, 1983). Heart rate (HR) and skin conductance level (SCL) have been studied as indicators of underarousal in relation to aggressive behavior, both during baseline and in reaction to stimuli. However, as pointed out by Lorber (2004), in empirical studies in this field, children have been defined not only in terms of aggressive behavior, but also in terms of antisocial behavior, delinquent behavior, psychopathic traits and conduct problems.

Results of meta-analyses conducted by Raine (1996) and Ortiz and Raine (2004) indicate that low resting HR is one of the best replicated biological markers of antisocial and aggressive behavior in children and adolescents. Effect sizes in the meta-analyses were calculated using Cohen's *d*: .20 indicates a small effect, .50 a medium effect and .80 a large effect size (Cohen, 1992). Effect sizes were medium ($d = -.56$) for HR during rest in children and adolescents with antisocial behavior in the first meta-analysis and in the meta-analysis of 2004 ($d = -.44$). For heart rate reactivity (HRR), Ortiz and Raine reported a large effect size ($d = -.76$). In another recent meta-analysis in which children, adolescents and adults were analyzed separately, Lorber (2004) found that conduct problems in children were associated with low resting HR ($d = -.34$), but greater HRR ($d = .20$). In this meta-analysis, it was also found that children with conduct problems had lower SCL ($d = -.30$) and skin conductance reactivity (SCR; $d = -.46$) (Lorber, 2004). In conclusion, these meta-analyses provide evidence that low resting HR and SCL, as well as SCR, are robust correlates of antisocial behavior in children, but there is less agreement regarding HRR.

As it appears from a large number of studies, there is evidence for autonomic underarousal in elementary school children and adolescents with aggressive or antisocial behavior. Yet, few studies regarding autonomic nervous system (ANS) functioning have been conducted in preschoolers and results are inconsistent. Some longitudinal studies starting in early childhood have been conducted to assess HR and SC as predictors of aggressive or antisocial behavior. In the Mauritius study, it was found that nine-year-old boys, who had been characterized by their teachers as indulging in fighting, had significantly lower SCR at age 3 than their non-fighting peers (Venables, 1989). Furthermore, aggression at age 11 was predicted by low resting HR at age 3 (Raine et al., 1997). However, results from another study revealed that low HR in infancy and toddlerhood (measured at 14, 20, 24 and 36 months) did not predict externalizing behavior problems at age 7 (Van Hulle

* Corresponding author at: Department of Child and Adolescent Psychiatry, Rudolf Magnus Institute of Neuroscience, University Medical Center Utrecht, A 01.468/A 01.449, PO Box 85500, 3508 GA Utrecht, The Netherlands.

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et al., 2000). From these studies, it remains unclear at what age underarousal in children with aggressive behavior arises. Besides these longitudinal studies, some cross-sectional studies have investigated HR and SC as correlates of aggressive or antisocial behavior. A recent study demonstrated that preschool children with Oppositional Defiant Disorder (ODD) showed less spontaneous skin conductance fluctuations and lengthened cardiac pre-ejection periods (Crowell et al., 2006). In a study in two-year-old children with externalizing behavior, no differences were found on HR (Calkins and Dedmon, 2000). Assuming that aggression and fearlessness are associated (Raine, 1993), the study conducted by Fowles et al. (2000) should be mentioned; fearless four-year-old children showed lower SCR than children who were fearful.

