Biological sensitivity to context: Cortisol awakening response moderates the effects of neighbourhood density on the development of adolescent externalizing problem behaviours

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ARTICLE INFO

ABSTRACT

This four-year longitudinal study attempted to test person-environment interaction theory and biological sensitivity theory by assessing whether individuals' biological stress activity CAR_{AUCg} (Cortisol Awakening Response Area Under the Curve with respect to ground) moderates the effects of neighbourhood density on the development of adolescent externalizing problem behaviours. Participants were 358 Dutch adolescents with a mean age of 15 years at the first measurement. Our analyses showed that CAR_{AUCg} moderated the effects of neighbourhood density on the level of parent-reported delinquency and aggression and adolescent self-reported delinquency. More specifically, for adolescents with high CAR_{AUCg}, higher neighbourhood density significantly predicted higher levels of parent-reported and adolescent self-reported delinquency and aggression, whereas the association was reversed or non-significant for adolescents with low CAR_{AUCg}. Our findings suggest that adolescents with different levels of CAR_{AUCg} respond differentially to the density of the neighbourhood they live in, supporting for person-environment interaction perspectives and biological sensitivity theory.

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1. Introduction

High neighbourhood density has been commonly considered an environmental stressor. It could create various stresses such as limited environmental resources, restricted freedom of choice, and the experience of a crowded and noisy environment, which could potentially stimulate individuals' externalizing problem behaviours (Regoeczi, 2008). The extent to which high neighbourhood density contributes to adolescents' externalizing problem behaviours might be determined by within-individual variables that affect the way neighbourhood density is processed. The effects of neighbourhood density on the development of externalizing problem behaviours might be dependent on adolescents' stress sensitivity as indicated by well-known biological markers like the cortisol activity (Hellhammer, Wüst, & Kudielka, 2009). Cortisol is

one of the stress hormones secreted by a major human physiological stress sensitivity system, the hypothalamic-pituitary-adrenal (HPA) axis. Cortisol activity is an important biological indicator of self-regulation and it plays a crucial role in the regulation of individuals' emotional and behavioural response to environmental stressors (Fries, Dettenborn, & Kirschbaum, 2009). Thus, cortisol activity might moderate the effects of neighbourhood density on adolescents' externalizing problem behaviours.

Several theories support the assumption that effects of neighbourhood density depend on individual characteristics. An interactionist perspective posits that individuals' developmental outcomes depend on the interplay between individual characteristics and environmental factors (Magnusson & Stattin, 2006). More specifically, hormones-context interaction theory asserts that individuals' hormone secretion can interact with environmental factors to predict antisocial behaviours (Susman, 1997). Furthermore, according to the notion of biological sensitivity-to-context (Ellis, Essex, & Boyce, 2005), certain biological markers that make individuals more vulnerable to environmental adversity also make them more likely to benefit from positive environmental influ-

ences. Taken together, individuals with different stress response sets as indicated by their cortisol activity would be expected to differentially respond to high density neighbourhoods in terms of elevated levels of externalizing problem behaviours. Individuals high in cortisol activity may, due to their higher sensitivity to the environment, be more likely influenced by both positive and negative aspects of the neighbourhood in which they live. The current study aimed to examine whether biological characteristics (i.e., morning cortisol activity) moderated the effects of environmental context (i.e., neighbourhood density) on the development of adolescents' externalizing problem behaviours.

1.1. Neighbourhood density and externalizing problem behaviours

Environmental stressors such as a high density neighbourhood might have a negative impact on youth externalizing problem behaviours (Lepore, Evans, & Palsane, 1991). Increases in neighbourhood density may be accompanied by the presence of an increasing number of people, which could cause a crowding experience, and by a decrease in open space, which may pose constraints such as limited access to public resources. These potential negative environmental stressors might restrict and interfere with the attainment of one's goals, which may thus generate frustration that could stimulate aggressive and delinquent behaviours (Regoeczi, 2003). In addition, high-density environments might create a more impersonal atmosphere and provide a greater number of targets for externalizing behaviours (Cohen & Felson, 1979; Stark, 1987). The accompanying anonymity of high population density might also form a structural limit to what can be achieved through social control (Sampson & Raudenbush, 1999).

Empirical studies investigating the associations between neighbourhood density and adolescents' externalizing problem behaviours have yielded mixed results. First, studies which measured the physical density of a neighbourhood (e.g., number of residential addresses per square kilometre) reported inconsistent findings. Weenink (2011) revealed that compared to adolescents living in Dutch urban areas (>1000 addresses per square kilometre), adolescents living in rural areas are slightly less likely to engage in delinquent behaviours including property offenses and violence. However, another Dutch study reported that urbanization (i.e., high residential addresses density) had no effects on youth parent- and self- reported externalizing problem behaviours (Reijneveld et al., 2010). Other studies which used social density (i.e., population density: number of inhabitants in a certain area) to assess neighbourhood density also revealed contradictory results. Some studies found population density to be linked to adolescent delinquent and criminal behaviours (Schmitt, 1957, 1966), whereas other studies suggest that population density has little effect on delinquency or crime (Gillis & Hagan, 1981; Gillis, 1974). Furthermore, Harden et al. (2009) reported inconsistent results regarding the neighbourhood density-externalizing problem behaviours association across informants. In particular, they found that population density was positively associated with youth self-reported but not mother-reported delinquent behaviours. Hence, existing empirical studies did not always find a significant association between neighbourhood density and adolescent externalizing problem behaviours.

1.2. Cortisol awakening response and externalizing problem behaviours

The Cortisol Awakening Response (CAR) is considered an index of the everyday human adrenal cortisol secretory activity and is defined as the change in cortisol concentration that occurs during the first hour after awaking from sleep (Clow, Thorn, Evans, & Hucklebridge, 2004). It is typically featured by a brisk increase of cortisol levels within 20-30 min after awakening in the morning and a decline thereafter (Clow et al., 2004). The overall volume of cortisol released over the waking period (Area Under the Curve with respect to ground [AUCg]; further referred to as cortisol activity), which was the main indicator of CAR in the current study, presents a useful and reliable index of adrenocortical activity (Pruessner et al., 1997; Schmidt-Reinwald et al., 1999).

Different theories have hypothesized different directions of the link between cortisol activity and externalizing problem behaviours. Two major theories have postulated an association between externalizing problem behaviours and physiological hypo-arousal. The fearlessness theory suggests that a low tendency to become aroused in reaction to fearful stimuli would result in a higher likelihood to become disruptive and antisocial (Raine, 1993). In addition, the sensation-seeking theory (Raine, 1993; Zuckerman & Neeb, 1979) hypothesizes that low arousal is an unpleasant physiological state and in order to get rid of this state, individuals with low arousal levels would seek stimulation by initiating antisocial behaviours that increase physical tension. Following this line of reasoning, lower cortisol levels should be related to higher levels of externalizing problem behaviours (Brennan & Raine, 1997). On the other hand, however, researchers recently have hypothesized that hyper-arousal is a risk factor in stressful contexts. Hyper-arousal may be evident as heightened physiological responses to stress or threats, such as irritability, hypervigilance, frustration, and an exaggerated startle response, which could in turn trigger externalizing problem behaviours such as aggressive and delinquent behaviours (Kerig, Vanderzee, Becker, & Ward, 2012). Hence, following this latter line of reasoning, higher cortisol levels indicating hyper-arousal should be associated with higher levels of externalizing problem behaviours.

