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# A prospective study of heart rate and externalising behaviours in young children

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**Background:** Low heart rate predicts externalising and delinquent behaviour in adults, adolescents and school-age children. In younger children the evidence is less clear. Moreover, the specificity of the relation between the autonomic nervous system and different forms of externalising behaviour is uncertain. We investigated the longitudinal relation between resting mean heart rate and different externalising behaviours. **Methods:** In 412 children of the Generation R Study, we measured resting mean heart rate at 14 months. At 3 years, child problem behaviour was assessed by the mother with the Child Behavior Checklist. In a gift delay task, we observed whether children were compliant and whether they lied about their noncompliance. The association of heart rate with behaviour was contrasted with the effect of harsh parenting. **Results:** In our main analysis, we examined the association between heart rate and reported and observed child behaviour. For comparison, the association of heart rate with behaviour was contrasted with the effect of harsh parenting. Mean heart rate was positively associated with Anxious/Depressed scale scores (β = .1, 95% CI = 0.01; 0.2, $p$ = .04), but not with Aggressive Behaviour (β = .02; 95% CI = −0.1; 0.1, $p$ = .8) nor Attention Problem scale scores (β = .08, 95% CI = −0.3; 0.5, $p$ = .8). We could not demonstrate an association between mean heart rate and noncompliance during the gift delay task (OR = 1.14, 95% CI = 0.9; 1.1, $p$ = .2), but lower heart rate predicted higher odds of the child lying (OR = 0.56, 95% CI = 0.3; 0.9, $p$ = .03). In contrast, harsh parenting was associated with mother-reported Aggressive Behaviour (β = .7, 95% CI = 0.4; 0.9, $p$ < .001) and Attention Problems (β = .2, 95% CI = 0.1; 0.3, $p$ < .001), but not with observed lying (OR = 1.03, 95% CI = 0.8; 1.4, $p$ = .8). **Conclusions:** Lower resting mean heart rate at age 14 months predicts low anxiety symptoms and higher odds of lying at age 3 years. Low resting mean heart rate may be less an indicator of early childhood aggression than of fearless behaviour. **Keywords:** Child, heart rate, anxiety, externalising behaviour, parenting, compliance.

## Introduction

Externalising behaviour in early childhood can be a precursor of more severe externalising psychopathology, which may persist into adolescence and adulthood (Campbell & Ewing, 1990; Tremblay et al., 2004). Yet to some extent, oppositional, hyperactive and aggressive behaviour in young children is in keeping with normal development (Alink et al., 2006). This has made it difficult to delineate normal age-limited behaviour from pathological externalising behaviour (Dunn & Munn, 1986; Hay, Castle, & Davies, 2000). This challenge has fuelled interest in identifying early risk factors and markers for more pathological and persistent externalising behaviour.

Variations in the autonomic nervous system and its proxy heart rate are considered a potential biomarker of externalising problems. While mean heart rate declines substantially between birth and 7 years of age, individual differences in heart rate are relatively stable over this age range (Van Hulle, Corley, Zahn-Waxler, Kagan, & Hewitt, 2000). Several prospective studies have shown that low autonomic arousal, as indexed by low resting mean heart rate, predicts externalising behaviour (Raine, Venables, & Mednick, 1997). The relation between low resting mean heart rate and externalising behaviour holds throughout later childhood, adolescence and beyond (Ortiz & Raine, 2004). Several theoretical models have been proposed for the observed relation between low heart rate and externalising behaviour. The stimulation seeking theory posits that low heart rate and low physiological arousal in general, is an unpleasant physiological state. Children with low arousal seek stimulation to increase their arousal levels. Externalising behaviour may be viewed as a form of stimulation-seeking for some children. The fearlessness theory argues that low heart rate is a marker of low levels of fear. Children who experience low levels of fear are less likely to head potential negative consequences of their actions. Furthermore, children with low levels of fear are less likely

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to be responsive to socialising punishments, which may in turn contribute to poor fear conditioning (Raine et al., 1997). Alternatively, low heart rate may not be a direct cause of externalising behaviour, but a marker for other processes that are implicated in externalising behaviour, such as poor right hemisphere functioning (Raine, 2002).