Few studies in preschoolers have been conducted and most studies included only one indicator of underarousal. On top of that, as mentioned earlier, children have been defined from different behavioral perspectives. Therefore, aims of the present study were to assess four indicators of underarousal (HR, SCL, HRR and SCR) in a sample of preschool children defined both from the perspective of aggressive behavior and from the perspective of syndromes of disruptive behaviors, i.e., the DSM-IV-TR categories ODD and Conduct Disorder (CD) (APA, 2000). ODD and CD are clusters of disruptive behavior or clinical syndromes consisting of a large variety of inappropriate behaviors, whereas aggressive behavior is more homogeneous. ODD and CD are being increasingly used to define children in ANS studies (e.g., Beauchaine et al., 2008; Crowell et al., 2006). Moreover, since aggressive behavior is frequently observed in children with ADHD (Connor et al., 2002), we also included children diagnosed with ADHD. To our knowledge, no studies have been conducted regarding ANS functioning in an ADHD-only group. Therefore, we did not formulate specific hypotheses regarding ADHD. Finally, because of a high comorbidity of ODD/CD and ADHD (Angold et al., 1999), a comorbid group was also included. Based on the literature about ANS functioning in school-aged children, we hypothesized that (1) children with a high level of aggressive behavior and (2) children with ODD/CD with or without ADHD, show lower basal levels of HR and SC, and decreased HR and SC responses when compared to children with a low level of aggressive behavior.

2. Method

2.1. Participants

Children were selected from a population-based sample (N = 16,002) from the province of Utrecht, The Netherlands. The sample used in this study was derived from a larger study into the effect of an indicated preventive intervention. Here, we report on the psychophysiological assessment that took place prior to the intervention. Addresses of children born in 2000 and 2001 were acquired by the Office for Screening and Vaccination. Parents of the four-year-old children were asked to fill out the Child Behavior Checklist 1½–5 (CBCL for ages 1½–5; Achenbach and Rescorla, 2000; Dutch version by Verhulst and Van den Ende). Parents of 8632 children returned the CBCL. The CBCL Aggressive Behavior scale, which consists of 19 items, e.g., 'often had temper tantrums', 'fights and attacks people', was used to select the children. Children (N = 452) with a score at or above the 80th percentile on the Aggressive Behavior scale of the CBCL were considered children with aggressive behavior and were invited to participate in the preventive study. In the present study, 140 children who scored at or above the 80th percentile of the CBCL Aggressive Behavior scale both at selection and at pre-intervention assessment were included (64% boys). In sixteen children (8 boys, 8 girls) assessment of HR and SC was not possible because of excessive noncompliant behavior. Thus, the final group of children with aggressive behavior consisted of 79 boys and 45 girls. The CBCL was also used to select 101 normal control children (64% boys) from the population-based sample. These children were required to score below the 50th percentile of the CBCL Aggressive Behavior scale. Exclusion criteria were an IQ below 80 and for normal control children the presence of ODD, CD or ADHD. Of both groups of children, 3.2% was non-Caucasian (mainly Antillean). All children were medication naïve.

2.2. Definition of groups

In order to compare the children with high and low levels of aggressive behavior, children were divided in two groups: a group of children with a low level of aggression (LOW AGGR; ≤50th percentile) and a group of children with a high level of aggression (HIGH AGGR; ≥80th percentile). The children were also divided into four diagnostic subgroups: an ODD/CD only group, an ADHD group, a comorbid ODD/CD + ADHD group and the LOW AGGR group without an ODD/CD/ADHD diagnosis. Characteristics of all groups of children are summarized in Table 1.

Independent sample t-tests showed that some groups differed significantly from LOW AGGR children on these demographic characteristics. HIGH AGGR children and children with ADHD had a lower IQ than the LOW AGGR group. The children with ODD/CD + ADHD had a lower IQ and were younger than the LOW AGGR group. Furthermore, the difference between inside and outside temperature was significantly smaller in the group of children with comorbid ODD/CD + ADHD. Educational level of the parent was measured with a 5-point scale (1: primary education, 2: secondary education, 3: intermediate vocational education, 4: higher vocational education and 5: university education). The mean percentage of educational level in the groups was 0.9% of the parents followed primary education, 4.9% received secondary education, 30.9% followed intermediate vocational education, 33.1% received higher vocational education and 30.2% went to university. Chi-square tests showed that educational level of the parents did not differ between the LOW AGGR group and the HIGH AGGR group; χ^2 (4, N = 223) = 1899, p = .754 and between the LOW AGGR group and the ADHD, ODD/CD and ODD/CD + ADHD groups; χ^2 (12, N = 210) = 10,376, p = .583.