Evidence regarding the associations between morning cortisol level and adolescent externalizing problem behaviours is mixed. Several studies examined cross-sectional associations between activity of the HPA-axis and disruptive behaviours in adolescents. Some researchers found an association between low morning basal cortisol levels and adolescent disruptive behaviours (Pajer, Gardner, Rubin, Perel, & Neal, 2001), whereas others did not found such association (Ruttle et al., 2011; Scerbo & Kolko, 1994). Longitudinal studies looking at whether low morning cortisol activity is a risk factor for future externalizing problem behaviour also revealed inconsistent results (Shirtcliff, Granger, Booth, & Johnson, 2005; Shoal, Giancola, & Kirillova, 2003; Van Bokhoven et al., 2005). Specifically, low morning cortisol levels predicted adolescent aggressive behaviours 5 years later (Shoal et al., 2003), risky behaviours one year later (Shirtcliff et al., 2005), and persistent aggressive behaviour over three years (Platje et al., 2013). On the contrary, Van Bokhoven et al. (2005) found that higher morning cortisol levels at age 13 predicted higher conduct disorder in boys at age 14–16. Furthermore, studies also reported a lack of associations between morning basal cortisol level and externalizing problem behaviours in adolescents (Dabbs, Jurkovic, & Frady, 1991; Klimes-Dougan, Hastings, Granger, Usher, & Zahn-Waxler, 2001; Sondeijker et al., 2008). Therefore, evidence for the association between morning cortisol activity and externalizing problem behaviours in adolescence is largely inconsistent, as negative, positive, as well as non-significant relations have been reported.

1.3. Moderation of neighbourhood density effects on externalizing problem behaviours by CAR_{AUCg}

According to person-environment interaction perspectives, externalizing problem behaviours are likely the result of both environmental influences and individuals' biological characteristics (Magnusson & Stattin, 2006; Susman, 1997). More specifically,

individuals with high biological sensitivity might especially benefit from a positive environment but might be vulnerable to the negative influence of an adverse environment (Ellis & Boyce, 2011). The presence of interaction effects between neighbourhood density and stress sensitivity as indicated by morning cortisol activity might provide some explanations for the inconsistent findings on the association between neighbourhood density and externalizing problems. Responses to a high-density neighbourhood environment may differ for adolescents who vary in their morning cortisol levels (Hellhammer et al., 2009). For instance, although some adolescents may view a high density neighbourhood an opportunity for social interactions and networks, other adolescents, who have difficulty in social and emotional regulation, may see it as crowded and noisy or feel threatened in their accessibility to neighbourhood recourses.

A pattern of hypo-arousal has been termed a low biological sensitivity to context (Ellis et al., 2005). A low biological sensitivity to context is defined as individuals' low ability to process environmental influences. Low biological sensitivity individuals might display a lack of biological sensitivity to environmental challenges, they might be buffered against stressors (Ellis et al., 2005). On the other hand, however, individuals with hyper-arousal have a higher biological sensitivity to context, which means greater responsiveness to both positive and negative environmental influences. Therefore, adolescents with high CAR_{AUCg} might be more likely to show increases in externalizing problem behaviours in response to a high-density neighbourhood and also be more likely to show decreases in externalizing problem behaviours in response to low-density neighbourhood. In contrast, adolescents with low CAR_{AUCg} may be not affected by their environment and their levels of externalizing behaviours might not vary with the density of their neighbourhood. Empirical research on the interplay between basal cortisol level and neighbourhood adversity has been limited. This study attempted to fill the knowledge gap by testing the moderating role of CAR_{AUCg} on the effects of neighbourhood density on the development of adolescents' externalizing problem behaviours.

1.4. The current study

The aims of the current study were to examine person-environment interaction effects in predicting adolescents' development of externalizing problem behaviours. We first replicated previous research by estimating the main effects of neighbourhood density and CAR_{AUCg} on adolescents' development of adolescent externalizing problem behaviours including aggression and delinquency across a period of four years from middle to late adolescence. As results from previous studies were inconsistent, no concrete hypotheses could be formulated. Subsequently, we investigated interaction effects between CAR_{AUCg} and neighbourhood density on the development of adolescent aggression and delinquency. We expected that adolescents with high CAR_{AUCg}, compared to those with low CAR_{AUCg}, would score higher in externalizing problem behaviours in a high-density neighbourhood but score lower in externalizing problem behaviour in a low-density neighbourhood.

2. Method

2.1. Sample

Participants were 358 adolescents (205 [57.3%] boys) who participated in a longitudinal study on adolescent development and who took part in cortisol awaking measurements at Wave 3, with a mean age of 15.03 years ($SD = 0.45$). They were part of the RADAR study (N = 497, Research on Adolescent Development And Relation-

ships; Meeus et al., 2010). RADAR is an ongoing longitudinal study focusing on various adolescent developmental outcomes including externalizing problem behaviours. The current study was based on data from the third to the sixth wave of RADAR. All participants in the current study identified themselves as Dutch. In this sample, 10.5% of adolescents were from low SES family in which father and mother were unemployed or held an elementary job (e.g., construction worker, janitor, truck driver; Statistics-Netherlands, 1993). Family SES was medium or high for the other 89.5% of the adolescents, implying that at least one of the parents' jobs was classified as medium level (e.g., police officer, physician's assistant) or high level (e.g., doctor, scientist, high school teacher). Between the total RADAR sample of 497 adolescents and the 358 adolescents who participated in the cortisol measurement at Wave 3, the only significant difference was in self-reported aggression (F [1,373] = 5.24, $p = 0.02$), with adolescents who participated in the cortisol measurement reporting a higher level of aggression. There were no significant differences between these two groups in parent-reported delinquency (F [N = 1, 384] = 0.25, $p = 0.66$) and aggression (F [N = 1, 384] = 0.19, $p = 0.66$), self-reported delinquency (F [N = 1, 387] = 2.52, $p = 0.11$), gender distribution ($\chi2$ [N = 497, 1] = 0.05, $p = 0.82$), age (F [3,494] = 0.05, $p = 0.77$), and neighbourhood density (F [N = 469, 1] = 1.92, $p = 0.17$).

The number of participants across Wave 3 to Wave 6 fluctuated per year, with 358 participants at Wave 3, 347 at Wave 4, 338 at Wave 5, and 323 at Wave 6. Attrition was 9.8% over the period of three years. To estimate the pattern of missing data, Little's Missing At Random (MCAR) test was conducted (Little, 1988) on all variables used in this study. Little's MCAR test revealed a normed $\chi2$ ($\chi2/df$) of 1.31 which, according to guideline by Bollen (1989), indicates that the pattern of the missing data was not meaningfully different from a missing completely at random pattern. Therefore, we applied Full Information Maximum Likelihood (FIML) in M$plus$ for the model estimations (Schafer & Graham, 2002).

2.2. Procedure

Participants were recruited from various Dutch elementary schools. An invitation letter and a description of the study were sent to adolescents' home addresses. Both parents and adolescents provided informed consent to participate. Adolescents and parents filled out various questionnaires during the annual home visits, supervised by trained research assistants. In addition to administration of the behavioural measurements, trained research assistants gave detailed verbal and written instruction for cortisol measurements during the home visit. Confidentiality was assured explicitly before participation in the study. Participants received €15 as a reward for their participation in each wave. The RADAR study has been approved by the responsible medical ethics committee, and was conducted in accordance with the Declaration of Helsinki.