Although there is good evidence for an intimate relation between the autonomic nervous system and externalising behaviour, gaps in our knowledge remain. First, it is uncertain if this association is evident in very young children. Early-onset externalising behaviour is of particular interest, because if it persists it has a poor prognosis when compared with adolescent-onset externalising behaviour (Moffitt, Caspi, Harrington, & Milne, 2002). A cross-sectional study of preschool children showed that children who displayed more externalising behaviour had lower heart rates (El-Sheikh, Hinnant, & Erath, 2011). However, most studies of resting heart rate have targeted older children or adolescents.

Second, the specificity of the relation between the autonomic nervous system and externalising behaviour remains unclear. Children with externalising behaviour are characterised by very different traits. Many young children with these problems are physically aggressive and oppositional, but some are predominantly emotionally (over)reactive; they experience high rates of anxiety and distress, and are often impulsive. Other aggressive children are fearless and plan their rule-breaking behaviour (Ellis, Weiss, & Lochman, 2009). Together with impaired guilt, these traits are termed callous-unemotional. Children with callous-unemotional traits are capable of premeditated externalising behaviour and aggression and have a heightened risk for developing severe psychopathology as an adult (Viding, Fontaine, & McCrory, 2012). Investigating whether low resting mean rate is a specific marker of certain aspects of externalising behaviour may yield further insight in its aetiology and development.

A relation between low heart rate and emotion regulation has been documented. Previous studies have established an association between low heart rate and the absence of anxiety in children (Gerra et al., 2000; Kagan, Reznick, & Snidman, 1987). Furthermore, fearless and emotionally less reactive children with conduct disorder showed little heart rate reactivity in response to a videotaped event involving fear (Anastassiou-Hadjicharalambous & Warden, 2008). A study of 94 preschoolers found that low resting mean heart rate was not associated with emotional over-reactivity (Gower & Crick, 2011).

Our main aim is to investigate the longitudinal relation between resting mean heart rate measured at age 14 months and different aspects of externalising behaviour at age 3 years. We used parental report by means of the Child Behavior Checklist (Achenbach & Rescorla, 2000) and observed the child's behaviour using a version of the well-known gift delay task. The gift delay task assesses the child's compliance and ability to delay gratification. It is part of a battery aimed at investigating emotional reactivity. (Kochanska, Murray, & Harlan, 2000). In addition, we examined the children's propensity towards lying by asking if they cheated during the gift delay task.

We hypothesise that low resting mean heart rate is indicative of fearless traits. Hence, we expect that low resting mean heart rate predicts low levels of anxiety and high levels of reported externalising behaviour. In addition, we expect low resting mean heart rate to predict higher odds of lying in the gift delay task. The various externalising behaviours are determined to a different extent by constitutional and environmental factors (Viding, Blair, Moffitt, & Plomin, 2005; Viding, Jones, Frick, Moffitt, & Plomin, 2008). Harsh parenting has been identified as a key environmental risk factor of child and adolescent externalising behaviour (Eddy & Chamberlain, 2000; Keiley, Lofthouse, Bates, Dodge, & Pettit, 2003). Several studies indicate that harsh parenting is specifically associated with childhood aggression and a diminished ability to delay gratification (Chang, Schwartz, Dodge, & McBride-Chang, 2003; Olson et al., 2011). The high prevalence and the clear effect on externalising behaviour, makes harsh parenting a suitable comparator for aetiological studies (Brenner & Fox, 1998).

We expect higher levels of harsh parenting to be associated with aggressive behaviour, attention problems as well as an impaired ability to delay gratification during the gift delay task. We will contrast the relation between resting mean heart rate, a biomarker, with the relation of harsh parenting to the various indicators of child externalising behaviour. Of particular interest will be whether mean heart rate, a biomarker, and harsh parenting to will relate differently to various indicators of child externalising behaviour.