2.3. Apparatus

The Vrije Universiteit Ambulatory Monitoring System 36 (VU-AMS; Klaver et al., 1994) was used to measure HR and SCL. The electrocardiogram (ECG) was amplified and filtered at 17 Hz. The R-top in the analogue signal triggered a level detector with

Table 1
Participant characteristics.

	LOW AGGR	HIGH AGGR	ODD/CD	ODD/CD + ADHD	ADHD
N	101	124	43	45	21
Gender in % boys	64.4%	63.7%	62.8%	68.9%	57.1%
Age in years (M, SD)	4.3 (0.2)	4.3 (0.3)	4.3 (0.3)	4.2 (0.3)*	4.3 (0.3)
WPPSI estimated IQ (M, SD)	110.5 (8.4)	107.6 (10.5)*	109.1 (10.9)	105.1 (9.4)**	106.1 (9.0)*
Temperature in Celsius					
Inside	21.2 (2.0)	20.7 (1.9)	20.7 (1.3)	21.3 (1.8)	20.8 (2.0)
Outside	10.7 (6.2)	11.8 (7.1)	11.3 (7.1)	13.7 (7.0)[a]	10.04 (6.1)
Humidity level in % (M, SD)	41.4 (8.5)	41.9 (8.7)	41.1 (8.7)	43.0 (8.9)	39.14 (6.3)
CBCL					
Aggressive behavior (M, SD)	3.5 (2.4)	22.2 (5.1)	21.0 (4.2)	25.0 (5.8)	20.5 (4.0)
DISC IV					
No diagnosis		15			
ODD/CD		43			
ODD/CD + ADHD		45			
ADHD		21			

* p =< .05.
** p =< .01.
[a] Inside–outside difference smaller than in LOW AGGR.

automatic level adjustment. This level detector stopped and reset a timer with millisecond resolution. For each R-top the output of this timer was stored in memory and later exported as a raw series of Inter Beat Intervals (IBI). SCL was measured with 0.5 V constant voltage method, as recommended by Fowles et al. (1981). To record skin conductance two Ag–AgCl electrodes (65 mm diameter) were used, filled with Biopac isotonic paste. Sample rate for SC measurement was set at 10 samples per second (10 Hz). ECG was recorded with disposable electrodes on the chest (sternum-V6 lead; bandwidth 5–30 Hz). ECG electrodes were attached above the jugular notch of the sternum between the collar bones, 4 cm under the left nipple, between two ribs and at the right lateral side, between the lower two ribs. Usually, SCL electrodes are attached to the nondominant hand. Since hand dominance is not crystallized by the age of 4, the skin conductance electrodes were attached to the volar surfaces of the medial phalanges of the middle and index finger of the left hand. Humidity level and the difference between inside and outside temperature are possible confounders of HR and SC (D.C. Fowles, personal communication, August 31, 2005). Therefore, inside temperature and humidity level were measured with a weather station. Outside temperature data were acquired by the archives of the Royal Netherlands Meteorological Institute in De Bilt.

2.4. Procedure

All children were individually assessed twice in their home environment, in order to reduce their fear. During the first home visit, children were neuropsychologically assessed for 45 min. After a short break, the assessment of HR and SC took place. The children sat at a table facing the monitor at approximately 60 cm. They were asked to sit still and to lay down their hands on the table, because motor activity is expected to elicit increases of SCL and HR. Before the electrodes were attached, the skin was cleaned and firmly rubbed with alcohol. During the second home visit, the CBCL and the Diagnostic Interview Schedule for Children IV—Parent version (DISC IV-P) (Shaffer et al., 2000) was administered to parents of all children in both groups, to assess symptoms of ODD, CD and ADHD. Intelligence of the child was assessed with the Wechsler Preschool and Primary Scales of Intelligence-Revised (WPPSI-R; Wechsler, 1997; Dutch version by Vander Steene and Bos, 1997). Subtests Vocabulary, Similarities, Picture Completion and Block Design were used to estimate full scale IQ (correlation subtests with full scale IQ = .92), following the guidelines of Sattler (1992). On each home visit, two trained experimenters were present.