2.3. Measure

2.3.1. Adolescent externalizing problem behaviours

Externalizing problem behaviours were measured through parents' report of their child's behaviours and through adolescents' self-report. Parents filled out the Dutch version of the Achenbach Child Behaviour Checklist (CBCL; Achenbach, 1991), reporting their child's delinquent and aggressive behaviours. Delinquency was measured using the Delinquent Behaviour scale (13 items; e.g., "Sets fires") and aggression was measured using the Aggressive Behaviour scale (20 items; e.g., "Fights a lot"). Parents responded to the questions on a 3-point scale (i.e., 0 = $never$; 1 = $sometimes$; 2 = $often$). The validity and reliability of this measure has been shown to be adequate (Achenbach, 1991). In the current sample, across the four annual waves, Cronbach's alphas ranged from 0.73

to 0.80 for the Delinquent Behaviour scale, and from 0.89 to 0.90 for the Aggressive Behaviour scale.

Adolescents also filled out the Youth Self Report (YSR; Verhulst, Van der Ende, & Koot, 1997), which is the self-report version of the CBCL. Specifically, 11 items were employed to assess delinquency (e.g., "I set fires") and 19 items were used to indicate aggressive behaviours (e.g., "I fight a lot"). Adolescents rated their frequency of delinquency and aggression on a three-point Likert scale (i.e., 0 = *never*; 1 = *sometimes*; 2 = *often*). Across four waves, Cronbach's alphas ranged from 0.70 to 0.75 for delinquency, and from 0.86 to 0.88 for aggression.

2.3.2. Neighbourhood density

Neighbourhood density was assessed by the average number of addresses per square kilometre. We linked six-digit postcode data in our sample to Statistics Netherlands (2011) which provides data on the address density of the surrounding area for each post-code in 2010 (i.e., around the fifth wave of data collection). As neighbourhoods with a high density might be poorer than those with low density, we controlled for the effect of neighbourhood wealth on neighbourhood density in the current study. We obtained the average property value of dwellings in neighbourhoods measured in 2004 from Statistics Netherlands (2006). The average property value captured the quality of dwellings and the social and physical attributes of the neighbourhood and therefore was considered a good proxy for neighbourhood wealth (Visser, Van Dam, & Hooimeijer, 2008).

2.3.3. CAR$_{AUCg}$

CAR$_{AUCg}$ was measured in saliva which was collected by passive drooling, immediately after awakening (Cort0), 30 minutes (Cort30), and 60 minutes (Cort60) later. The saliva sampling was scheduled on a typical weekday, following detailed verbal and written instruction. Participants were instructed to rinse their mouths with water before sampling, and not to eat, drink, smoke or brush their teeth before completing Cort60. They were requested to collect their saliva through a small straw into a polypropylene tube, and label these tubes with the time and date of sampling. After collection, participants were asked to store the samples in the refrigerator and send them by mail to the research center the same day.

At the research center, the cortisol collections were stored uncentrifuged at -20 °C until analysis. Salivary cortisol levels were analyzed using electrochemiluminescence immunoassay ECLIA (E170 Roche, Switzerland). The lower detection limit was 0.5 nmol/l, and mean intra-assay and inter-assay coefficients of variation were, respectively, 3% and 12%. All samples were checked for correctness of sampling. Cases were excluded from analyses if the cortisol data were of incorrect sampling time, unclear how it was sampled (i.e., not registered), contaminated (e.g., by smoking or brushing teeth), or of extreme values (i.e., > 3 *SD* from average). In the current study, 358 participants provided qualified data. CAR$_{AUCg}$ is considered a summary parameter of the repeated measurements of CAR (i.e., 0, 30, and 60 minutes after awakening). Thus, it is an estimation of total adrenal cortisol secretion during the first hour after awakening. We calculated the CAR$_{AUCg}$ with the formula provided by Pruessner, Kirschbaum, Meinlschmid and Hellhammer (2003).

2.3.4. Control variables

As gender, physical development, substance use, and stressful life experiences might affect CAR$_{AUCg}$ (Clow et al., 2004; Platje et al., 2013), we tested whether these variables had a significant effect on CAR$_{AUCg}$ and controlled for the significant predictors in our final statistical models. These variables were assessed when adolescents were 15 years old, the same age when their CAR$_{AUCg}$ was measured.

Physical development was indicated with adolescents' body mass index (BMI) which was calculated as weight in kg/(length in m)^2. Substance use was indicated as nicotine and alcohol use. Nicotine use was assessed by a nine-option question ranging from "*I have never smoked*" to "*I smoke everyday*". The data were dichotomized: responses from "*I have never smoked*" to "*I smoke less than once a month*" were defined as "*not use nicotine*" and those from "*I do not smoke weekly, but at least once a month*" to "*I smoke every day*" were defined as "*using nicotine*". Alcohol use over the last four weeks was assessed with a question with six response options, ranging from "*none*" to "*daily*". These data were dichotomized too: "*none*" was defined as "*not using alcohol*" and responses from "*1-3 days in the last four weeks*" to "*everyday*" were defined as "*using alcohol*". Stressful experiences including sexual assault, physical assault, and being threatened with violence, were measured with the International Crime Victims Survey (ICVS; Nieuwbeerta, 2002). Our regression model with CAR$_{AUCg}$ as a dependent variable and with gender, smoking, alcohol use, BMI, sexual abuse, physical assault, and being threatened with violence as predictors indicated a significant effect of gender (β = 0.14, p = 0.02). All the other variables in the model did not have a significant effect on CAR$_{AUCg}$ (βs ranged from -0.01 to 0.11, and ps > 0.05). Therefore, we controlled for gender effects on CAR$_{AUCg}$ in our following statistical models.

2.4. Statistical analysis

Multiple regression models incorporating latent growth models were conducted to test the interaction effects between CAR$_{AUCg}$ and neighbourhood density on the development of externalizing problem behaviours. Before testing multiple regression models, we first determined the shape of growth in adolescent externalizing problem behaviours (i.e., delinquency and aggression) from age 15 to 18. To that end, we compared the chi-square values of models including a linear and quadratic growth to capture changes in delinquency and aggression (Satorra & Bentler, 2001).

The models for parent-reported delinquency and aggression indicated that adding quadratic slopes significantly improved model fit (i.e., a significantly lower chi-square value; $\Delta\chi^2$ [N = 358, 4] = 56.38, *p* = 0.00 and $\Delta\chi^2$ [N = 358, 4] = 21.11, *p* = 0.01, respectively). For self-reported delinquency and aggression, adding quadratic slopes did not significantly improve model fit ($\Delta\chi^2$ [N = 358, 4] = 9.49, *p* = 0.26 and $\Delta\chi^2$ [N = 358, 4] = 9.54, *p* = 0.13, respectively). However, to facilitate the comparability between models across parent- and self- reported externalizing problem behaviours, we chose models with both linear and quadratic slopes. To avoid convergence problems, the variances of quadratic slopes were fixed at zero.