## Materials and methods

### *Participants*

This study was conducted within the Focus cohort of the Generation R Study, a population-based cohort study from foetal life onwards. All children were born between February 2003 and August 2005 in the city of Rotterdam. The cohort consists of Dutch children and their parents and is ethnically homogeneous to rule out confounding and effect modification by ethnicity. Midwives and obstetricians informed eligible mothers about the study at their first prenatal visit in routine care, handed out the information package and asked these mothers to make an appointment for the first ultrasound examination. The study staff contacted these mothers by phone for additional information about the study and in person at the ultrasound examination to obtain

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informed consent. The general design, all research aims and the specific measurements in the Generation R Study have been approved by the Medical Ethical Committee of the Erasmus Medical Center, Rotterdam. (Jaddoe et al., 2012).

As described previously, measurements of autonomic indices were added to the protocol of the examination round, while assessments were already ongoing. We obtained physiological measurements for 528 participants as described previously (Dierckx, Tulen, et al., 2009). The current sample consisted of the 412 children for whom physiological measurements at 14 months and Harsh parenting and Child Behavior Checklist scores at 3 years were available.

### *Psychophysiological measurements*

Infant heart rate at 14 months was registered with a three pole ECG lead. We monitored the breathing pattern using a piëzo-electric transducer. Signals were recorded for 8 min using a Vitaport 3 recorder (Temec Instruments Inc, Kerkrade, the Netherlands) while the child was resting in its mothers' lap. To calculate the child's mean heart rate level, we used the mean lengths of the interbeat intervals in the 100–180 s of time when breathing was most regular.

### *Harsh parenting*

Harsh parenting was assessed with a Dutch version of the Parent-Child Conflict Tactics Scales (Straus, Hamby, Finkelhor, Moore, & Runyan, 1998). This instrument was designed to measure psychological and physical maltreatment and neglect of children by parents, as well as nonviolent modes of discipline. The translation was carried out using a standard forward-backward translation method. The scale was completed by the mother when her child was 3 years old. She rated use of discipline types during the past 2 weeks on a 6-point scale ranging from never to five times or more. Several categories were combined because of very low prevalence rates. This resulted in three categories: never (0), once (1) and twice or more (2).

Three items from the Parent-Child Conflict Tactics Scale assessing hitting and spanking were not used. In the Netherlands severe harsh punishment is prohibited. The review board of the Generation R Study decided to exclude items concerning possibly illegal practices. in addition, one item of the Psychological Aggression scale ('said you would kick child out of the house') was excluded to make the assessment age appropriate (Jansen et al., 2012).

### *Maternal report of child behaviour*

We used the Child Behavior Checklist/1½–5 (CBCL), a parent questionnaire for assessing behavioural and emotional problems in children aged 1½–5. The CBCL has good reliability and validity (Achenbach & Rescorla, 2000). When the child was 3 years old, the mother rated the child's emotional and behavioural problems over the preceding 2 months on a 3-point rating scale. For a subset of the children ($n$ = 378) CBCL questionnaires at 18 months of age were available as well. In the current study, we used the Anxious/Depressed scale, and the Externalising subscales Aggressive Behaviour and Attention Problems syndrome scales.

Paternal report of child behaviour was available for a subset of the children (n = 397). We studied the association of harsh parenting and heart rate with paternally reported behaviour as well.

### *Gift delay task*

We used an adapted version of the well-known gift delay task (Kochanska et al., 2000). This task was originally developed as part of a larger battery of tests aimed at assessing the children's control over their behaviour. It specifically measures situational compliance and the ability to delay gratification. The task was conducted by trained experimenters during a laboratory session. It was framed as a game in which the child was asked to wait for a specific sign by the experimenter to retrieve the gift.