Written informed consent was obtained from the parents prior to participation and all families received a financial reimbursement for participation. Children received a small gift for their participation. The study was approved by the Medical Ethical Review Committee of the University Medical Center Utrecht.

2.5. Assessment of HR and SCL

Given the age of the children in this study, a stimulus such as a movie was necessary in order to keep the child seated at the table and to limit movement artefacts in HR and SC data. The children were asked to relax and enjoy the Bob the Builder movie[1], 'Dizzies crazy garden path', which lasted for 9:28 min. The Event Button of the VU-AMS was used to provide synchronization between the start of the film and the physiological signals. Baseline HR and SCL were defined as its average level from minutes 2–5 of the Bob the Builder film. A small pilot study ($N = 25$) confirmed that assessment of HR and SCL during video-watching did not differ from that during unfilled rest. After 6:20 min, an exciting moment occurred in the film. This moment was used to measure HR and SC responses. SCR was defined as the maximum response in the one-minute time window following the exciting moment, relative to the local minimum preceding the maximum[2]. For HRR, the average HR from 6:05 to 6:20 min served as a baseline. Next, the average HR was calculated for 7 intervals of 10-s duration, with 5 s overlap (from 6:20 to 6:55). The baseline value was subtracted from the averages to arrive at HRR values for each interval (see also: Pérez et al., 2000; Sanchez-Navarro et al., 2006). The time series of these values showed a 10-s deceleration and recovery after 25 s in all groups. Due to missing markers SCR and HRR were missing in 9 normal controls and 12 children with aggressive behavior.

2.6. Statistical analyses

Since IQ differed between the HIGH and LOW AGGR group, IQ was used as a covariate in this comparison. In the omnibus ANCOVA, all variables on which diagnostic subgroups differed from the LOW AGGR children, were used as covariates (age, IQ and the difference between inside and outside temperature).

SPSS 15.0 (2006) was used to conduct statistical analyses. In all analyses, an α of .05 was used. Skewness was <1, therefore, log transformation was not necessary. Effect sizes were calculated using Cohen's d: 0.2 indicates a small effect, 0.5 a medium effect and 0.8 a large effect size (Cohen, 1992). Three outliers, defined as individual values more than 3 SD's above the mean group value, were removed from the final analyses.

3. Results

All analyses were run separately for boys and girls but no differences were obtained, nor were there any group by gender interactions (all F's were smaller than 3190). Therefore, the results from analyses without the factor gender will be presented below.

3.1. Children with aggressive behavior problems

Results of the comparisons between children with a high level of aggressive behavior and children with a low level of aggressive behavior are presented in Table 2. According to expectations, children with a high level of aggression had significantly lower SCL ($d = .33$) and SCR ($d = .36$) than children with a low level of aggression. We expected to find that children with a high level of aggressive behavior had lower resting HR and HRR, but we observed no significant differences between the groups of children with high and low levels of aggression (HR: $d = .10$; HRR: $d = .20$).

3.2. Children with a DSM-IV-TR diagnosis

Results of the comparisons between children with a DSM-IV-TR diagnosis and children with a low level of aggressive behavior are presented in Table 3. Only SCL did show group differences. Post hoc analyses showed that, according to expectations, children with ODD/CD had significantly lower SCL than children with a low level of aggression ($d = -.45$, $p < .05$). We expected to find that children with ODD/CD would also have lower HR, HRR and SCR than children with a low level of aggressive behavior, but we observed no significant differences (HR: $d = -.10$; HRR: $d = -.12$; SCR: $d = -.35$). There were no significant differences neither between children with comorbid ODD/CD + ADHD and children with a low level of aggressive behavior (all d's $\leq -.27$) nor between children with ADHD-only and children with a low level of aggression on any of the autonomic measures (all d's $\leq -.54$).