After determining the shape of the growth of externalizing problem behaviours, we added predictors to the growth model. We first assessed the main effects of neighbourhood density and CAR$_{AUCg}$ on the development (i.e., intercept and linear slope) of adolescent delinquency and aggression. Next, we tested the interaction effects by including the CAR$_{AUCg}$ by neighbourhood density interactive term. In all models, we controlled for effects of Social Economic Status (SES) and gender. Furthermore, as neighbourhoods with a high density might be poorer than those with low density, neighbourhood density was controlled for the effects of mean levels of property values (βs = -0.26, ps < 0.00 across models). As CAR$_{AUCg}$ differ between girls and boys, CAR$_{AUCg}$ was controlled for gender effects (βs ranged from 0.26 to 0.27, ps ranged from 0.01 to 0.02 across models). Moreover, when the interaction effects between CAR$_{AUCg}$ and neighbourhood density were significant, we assessed SES differences in the interaction effects by conducting three-way interaction analyses. In addition, we tested whether the moderating effects of CAR$_{AUCg}$ can be explained by the potential overlap between neighbourhood density and SES, by assessing interac-

Table 1
Means and Standard Deviations of the Observed Values of CAR_{AUCg}, Neighbourhood Density, Parent- and Self- Reported Externalizing Problem Behaviours from 15 to 18 Years.

Measure	M (SD)			
	15 years	16 years	17 years	18 years
1. CAR_{AUCg}	1030 (365)	–	–	–
2. Neighbourhood Density	2030 (1911)	–	–	–
3. Delinquency (CBCL)	1.85 (2.15)	2.12 (2.57)	2.22 (2.57)	2.09 (2.26)
4. Aggression (CBCL)	7.00 (5.42)	6.55 (5.42)	5.79 (5.45)	5.05 (5.04)
5. Delinquency (YSR)	3.45 (2.95)	3.77 (2.97)	3.83 (2.87)	3.75 (2.87)
6. Aggression (YSR)	7.11 (5,75)	6.87 (5.68)	6.43 (5.45)	5.70 (5.09)

Note: M (SD) = Mean (Standard Deviation). CAR_{AUCg} = Cortisol Awakening Response Area Under the Curve with respect to ground. CBCL = Child Behaviour Checklist. YSR = Youth Self Report.

tion effects between SES and CAR_{AUCg} in predicting adolescent externalizing problem behaviours. Finally, we also examined if the moderating effects of CAR were specific to AUCg (i.e., the overall cortisol secretion post-awakening), or also occurred for the absolute change in cortisol levels post-awakening: AUCi (Area under the curve with respect to increase; see Pruessner et al., 2003 for detailed computational procedure). To this end, we assessed the interaction effects between CAR_{AUCi} and neighbourhood density on adolescents' externalizing problem behaviours. All analyses were conducted within M*plus* 7.0 (Muthén & Muthén, 1998–2012). In addition, since the dependent variables delinquency and aggression were not normally distributed, we adopted a robust maximum likelihood estimator (MLR; Satorra & Bentler, 2001), to take the non-normal distribution of the data into account.

When the interaction effects were significant, we examined the shape of the interaction by probing the interaction effects. To examine this, simple slopes for each interaction were presented (at 1 *SD* above and below mean of the moderators). Moreover, we applied the Johnson-Neyman technique, using the computational tool of Preacher, Curran, and Bauer, (2006), to identify for which regions in the range of the moderator variable effects of the focal predictor on the outcome were significant ($p < 0.05$) (Bauer & Curran, 2005; Hayes & Matthes, 2009).

3. Results

Table 1 presents descriptive statistics, including the means and standard deviations of neighbourhood density and CAR_{AUCg} when adolescents were on average 15 years of age and parent- and self-reported delinquent and aggressive behaviours across four annual waves (i.e., from age 15 to 18 years). Table 2 presents bivariate correlations among CAR_{AUCg} and neighbourhood density measured at age 15 years, and parent- and self- reported externalizing problem behaviours assessed from age 15 to 18 years. Tables 3 and 4 present the results of our final structural equation models examining the main effects of and the interaction effects between CAR_{AUCg} and neighbourhood density on the development of externalizing problem behaviours across middle to late adolescence.

3.1. Main effects of neighbourhood density and CAR_{AUCg} on the development of parent-reported adolescent externalizing problem behaviours

We examined the main effects of neighbourhood density and CAR_{AUCg} on the development of parent-reported externalizing problem behaviours, controlling for effects of SES and gender. In the two models predicting development of parent-reported delinquency and aggression, the only significant effect was the effect of SES (i.e., low vs. high) on the intercept of aggression ($N = 358$, $B = 2.47$, $\beta = 0.15$, $p = 0.04$). Lower SES was linked to higher

Table 2
Bivariate Intercorrelations among CAR_{AUCg}, Neighbourhood Density, Parent- and Self- Reported Externalizing Problem Behaviours from 15 to 18 Years.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	CAR_{AUCg} T3																		
2	NB Density T3	0.05																	
3	Delinquency$_{CBCL}$ T3	0.05	0.02																
4	Delinquency$_{CBCL}$ T4	0.04	0.03	0.74**															
5	Delinquency$_{CBCL}$ T5	0.03	0.02	0.67**	0.77**														
6	Delinquency$_{CBCL}$ T6	-0.04	0.05	0.60**	0.66**	0.79**													
7	Aggression$_{CBCL}$ T3	0.00	-0.03	0.70**	0.60**	0.58**	0.55**												
8	Aggression$_{CBCL}$ T4	0.02	-0.00	0.59**	0.72**	0.69**	0.60**	0.81**											
9	Aggression$_{CBCL}$ T5	0.06	-0.02	0.52**	0.54**	0.73**	0.61**	0.75**	0.85**										
10	Aggression$_{CBCL}$ T6	0.04	0.02	0.43**	0.42**	0.57**	0.66**	0.68**	0.76**	0.83**									
11	Delinquency$_{YSR}$ T3	0.11	0.05	0.43**	0.43**	0.41**	0.40**	0.35**	0.33**	0.31**	0.26**								
12	Delinquency$_{YSR}$ T4	-0.01	0.08	0.31**	0.37**	0.37**	0.40**	0.29**	0.31**	0.28**	0.25**	0.70**							
13	Delinquency$_{YSR}$ T5	0.08	0.07	0.29**	0.33**	0.44**	0.42**	0.25**	0.29**	0.32**	0.26**	0.59**	0.66**						
14	Delinquency$_{YSR}$ T6	-0.05	0.12*	0.17**	0.22**	0.27**	0.32**	0.17**	0.16**	0.18**	0.14**	0.46**	0.58**	0.68**					
15	Aggression$_{YSR}$ T3	0.12*	-0.02	0.28**	0.25**	0.29**	0.25**	0.38**	0.34**	0.35**	0.29**	0.68**	0.54**	0.50**	0.40**				
16	Aggression$_{YSR}$ T4	0.08	-0.01	0.27**	0.28**	0.31**	0.26**	0.39**	0.42**	0.40**	0.31**	0.60**	0.68**	0.59**	0.49**	0.76**			
17	Aggression$_{YSR}$ T5	0.14*	-0.03	0.24**	0.24**	0.34**	0.24**	0.33**	0.35**	0.38**	0.29**	0.47**	0.51**	0.68**	0.52**	0.68**	0.73**		
18	Aggression$_{YSR}$ T6	0.00	0.03	0.12*	0.10	0.17**	0.13*	0.21**	0.22**	0.29**	0.25**	0.41**	0.45**	0.52**	0.64**	0.60**	0.65**	0.73**	