The experimenter brought a paper bag containing a wrapped gift and placed the bag on the table. Then the experimenter asked the child to wait and not to touch the bag or look into the bag until she brought the card accompanying the gift. Subsequently, the child was left alone in the room for 180 s. The behaviour of the children was monitored with a hidden camera setup. We scored the gift delay task dichotomously, children who did not touch, inspect or open the gift while the experimenter was out of the room scored 0 (compliant), children who touched, inspected or opened the gift scored 1 (noncompliant).

Immediately after the return of the experimenter, children were asked by their attending parent or, in case the attending parent forgot, by the trained experimenter, whether they had cheated or not. Noncompliant children who admitted noncompliance scored 0, noncompliant children who lied scored 1. Compliant children did not receive a score on lying.

Three hundred and sixty-nine children performed the gift delay task. Due to procedural errors, nine children (6.7%) of the 134 non-compliant children were not asked whether they had cheated and were excluded from the respective analyses.

### *Covariates*

The choice of covariates was based on previous studies (Dierckx, Tulen, et al., 2009). Gender of the child, gestational age and weight at birth, maternal age, and smoking and drinking behaviour during pregnancy were available as covariates. Level of highest completed education by the mother was

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entered as a measure of socioeconomic status. The Dutch Standard Classification of Education was used to define three categories of education: higher education phase 2 (university degree), higher education phase 1 (higher vocational training, Bachelor's degree) and secondary education or lower. Gestational age at birth and birth weight were obtained from community midwife and hospital registries at birth. Information on maternal smoking and drinking habits during pregnancy as well as highest completed education were obtained by means of a questionnaire completed by the mother.

### *Statistical analysis*

For our main analysis, we performed a series of regression analyses to investigate the association of heart rate with the Anxious/Depressed, Aggressive Behaviour and Attention Problems scores, with observed compliance during the gift delay task and with lying after the gift delay task. First, we performed linear regression analyses with heart rate as the independent variable and child Anxious/Depressed, Aggressive Behaviour or Attention Problems scores as dependent variables. The regression residuals of the analyses between heart rate and anxiety were not normally distributed even after we removed outliers (i.e. the regression residuals deviated more than 3 SD from the mean). In addition, the homoscedacity assumption was violated. Hence, we tested the robustness of significant results of these analyses using logistic regressions. To perform the logistic regressions we dichotomised CBCL scores at 1 SD above the mean in line with earlier reports (Dierckx, Tharner, et al., 2009). Scores above 1 SD should be seen as above average. Again, outliers were excluded from the analysis. Second, we determined whether child heart rate predicted noncompliant behaviour during the gift delay task using logistic regression. Third, we investigated whether child heart rate was associated with lying after the gift delay task using logistic regressions. For comparison, the same set of analyses were run with harsh parenting as independent variable. Heart rate and harsh parenting variables were standardised to facilitate the interpretation of the effect estimates. Heart rate and harsh parenting variables were standardised to facilitate the interpretation of the effect estimates. All analyses were adjusted for gender of the child and maternal education as an indicator of socioeconomic status. Adding gestational age and weight at birth, maternal age, and smoking and drinking during pregnancy to the models did not change the effect estimates. Cases whose regression residuals deviated more than 3 standard deviations from the mean were excluded from the analysis. In exploratory analyses, we used ANOVA to compare compliant children with noncompliant children who admitted noncompliance and noncompliant children who lied. Effect sizes for significant effects are given as Cohen's *d*. By convention, values of *d* up to 0.2 are defined as a small effect size, values up to 0.5 are defined as medium, values larger than 0.5 are considered large.

All analyses were performed using the Statistical Package for the Social Sciences 15.0 for Windows (SPSS Inc).

## Results

Table 1 displays the baseline characteristics of the participants. Mean maternal age was 31.9 ± 3.6 years. Of the mothers 33.7 percent completed only secondary education or lower, 28% completed higher education, phase 1, while 38.3% completed higher education, phase 2.