4. Discussion

In the present study, various measures of autonomic arousal were investigated in groups of preschool children, defined from the perspective of aggressive behavior and from the perspective of clinical syndromes of disruptive behaviors. The main finding was that four-year-old children with a high level of aggressive behavior showed lower SCL and SCR than children with a low level of aggressive behavior, and that four-year-old children with ODD/CD showed lower SCL, relative to children with a low level of aggressive behavior. Our results are in line with findings in older children with conduct problems (Lorber, 2004). This suggests that decreased SCL and SCR are correlates of aggressive behavior from the preschool years onwards. Yet, the meaning of these results is unclear, but if we assume that low SCL and SCR are markers of punishment sensitivity (Fowles, 1980), young children with reduced SCL and SCR would be at risk for problems in socialization because of their reduced responsiveness to negative feedback on their misbehavior.

Contrary to expectations, we did not find lower HR in preschool children with aggressive behavior or in children with a DSM-IV-TR ODD or CD diagnosis. This is in line with findings in younger

[1] Story line Bob the Builder: Bob, his co-worker Wendy and the machines (who have human qualities) are creating a new garden path in the garden of a very respectable lady. While Bob and Wendy are absent, one of the machines is carrying the tiles for the garden path. The tiles are too heavy and the machine has to let them go. The tiles fall and break into pieces. What would the lady say and what should they do now? As usual, they come up with a solution (to make a mosaic path with the broken tiles) and the lady likes her new garden path.

[2] Note that when skin conductance is measured by the constant-voltage method, as it was in the present study, the SC signal decreases very gradually but monotonously over time in the absence of skin responses. Therefore, identifying the local minimum which precedes the response is a valid heuristic to derive the level at the start of the response.

Table 2
HR and SC results from one-way ANCOVA's in children with low and high aggression levels.

	LOW AGGR		HIGH AGGR		*F*	df	*p*
	N	M (SD)	*N*	M (SD)			
HR in bpm	101	97.05 (10.46)	123	94.87 (12.66)	0.2	1	ns
SCL in μS	101	13.26 (7.50)	120	11.09 (5.94)	5.5	1	.020
HRR[a]	92	−0.60 (4.66)	111	−1.46 (3.99)	1.77	1	ns
SCR	93	2.28 (2.24)	111	1.61 (1.55)	5.97	1	.015

LOW AGGR: children with a low level of aggression (<50th percentile CBCL); HIGH AGGR: children with a high level of aggression (>80th percentile CBCL).
[a] Because the time series of HRR intervals did not interact with the between subjects factor the table shows the average value over time.

Table 3
HR and SC results from omnibus ANCOVA in children with ODD/CD and/or ADHD and LOW AGGR children.

	LOW AGGR		ODD/CD		ODD/CD + ADHD		ADHD		*F*	df	*p*
	N	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)			
HR in bpm	101	97.05 (10.46)	43	95.99 (12.54)	44	95.24 (12.47)	21	90.59 (13.69)	1.73	3	ns
SCL in μs	101	13.26 (7.50)	42	9.77 (5.30)	44	12.65 (5.99)	19	11.06 (6.29)	2.85	3	.04
HRR[a]	92	−0.60 (4.66)	39	−1.10 (3.91)	43	−1.06 (4.04)	18	−2.62 (4.11)	2.85	3	.09
SCR	93	2.23 (2.24)	39	1.64 (1.78)	43	1.796 (1.41)	17	1.46 (1.61)	1.54	3	ns

[a] Since the time series of HRR intervals did not interact with the between subjects factor the table shows the average value over time.