*Note. CAR_{AUCg} = Cortisol Awakening Response Area Under the Curve with respect to ground. NB = Neighbourhood. CBCL = Child Behaviour Checklist. YSR = Youth Self Report. *$p < 0.05$; ** $p < 0.01$.*

aggression. Neighbourhood density did not predict the development (i.e., intercept and slope) of parent-reported delinquency (N = 358, B = 0.04, β = 0.02, p = 0.64 and N = 358, B = 0.02, β = 0.03, p = 0.67, respectively) and aggression (N = 358, B = -0.17, β = -0.03, p = 0.49 and N = 358, B = 0.06, β = 0.06, p = 0.46, respectively). Moreover, CAR_{AUCg} did not have main effects on the intercept and slope of parent-reported delinquency (N = 358, B = 0.17, β = 0.08, p = 0.19 and N = 358, B = -0.06, β = -0.10, p = 0.16, respectively), neither did it have main effects on the intercept and slope of parent-reported aggression (N = 358, B = 0.13, β = 0.03, p = 0.69 and N = 358, B = 0.05, β = 0.05, p = 0.57, respectively).

3.2. Main effects of neighbourhood density and CAR_{AUCg} on the development of adolescent self-reported externalizing problem behaviours

We examined the main effects of neighbourhood density and CAR_{AUCg} on the development of self-reported externalizing problem behaviours, controlling for effects of SES and gender. In the two models predicting development of self-reported delinquency and aggression, significant effects of SES and CAR_{AUCg} were observed. Specially, lower SES was related to lower slope (i.e., change rate) of self-reported delinquency (N = 358, B = -0.46, β = -0.18, p = 0.01). In addition, lower SES was related to higher intercept (N = 358, B = 3.48, β = 0.20, p = 0.00) and lower slope (N = 358, B = -0.85, β = -0.22, p = 0.00) of self-reported aggression. Furthermore, CAR_{AUCg} was positively associated with the intercept of adolescent aggression (N = 358, B = 0.84, β = 0.16, p = 0.02).

No other main effects of CAR_{AUCg} on the intercepts and slopes of adolescent externalizing problem behaviours were found. CAR_{AUCg} did not predict the intercept (N = 358, B = 0.33, β = 0.13, p = 0.06) nor the slope of self-reported delinquency (N = 358, B = -0.12, β = -0.15, p = 0.09). Moreover, CAR_{AUCg} was not significantly related to the slope of self-reported aggression (N = 358, B = -0.20, β = -0.16, p = 0.08). In addition, neighbourhood density did not predict the intercept and slope of self-reported delinquency (N = 358, B = 0.13, β = 0.05, p = 0.35 and N = 358, B = 0.04, β = 0.05, p = 0.35, respectively) and aggression (N = 358, B = -0.16, β = -0.03, p = 0.48 and N = 358, B = 0.05, β = 0.04, p = 0.50, respectively).

3.3. Interaction effects between CAR_{AUCg} and neighbourhood density on the development of parent-reported externalizing problem behaviours

Table 3 presents the results of the interaction effects between CAR_{AUCg} and neighbourhood density on parent-reported adolescent delinquency and aggression, while controlling for the effects of SES and gender. The results from the regression analyses showed significant interaction effects between CAR_{AUCg} and neighbourhood density on the intercept of parent-reported delinquency (N = 358, B = 0.31, β = 0.15, p = 0.01) and parent-reported aggression (N = 358, B = 0.98, β = 0.19, p = 0.01). These significant interaction effects indicated that the associations between neighbourhood density and parent-reported delinquent and aggressive behaviours differed for adolescents with varying levels of CAR_{AUCg}. Region of significance tests revealed that for adolescents with CAR_{AUCg} levels ≥ 0.62 SD and ≥ 1.90 SD above the mean, higher neighbourhood density significantly predicted higher levels of delinquency and aggression, respectively. Remarkably, the reverse was true for the relation between neighbourhood density and externalizing problem behaviours for adolescents with CAR_{AUCg} lower than certain levels. Specifically, for adolescents with CAR_{AUCg} levels ≤ -0.97 SD and ≤ -0.09 SD below the mean, lower neighbourhood density significantly predicted higher levels of delinquency and aggression. To determine whether the interaction was in support of the biolog-

ical sensitivity theory, we also probed this interaction for varying levels of neighbourhood density. We found that for adolescents living in a neighbourhood with density levels ≥ 0.27 SD and ≥ 0.85 SD above the mean, higher CAR_{AUCg} significantly predicted higher levels of delinquency and aggression, respectively. The reverse was true for the relationship between CAR_{AUCg} and externalizing problem behaviours, for adolescents living in a neighbourhood with density levels ≤ -2.57 SD and ≤ -0.96 SD below the mean, lower CAR_{AUCg} significantly predicted higher levels of delinquency and aggression, respectively. The interactive effects are visualized by showing simple slopes for adolescents high (at 1 SD above the mean) and low (at 1 SD below the mean) in CAR_{AUCg} in Figs. 1a and 2a , and for adolescents who live in high (at 1 SD above the mean) and low (at 1 SD below the mean) density neighbourhood in Figs. 1b and 2b. Further three-way interaction analysis did not indicate that these significant interaction effects were different by SES levels.

3.4. Interaction effects between CAR_{AUCg} and neighbourhood density on the development of self-reported externalizing problem behaviours

Table 4 presents the results of the interaction effects between CAR_{AUCg} and neighbourhood density on self-reported adolescents' delinquency and aggression, while controlling for the effects of SES and gender. There were significant interaction effects between CAR_{AUCg} and neighbourhood density in predicting the intercept (N = 358, B = 0.30, β = 0.11, p = 0.04) but not the slope (N = 358, B = 0.02, β = 0.03, p = 0.68) of self-reported delinquency. There were no significant interaction effects between CAR_{AUCg} and neighbourhood density in predicting the intercept (N = 358, B = 0.21, β = 0.04, p = 0.46) neither the slope (N = 358, B = 0.05, β = 0.04, p = 0.63) of adolescents' self-reported aggression. Probing of the interaction for different levels of CAR_{AUCg} revealed that for adolescents with CAR_{AUCg} levels ≥ 0.02 SD above the mean, higher neighbourhood density significantly predicted higher levels of delinquency. To determine whether the interaction was in support of the biological sensitivity theory, we also probed this interaction for varying levels of neighbourhood density. We found that for adolescents living in a neighbourhood with density levels ≥ 1.07 SD above the mean, higher CAR_{AUCg} levels predicted higher levels of self-reported delinquent behaviours. The interactive effects are visualized by showing simple slopes for adolescents high (at 1 SD above the mean) and low (at 1 SD below the mean) in CAR_{AUCg} in Fig. 3a, and for adolescents who live in high (at 1 SD above the mean) and low (at 1 SD below the mean) density neighbourhood in Fig. 3b. Further three-way interaction analyses did not indicate SES differences in these significant interaction effects.
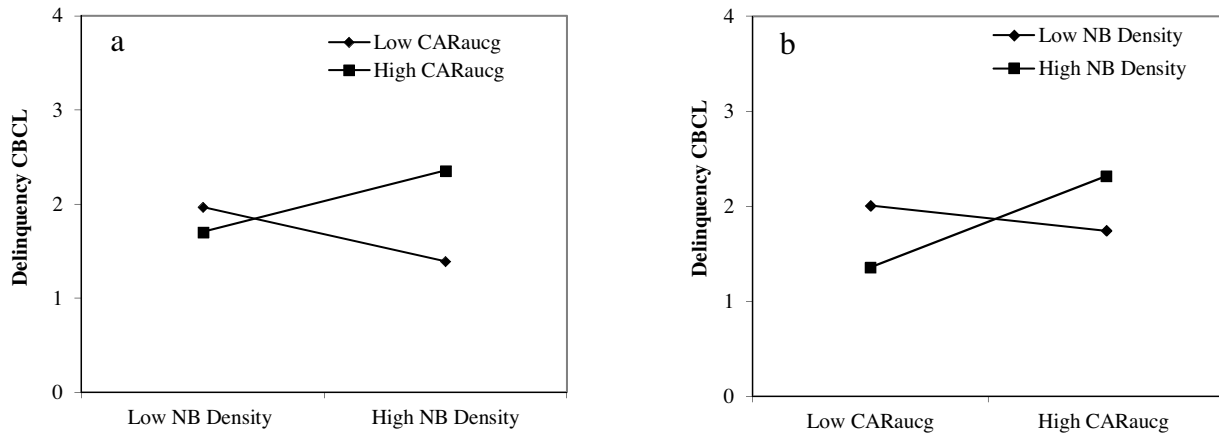
3.5. Interaction effects between SES and neighbourhood density on the development of externalizing problem behaviours