The children had a mean resting heart rate of 124.1 ± 10.6 bpm at age 14 months. All heart rate values recorded were within the normal, physiologic range for 14 month old infants. About 1-2% of CBCL scale scores were in the clinical range as expected in a population based study. Equal numbers of boys and girls participated.

### *Child behaviour as reported by the parents*

Table 2 displays the associations of mean resting heart rate with child CBCL scores at age 3 years, as well as the associations between harsh parenting and child CBCL scores. The higher a child's heart rate, the higher the child's Anxious/Depressed scores (β = .1, 95% CI = 0.01; 0.2, $p$ = .04). Heart rate explained 10% of the variation in the child Anxious/Depressed scores. When we corrected for Anxious/Depressed scores at 18 months, the relation was only slightly attenuated (β = .09, 95% CI = −0.01; 0.2, $p$ = .07). This suggests that part of the relation between heart rate and anxiety was indeed already present at baseline. In a dichotomous analysis, the resting mean heart rate of the children was positively associated with their odds of having high anxiety symptoms at borderline significance (OR = 1.31, 95% CI = 0.99; 1.7, $p$ = .05). We

**Table 1** Characteristics of the study population

| *N* = 412 | |
|---|---|
| Age mother at intake, years (*SD*) | 31.9 ± 3.6 |
| Maternal education | |
| Secondary education or lower (%) | 33.7 |
| Higher education, phase 1 (%) | 28.0 |
| Higher education, phase 2 (%) | 38.3 |
| Child gender, male (%) | 49.8 |
| Heart rate, bpm (*SD*) | 124.11 ± 10.6 |
| Aggressive parenting (*SD*) | 2.06 ± 2.3 |
| Noncompliance during Gift Delay Task (*n*) | 134 |
| Lying about compliance during Gift Delay Task (*n*) | 21 |
| CBCL Anxiety symptoms (*SD*) | 0.65 ± 1.1 |
| CBCL Attention problems (*SD*) | 1.28 ± 1.5 |
| CBCL Aggressive behaviour (*SD*) | 6.11 ± 4.5 |

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**Table 2** Child heart rate and aggressive parenting as predictors of behaviour symptoms reported by the mother

| | Anxiety symptoms | | | Attention problems | | | Aggressive behaviour | | |
|---|---|---|---|---|---|---|---|---|---|
| | B | 95% CI | *p* | B | 95% CI | *p* | B | 95% CI | p |
| Heart rate/*SD* (bpm) | 0.1 | 0.01; 0.2 | .04 | 0.02 | −0.1; 0.1 | .8 | 0.08 | −0.3; 0.5 | .8 |
| Harsh parenting/*SD* | 0.05 | −0.02; 0.2 | .1 | 0.2 | 0.1; 0.3 | <.001 | 0.7 | 0.4; 0.9 | <.001 |

Results displayed from linear regression models. A β of 1.0 indicates the change in CBCL symptom score when the predictor changes by a standard deviation. All analyses were corrected for child gender and maternal level of education.

observed no association between child heart rate and child Attention Problems (β = .02; 95% CI = −0.1; 0.1, $p$ = .8) or child Aggressive Behaviour (β = .08, 95% CI = −0.3; 0.5, $p$ = .8).

In contrast with the pattern of associations of heart rate, there was no association between harsh parenting and child Anxious/Depressed scores (β = .05, 95% CI = −0.02; 0.1, $p$ = .1), however, harsh parenting was positively associated with both child Attention Problems (β = .2, 95% CI = 0.1; 0.3, $p$ < .001) and with child Aggressive Behaviour (β = .7, 95% CI = 0.4; 0.9, $p$ < .001). When we corrected for CBCL scale scores at 18 months the relationships were attenuated, but harsh parenting was still clearly associated with both child Attention Problems (β = .2, 95% CI = 0.1; 0.3, $p$ = .002) and with child Aggressive Behaviour (β = .5, 95% CI = 0.1; 0.9, $p$ = .01). Results from dichotomous analysis were similar and showed a significant association between harsh parenting and child Anxiety/Depression (OR = 0.3, 95% CI = 1.1; 1.75, $p$ = .008) child Attention problems (OR = 1.48, 95% CI = 1.13; 1.95, $p$ = .004) as well as with child Aggressive Behaviour (OR = 1.65, 95% CI = 1.2; 2.12, $p$ < .001).