children (14–36 months) (Van Hulle et al., 2000; Calkins and Dedmon, 2000), as well as in somewhat older children (five-year-old) (Calkins et al., 2007) with aggressive behavior, who also did not display lower HR. In contrast, numerous studies in school-aged children with clinical syndromes of disruptive behavior did show lower HR (e.g., Van Goozen et al., 1998) and lower SCL during rest (e.g., Van Goozen et al., 2000). Moreover, results from meta-analyses show that low resting HR is a correlate of school-aged children with aggressive behavior (Ortiz and Raine, 2004; Raine, 1996). Results of these studies suggest that differences on HR between children with aggressive behavior and normal controls arise during elementary school. It is possible that the group of children with a high level of aggressive behavior at the age of four consists of a subgroup of children who will show a decrease in aggression over time (Shaw et al., 2005; Hill et al., 2006) and in which lower HR is not a characteristic. This leads to the working hypothesis that lower HR is a characteristic only in the group of school-aged children with persistent aggressive behavior or a DSM diagnosis of ODD/CD.

Although we expected children with aggressive behavior or a DSM-IV-TR diagnosis of ODD/CD with or without ADHD to have decreased HRR, we did not find significant results. Results of meta-analyses are contradictory with respect to HRR in children with aggressive behavior; Lorber (2004) found that greater HRR was associated with conduct problems, whereas Ortiz and Raine (2004) found children with aggressive behavior to have decreased HRR.

Thus, our results suggest that electrodermal activity is a more sensitive correlate of aggression than HR in preschool boys and girls, which is also reflected by the effect sizes. However, in contrast to Beauchaine et al. (2008), who found reduced respiratory sinus arrhythmia and cardiac pre-ejection periods in 8–12-year-old boys with conduct problems and greater SCR in girls with conduct problems, we did not find sex differences on any of the autonomic measures. Since we used different indicators of underarousal than Beauchaine et al. (2008), further research should decide whether this is a real developmental gender difference or not.

From the analyses with the comorbid ODD/CD + ADHD group, it appeared that these children do show neither lower HR and SCL, nor decreased HRR and SCR. To date, it is unclear whether children with ODD/CD + ADHD should be considered as a subgroup of children with ODD/CD, as a subgroup of children with ADHD, or as a distinct diagnostic category. There is evidence that the ODD/CD + ADHD group cannot be distinguished as an independent disorder (Rhee et al., 2008). If the ODD/CD + ADHD group in the present study would have been a subgroup of the ODD/CD group, decreased SCL should have been a characteristic. The meaning of the absence of differences between children with comorbid ODD/CD + ADHD and children with a low level of aggressive behavior is unclear. Furthermore, children with ADHD do not differ from children with a low level of aggressive behavior on any of the autonomic measures in the present study. It is difficult to compare these results with other research regarding autonomic measures in children with ADHD, because most studies did not include an ADHD-only group (but instead, used children with comorbid ADHD + ODD/CD).

The results of the study should be interpreted in the context of some limitations. First, the educational level of the parents participating in this study is rather high. Comparing the distribution of educational level in our sample to the distribution of educational level in the entire Dutch population (CBS, 2007) indicates that the parents in our sample received higher education. Thus, our findings have limited generalizability to children from less educated parents. Second, it would have been interesting to measure psychopathic traits in this group in relation to autonomic measures, for Lorber (2004) showed in his meta-analysis that adult psychopaths are characterized by low SCL, but not low HR. In an early review by Hare (1978) it was shown that psychopaths had decreased SCR, but normal or even larger cardiac responses. Unfortunately, there are no reliable measures to assess psychopathy in preschoolers. Finally, the DSM-IV-TR subgroup comparisons had less power than the analyses using continuous aggression scores due to a relatively small number of children in the DSM-IV-TR subgroups.

Regarding methodological issues, there are two particular strengths in this study. First, we controlled for inside and outside temperature and humidity level as possible confounding factors in the analyses. Second, by assessing these young children at home, the influence of fear and excitement on autonomic measures was minimized.

In conclusion, the present study showed low SCL and SCR to be characteristics of four-year-old children with aggressive behavior. This finding is similar to the results of four-year-old children with ODD/CD; those children showed lower SCL. In contrast, we did not find lower HR in preschool children with aggressive behavior or

DSM-IV-TR ODD/CD diagnosis. Lower HR seems to be a correlate of aggression in children at a later age.

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