To test whether the moderating effects of CAR_{AUCg} can be explained by the potential overlap between neighbourhood density and SES, we examined interaction effects between SES and CAR_{AUCg} in predicting adolescent externalizing problem behaviours. In four statistical models predicting eight outcomes (i.e., four intercepts and four slopes of externalizing problem behaviours), the only significant CAR_{AUCg} by SES interaction effect was in predicting the slope of self-reported delinquency (i.e., B [SE] = 0.34 [0.16], β = 0.14, p = 0.03). This interaction showed that for adolescents with CAR_{AUCg} levels ≤ 0.20 SD below the mean, lower SES significantly predicted higher slope (i.e., faster growth) of delinquent behaviours. No other CAR_{AUCg} by SES interaction effects appeared.
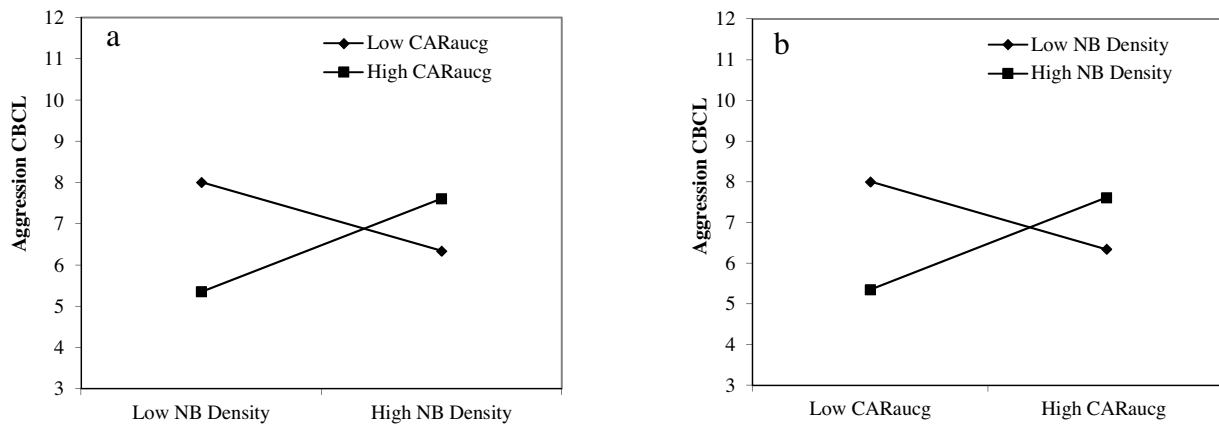
Table 3

Interaction Effects between Adolescent CAR$_{AUCg}$ and Neighbourhood Density on Parent-Reported Externalizing Problem Behaviours from 15 to 18 Years.

(N = 358)	Delinquency (CBCL)				Aggression (CBCL)			
	Intercept		Slope		Intercept		Slope	
	B (SE)	β	B (SE)	β	B (SE)	β	B (SE)	β
Model 1								
SES (L vs. H&M)	0.73 (0.40)	0.11	0.25 (0.15)	0.14	2.47 (1.20)	0.15*	0.43 (0.31)	0.14
Gender (Girl vs. Boy)	-0.28 (0.23)	-0.07	-0.12 (0.07)	-0.12	-0.41 (0.58)	-0.04	0.24 (0.15)	0.13
CAR$_{AUCg}$	0.17 (0.13)	0.08	-0.06 (0.04)	-0.11	0.13 (0.33)	0.03	0.05 (0.09)	0.05
NB Density	0.04 (0.04)	0.02	0.02 (0.04)	0.03	-0.17 (0.24)	-0.03	0.06 (0.08)	0.06
Model fit	CFI = 0.94, RMSEA =0.07, SRMR = 0.05				CFI = 0.98, RMSEA = 0.06, SRMR = 0.05			
Model 2								
SES	0.77 (0.40)	0.12	0.25 (0.15)	0.14	2.61 (1.17)	0.16*	0.42 (0.31)	0.14
Gender	-0.26 (0.22)	-0.06	-0.13 (0.07)	-0.12	-0.33 (0.57)	-0.03	0.23 (0.15)	0.12
CAR$_{AUCg}$	0.18 (0.12)	0.09	-0.06 (0.04)	-0.11	0.15 (0.31)	0.03	0.05 (0.09)	0.05
NB Density	-0.02 (0.08)	-0.01	0.02 (0.04)	0.04	-0.35 (0.22)	-0.07	0.08 (0.07)	0.08
CAR$_{AUCg}$ * NB Density	0.31 (0.12)	0.15**	-0.02 (0.04)	-0.03	0.98 (0.37)	0.19**	-0.10 (0.10)	-0.11
Model Fit	CFI = 0.94, RMSEA = 0.06, SRMR = 0.05				CFI = 0.97, RMSEA = 0.05, SRMR = 0.05			

Note: Score of delinquency and aggression was based on the mean score of mother and father reports. CBCL = Child Behaviour Checklist. SES = Social Economic Status. L vs. H&M = Low vs. High & Medium. CAR$_{AUCg}$ = Cortisol Awakening Response Area Under the Curve with respect to ground. NB = Neighbourhood. B = unstandardized regression coefficient. β = standardized regression coefficient. *$p < 0.05$; **$p < 0.01$.

Fig. 1. Interaction Effects between Adolescent CAR$_{AUCg}$ and Neighbourhood Density on Development of Parent-Reported Delinquency.

Fig. 2. Interaction Effects between Adolescent CAR$_{AUCg}$ and Neighbourhood Density on Development of Parent-Reported Aggression.