The results from the analyses with paternally reported child behaviour measures did not differ substantially from the results obtained using maternally reported child behaviour measures.

### *Child behaviour during the gift delay task*

Table 3 shows the relations between mean resting heart rate, harsh parenting and child behaviour during the gift delay task. The child's heart rate was not associated with the odds of noncompliance during the gift delay task (OR = 1.14, 95% CI = 0.9; 1.1, $p$ = .2). Likewise, harsh parenting was not associated with noncompliance (OR = 1.13, 95% CI = 0.9; 1.3, $p$ = .08). The resting mean heart rate of the children was, however, significantly associated with their odds of lying. A lower heart rate predicted higher risk of lying (OR = 0.56, 95% CI = 0.3; 0.9, $p$ = .03);a child with a heart rate at one *SD* below the mean had a 1.78 times higher odds of lying than a child with a heart rate at the mean. Heart rate explained 4% of the odds of lying. There was no relation between harsh parenting and lying of the child (OR = 1.03, 95% CI = 0.8; 1.4, $p$ = .8).

### *The relation between reported behaviour problems and observed compliance and lying*

Table 4 shows the secondary analyses, we compared the following three groups of children: compliant children, children who were noncompliant but did not lie and children who were noncompliant and lied after the gift delay task. We found similar levels of mother-reported Anxious/Depressed scores ($F$ = 0.41, $df$ = 2, $p$ = .6) and Attention Problems ($F$ = 1.66, $df$ = 2, $p$ = .2) across the groups. In contrast, maternal report of child Aggressive Behaviour differed between the groups ($F$ = 4.04, $df$ = 2, $p$ = .02). Noncompliant children who lied had lower Aggressive Behaviour scores (3.8 ± 4.4) than compliant children (5.95 ± 4.5, $p$ = .04, effect size $d$ = 0.48) and children who admitted noncompliance (6.80 ± 4.5, $p$ = .007, effect size $d$ = 0.67).

## Discussion

In this longitudinal population-based study, we found that a lower heart rate in children aged 14 months positively predicted lying during a gift delay task at age 3 years. Lower heart rate was also positively associated with lower levels of Anxious/Depressed scale scores at age 3 years, but did not predict overt externalising behaviour such as Attention Problems and Aggressive Behaviour.

**Table 3** Child heart rate and aggressive parenting as predictors of behaviour during the gift delay task

| | Odds of noncompliance, $n$ = 369 | | | Odds of lying, $n$ = 125 | | |
|---|---|---|---|---|---|---|
| | OR | 95% CI | *P* | OR | 95% CI | *p* |
| Heart Rate/*SD* (bpm) | 1.14 | 0.9; 1.1 | .2 | 0.56 | 0.3; 0.9 | .03 |
| Harsh parenting/*SD* | 1.13 | 0.9; 1.3 | .08 | 1.03 | 0.8; 1.4 | .8 |

Results displayed from logistic regression models. The OR reflects the change in odds of the child cheating or lying per standard deviation change of the predictor. All analyses were corrected for child gender and maternal level of education.