3.6. Interaction effects between CAR$_{AUCi}$ and neighbourhood density on the development of externalizing problem behaviours
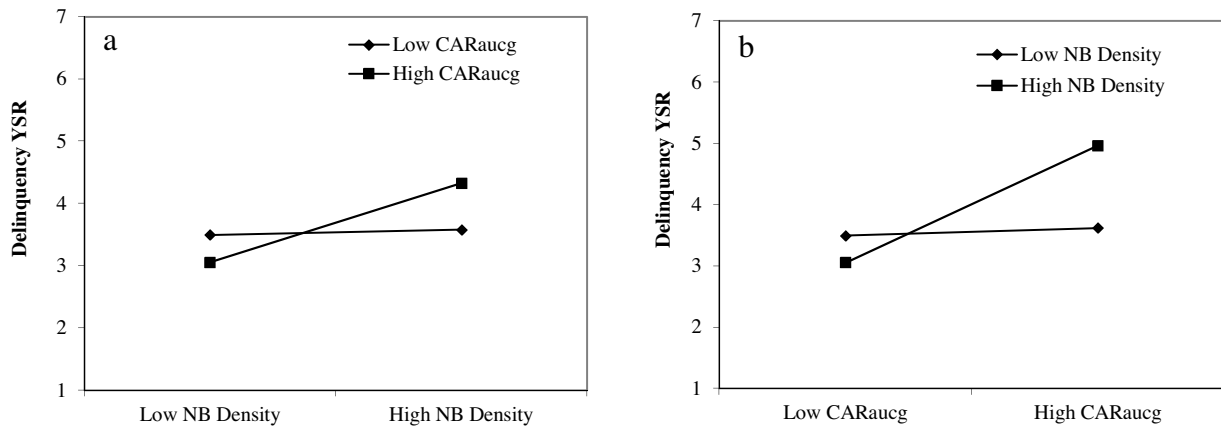
We additionally tested whether the moderating effects of CAR were specific to cortisol activity (i.e., AUCg), or also occurred for cortisol reactivity (i.e., AUCi). Our analyses showed significant CAR$_{AUCi}$ by neighbourhood density interaction effects in predicting adolescent self-reported delinquency (i.e., B [SE] = -0.21 [0.11], β = -0.08, $p = 0.06$ in predicting the intercept; B [SE] = 0.08 [0.04], β = 0.11, $p = 0.03$ in predicting the slope) and adolescent self-reported aggression (i.e., B [SE] = 0.41 [0.19], β =- 0.08, $p = 0.03$ in predicting the intercept; B [SE] = 0.23 [0.07], β = 0.19, $p = 0.001$

Table 4
Interaction Effects between Adolescent CAR$_{AUCg}$ and Neighbourhood Density on Self-Reported Externalizing Problem Behaviours from 15 to 18 Years.

(N = 358)	Delinquency (YSR)				Aggression (YSR)			
	Intercept		Slope		Intercept		Slope	
	B (SE)	β	B (SE)	β	B (SE)	β	B (SE)	β
Model 1								
SES (L vs. H&M)	1.07 (0.60)	0.12	-0.46 (0.18)	-0.18**	3.48 (1.12)	0.20**	-0.85 (0.29)	-0.22**
Gender (Girl vs. Boy)	-0.52 (0.32)	-0.10	-0.04 (0.11)	-0.02	-0.42 (0.60)	-0.04	0.09 (0.17)	0.04
CAR$_{AUCg}$	0.33 (0.18)	0.13	-0.12 (0.07)	-0.15	0.84 (0.35)	0.16*	-0.20 (0.11)	-0.16
NB Density	0.13 (0.14)	0.05	0.04 (0.05)	0.05	-0.16 (0.24)	-0.03	0.05 (0.07)	0.04
Model fit	CFI = 0.97, RMSEA = 0.05, SRMR = 0.04				CFI = 0.98, RMSEA = 0.04, SRMR = 0.03			
Model 2								
SES	1.11 (0.59)	0.13	-0.46 (0.18)	-0.18*	3.50 (1.12)	0.20**	-0.85 (0.29)	-0.22**
Gender	-0.50 (0.32)	-0.09	-0.04 (0.11)	-0.02	-0.41 (0.60)	-0.04	0.10 (0.18)	0.04
CAR$_{AUCg}$	0.34 (0.18)	0.13	-0.12 (0.07)	-0.15	0.84 (0.35)	0.16*	-0.19 (0.11)	-0.16
NB Density	0.08 (0.13)	0.03	0.04 (0.04)	0.05	-0.20 (0.25)	-0.04	0.04 (0.07)	0.03
CAR$_{AUCg}$ * NB Density	0.30 (0.15)	0.11*	0.02 (0.05)	0.03	0.21 (0.29)	0.04	0.05 (0.10)	0.04
Model Fit	CFI = 0.97, RMSEA = 0.04, SRMR = 0.04				CFI = 0.97, RMSEA = 0.04, SRMR = 0.04			

Note. YSR = Youth Self Report. SES = Social Economic Status. L vs. H&M = Low vs. Medium & High. CAR$_{AUCg}$ = Cortisol Awakening Response Area Under the Curve with respect to ground. NB = Neighbourhood. B = unstandardized regression coefficient. β = standardized regression coefficient. *p < 0.05; **p < 0.01.

Fig. 3. Interaction Effects between Adolescent CAR$_{AUCg}$ and Neighbourhood Density on Development of Self-Reported Delinquency.

in predicting the slope). The interaction pattern indicated that for adolescents with a high CAR$_{AUCi}$, delinquency and aggression were overall higher for those from a high density neighbourhood. There were no significant CAR$_{AUCi}$ by neighbourhood density interaction effects on parent-reported externalizing problem behaviours.

4. Discussion

This longitudinal study examined the effects of neighbourhood density and adolescents' morning cortisol activity on the development of externalizing problem behaviours from middle to late adolescence. Our results indicated that neither neighbourhood density nor adolescents' cortisol activity in general did have main effects on the initial levels and developmental changes of adolescent externalizing problem behaviours. However, there were significant interaction effects between CAR$_{AUCg}$ and neighbourhood density in predicting adolescents' aggression and delinquency over a period of four years. Level of CAR$_{AUCg}$ moderated the effects of neighbourhood density on the development of adolescents' externalizing problem behaviours. These findings provide support for person-environment perspectives and also biological sensitivity theory on the development of adolescent externalizing problem behaviours (Ellis & Boyce, 2011; Magnusson & Stattin, 2006; Susman & Ponirakis, 1997).

4.1. Main effects of neighbourhood density on adolescent externalizing problem behaviours

The lack of main effects of neighbourhood density on aggressive and delinquent behaviours is consistent with some prior studies (Gillis, 1974; Reijneveld et al., 2010; Wichstrom, Skogen, & Osia, 1996). However, findings were contradictory to results from other studies reporting positive associations (Harden et al., 2009; Schmitt, 1957), negative relations (Bao, Haas, & Pi, 2004), and non-linear links (Browning et al., 2010). The inconsistent findings could be due to neighbourhood differences across studies. Specifically, these studies are from different countries or different areas within a country, and it might be that in different countries or areas living in a high density environment implies differences in terms of distributions of educational resources (Boyle, Georgiades, Racine, & Mustard, 2007), income equality (Kawachi, 2000), or ethnic composition (Semyonov, Gorodzeisky, & Glikman, 2012) which are related to adolescent externalizing problem behaviours (MacDonald, Hipp, & Gill, 2013; Schindler et al., 2015; Wilkinson & Pickett, 2009).