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**Table 4** Maternally reported behaviour and behaviour during the gift delay task

| | Compliant $n = 235$ | | Noncompliant | | | | |
|---|---|---|---|---|---|---|---|
| | | | Did not lie $n = 104$ | | Lied $n = 21$ | | |
| | Mean | *SD* | Mean | *SD* | Mean | *SD* | Overall *p* |
| Anxiety symptoms | 0.67 | 1.1 | 0.61 | 1.1 | 0.45 | 0.60 | 0.6 |
| Attention problems | 1.14 | 1.5 | 1.44 | 1.5 | 1.17 | 1.0 | 0.2 |
| Aggressive behaviour | 5.95 | 4.5 | 6.80 | 4.5 | 3.8 | 4.4 | 0.02 |

Results displayed from ANCOVA models.

A few studies have previously reported an association between heart rate and anxiety. For example, Monk et al. showed that adolescents with anxiety disorders had higher and less fluctuating heart rate during a resting condition (Monk et al., 2001). Similarly, a higher resting mean heart rate has been observed in behaviourally inhibited children (Kagan et al., 1987).

Most psychophysiological research in children or adolescents focussed on externalising behaviour. Numerous studies showed an association between low mean resting heart rate and externalising behaviour (Ortiz & Raine, 2004). However, the specificity of the relation between the autonomic nervous system and externalising behaviour remains unclear. In this study we explored several externalising behaviours: aggression, compliance and lying. However, contrary with our hypothesis, heart rate did not predict overt externalising behaviour such as Attention Problems and Aggressive Behaviour.

In the Mauritius study, Raine et al. measured children's heart rate at age 3 and assessed their externalising behaviour at age 11. They suggested that low HR may predispose not so much to externalising behaviour in general, but to aggression in particular (Raine et al., 1997). We could not demonstrate an association between heart rate at a very young age and aggressive behaviour at age 3 years.

However, the children in our study were considerably younger than those in earlier studies. In young children aggressive behaviour is common, but usually time limited. At this age, aggression is most often reactive, triggered on impulse and by strong emotions (Dunn & Munn, 1986). Consequently, the relationship between heart rate and aggressive behaviour in our study may have been diluted by the large number of children displaying age appropriate aggressive behaviour. In addition, proactive, planned aggression, which is commonly accompanied by low levels of emotional reactivity, develops later in life than reactive aggression (Dodge, Lochman, Harnish, Bates &Pettit, 1997).

We found no association between heart rate and compliance during the gift delay task. It is tempting to view compliance during the gift delay task solely as a marker of emotional reactivity (Blair & Razza, 2007). However, while the gift delay task was designed to measure situational compliance and the ability to delay gratification, one could argue that the outcome of the task is influenced by such factors as novelty seeking and moral development as well. Unless all these traits are uniformly associated with heart rate, this may have obscured specific associations between heart rate and any of the traits.

In our study, low mean resting heart rate was positively associated with the odds of lying during the gift delay task. This finding should be interpreted with care, as only a small number of children lied ($n = 21$), which may limit the generalisability of the findings. In addition lying is not unequivocally an indicator of externalising behaviour. First, research has shown that the ability to lie depends on the child's cognitive development. Talwar and colleagues used a similar testing paradigm to the gift delay task to probe the association between lying and cognitive development in 150 three to eight-year-old children. They found that the child's odds of lying were positively associated with the child's theory of mind and executive functioning. They suggest that the child needs some understanding of theory of mind and realise that it is possible to hide noncompliance and escape any negative consequences by denial. In addition, some executive functions, such as working memory and the ability to suppress telling the truth, may need to be developed enough to able to lie (Talwar & Lee, 2008). Second, lying could be construed as a form of avoidant behaviour. Anxious children may be more likely to lie, because they are keen to avoid the researcher's disapproval. Yet, this cannot easily explain our observations, as the children who lied had similar Anxious/Depressed scores as those who did not lie. Finally, lying can be part of planned, covert, low emotionally reactive externalising behaviour, and is one of the first symptoms of this behaviour to manifest itself in children.

The pattern of low anxiety and a propensity towards lying is in accordance with the fearlessness theory which integrates physiological and psychological perspectives in child development. The fearlessness theory asserts that low resting mean heart rate is indicative of low levels of fear. Children who experience low levels of fear are less likely to head potential negative consequences of their actions (Raine, 1993; Raine et al., 1997).

We suggest that low anxiety and a tendency to lie are indicative of low levels of emotional reactivity. Low heart rate may thus delineate a small group of

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children that are composed and calculating, rather than overly emotionally reactive and overtly aggressive. Indeed, the children who lied during the observational task were less likely to display reactive aggression according to maternal report. It is tempting to speculate that low heart rate at age 14 months may predict future callousness-unemotional traits, which are characterised by a lack of guilt and by shallow affect (Viding et al., 2012). Previous research already demonstrated an association between lower HR reactivity and callous unemotional traits in older, school-age, children (Anastassiou-Hadjicharalambous & Warden, 2008). While several longitudinal studies suggest that callous – unemotional traits can initially occur in the absence of overt externalising behaviour, however, such overt externalising behaviour often develops later on (Frick et al., 2003; Rowe et al., 2010). Hence, longer follow-up is needed to ascertain if the children in the current study develop overt externalising behaviour and in particular proactive aggression at an older age.

Harsh parenting was associated with different aspects of externalising behaviour than was heart rate. Harsh parenting was strongly associated with child attention problems and aggressive behaviour. While our results are consistent with previous findings (Chang et al., 2003; Olson et al., 2011), it is important to note that both parenting style and child aggressive behaviour and attention problems were measured with parental report. Lau et al. compared parental report to an independent observation of child behaviour, and concluded that parents with a history of harsh parenting tended to over-report externalising behaviour in their children (Lau, Valeri, McCarty, & Weisz, 2006). This effect is likely to have contributed to the strong association between harsh parenting and child externalising behaviour in the present study. In our study, distinct risk factors were thus associated with different categories of externalising behaviour. If not accounted for by chance, this may point to different pathogenetic pathways in the development of externalising behaviour. Several authors have investigated interaction effects of environmental and biomarkers (Oldehinkel, Verhulst, & Ormel, 2008; Raine, 2002). Some have suggested that environmental factors, such as aggressive parenting, may not affect all children equally. Instead, children with certain innate characteristics such as fearlessness may be more susceptible to environmental influences. Unfortunately, the number of participants in the current study is too low to allow for meaningful statistical analysis of interaction effects. More longitudinal research is needed to further elucidate the complex interplay between biological and environmental risk factors in the developmental trajectory of psychopathology.

The strengths of the present study include the large population based sample, the combination of maternal report and observational measures, the longitudinal design and a focus on an age when aggressive psychopathology is still in development.

Some methodological limitations need to be discussed. Not all participants of the Generation R Focus Cohort could be included, because we added physiological measurements to our assessment protocol while the study was already ongoing. The Focus Cohort is ethnically homogeneous, which has the advantage that it excludes potential confounding or effect modification by ethnicity, but which limits the generalisability of the results. We used a self-report questionnaire to assess smoking and drinking during pregnancy. The limited reliability of such a self-report questionnaire may explain why smoking and drinking behaviour during pregnancy did not influence the effect estimates of our statistical models. Finally, the possibility of false positive results due to the number of statistical analyses performed should be carefully considered.

## Conclusion

Low resting mean heart rate level at 14 months was associated with low levels of anxiety and a propensity towards lying at age 3 years. We suggest that even at this young age, low heart rate is an indicator of fearlessness. We recommend longitudinal research to further elucidate the complex interplay between biomarkers and environmental risk factors in the developmental trajectories of externalising behaviour. Future studies may benefit from additional observational measures to assess aggressive behaviour.

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## Key Points

- Low heart rate level at 14 months predict low levels of anxiety at age 3 years.
- Children with a low heart rate at 14 months are more likely to lie during the gift delay task at age 3 years.
- Heart rate and aggression are not related in young children.
- Low heart rate may be an indicator of fearlessness in young children.

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