The inconsistency could also reflect other differences in methods among studies, such as the controlling variables and study design. For instance, some researchers controlled for unemployment, mean income, and educational level (Reijneveld et al., 2010), others controlled for parental divorce (Weenink, 2011). Difference in these measured covariates as statistical controls might explain differences among studies. Furthermore, most of the stud-

ies adopted a cross-sectional design which does not provide information on the direction of effects. A more ideal approach is to adopt a longitudinal design that takes into account the mobility of adolescents (i.e., move from areas of high to low density neighbourhood environment and vice versa). It has been shown that some significant relations between neighbourhood density and externalizing problem behaviours demonstrated in cross-sectional analyses disappear in longitudinal investigations (Harden et al., 2009). Furthermore, individual characteristics might moderate the association between neighbourhood environments and externalizing problem behaviours (Jaffee et al., 2015; Obradović, Bush, Stamperdahl, Adler, & Boyce, 2010). In sum, more research is needed on factors that qualify the effect of neighbourhood density on adolescent externalizing problem behaviours.

4.2. Main effects of CAR$_{AUCg}$ on adolescent externalizing problem behaviours

The current study indicates that in general there were no significant effects of CAR$_{AUCg}$ on the development (i.e., initial levels and developmental changes) of externalizing problem behaviours across middle to late adolescence. The only exception was that CAR$_{AUCg}$ was positively linked to the intercept of adolescent self-reported aggression. The non-significant links between CAR$_{AUCg}$ and externalizing problem behaviours found in the current community sample are in accordance with findings from studies of early to middle normally developing adolescents (Klimes-Dougan et al., 2001; Sondeijker et al., 2008). In addition, the lack of CAR$_{AUCg}$-externalizing problem behaviours associations are in general consistent with a prior meta-analytic review concluding no associations between (morning) basal cortisol levels and externalizing behaviours in adolescent samples with ages ranged from 12 to 19 years (Alink et al., 2008).

Findings from the current study are, however, inconsistent with studies showing negative associations between morning basal cortisol levels and adolescents' externalizing problem behaviours (Pajer et al., 2001; Shirtcliff et al., 2005; Shoal et al., 2003). The divergent findings on the relation between CAR$_{AUCg}$ and externalizing behaviour problems could be due to studies not accounting for issues of sample characteristics such as severity of externalizing behaviours and comorbidity of traits or internalizing problem behaviours (Marsman et al., 2008; Ruttle et al., 2011; Shirtcliff & Essex, 2008). Some studies have suggested that the negative cortisol-externalizing problem behaviours association may be characteristic for a particular severe subgroup only, such as adolescents with conduct disorders, oppositional defiant disorder, or adolescents with persistent aggressive behaviours (Platje et al., 2013; Shoal et al., 2003). This association might also be dependent on the comorbidity of individual traits (e.g., callous-unemotional traits; Hayes & Matthes, 2009) and internalizing problem behaviours (Shirtcliff & Essex, 2008). Hence, further studies are necessary to understand the relationship between CAR$_{AUCg}$ and externalizing problem behaviours.

4.3. Moderating effects of CAR$_{AUCg}$ on the association between neighbourhood density and development of adolescent externalizing problem behaviours

We found significant interaction effects between CAR$_{AUCg}$ and neighbourhood density in predicting adolescent parent-reported aggression and delinquency and self-reported delinquency. CAR$_{AUCg}$ appeared to be a moderator of the association between neighbourhood density and adolescents' externalizing problem behaviours. In predicting parent-reported aggression and delinquency, the interaction effects showed a contrastive pattern—meaning that the valence of the associations between

neighbourhood density and adolescent externalizing problem behaviours runs in the opposite direction at relatively high versus low levels of the moderator CAR$_{AUCg}$ (Belsky, Bakermans-Kranenburg, & Van IJzendoorn, 2007). The contrastive pattern suggests that high CAR$_{AUCg}$ could be a protective factor in a low density environment but a risk factor in a high density environment. In contrast, low CAR$_{AUCg}$ could be a protective factor in a high density environment but a vulnerable factor in a low density environment. These findings suggest that neither high nor low CAR$_{AUCg}$ is a protective or vulnerable factor as such. Instead, it is more of the match and combination of the level of an individual's CAR$_{AUCg}$ and the level of density of a neighbourhood environment that predicts the development of parent-reported externalizing problem behaviours. We also observed interactive effects between CAR$_{AUCg}$ and neighbourhood density in predicting adolescent self-reported delinquent behaviours. For adolescents with low CAR$_{AUCg}$, there was no significant association between neighbourhood density and delinquent behaviours, whereas for those with high CAR$_{AUCg}$, there were positive associations between neighbourhood density and delinquency. These findings together provide support for general interactive perspectives and hormones-context interactions theory, claiming that individuals' developmental outcomes are dependent on interactive processes between individuals' characteristics and contextual factors (Magnusson & Stattin, 2006; Susman & Ponirakis, 1997).

In general, the interactive patterns between neighbourhood density and CAR$_{AUCg}$ in predicting parental reported delinquency and aggression and self-reported delinquency suggest that high CAR$_{AUCg}$ is a sensitivity factor which increases the negative effects of adverse environments (i.e., high density neighbourhood) but enhances the beneficial effects of positive environments (i.e., low density neighbourhood). Hence, these results support the biological sensitivity theory (Ellis & Boyce, 2011). More specifically, these findings indicate that hyper-aroused adolescents might have higher sensitivity towards not only the stresses that could be generated by a high density environment such as overcrowding, noise, impersonal space, or limited accessibility to resources but also the benefits that might be provided in a low density neighbourhood such as physical space, quietness, or availability of resources. For instance, it has been suspected that a serious consequence of high-density living may be a real or perceived inability to control the environment and to regulate one's social interactions (Rodin, 1976). It is likely that hyper-aroused adolescents sense higher stress of inability to control over what goes on in a neighbourhood and over interpersonal change, than less-aroused adolescents, thus they act more delinquent and aggressive in high-density environment. In sum, findings corroborate a conceptualization of stress activity as biological sensitivity to context by showing that high CAR$_{AUCg}$ can both hinder and promote adaptive functioning.

In predicting parent-reported externalizing problem behaviours, we observed detrimental effects of a combination of a hypo-aroused biological response, namely a low cortisol awaking response, and a low density neighbourhood in predicting adolescents' externalizing problem behaviours. This finding is inconsistent with the theory of biological sensitivity to context in which adolescents with a low CAR$_{AUCg}$ would be expected to be not influenced by their environment. This finding might however provide some support for the sensation seeking theory of antisocial behaviours (Raine, 1993; Zuckerman & Neeb, 1979). A low density neighbourhood environment is probably not only quieter and calmer but also provides fewer opportunities for involvement in interpersonal contacts or social events than a high-density neighbourhood environment. Hence, such an environment might be boring for hypo-aroused adolescents as they are less likely to be aroused by their environment. As low arousal represents an aversive physiological condition, to attain a higher and more optimal level of arousal, hypo-aroused adolescents might seek

stimulation through delinquent and aggressive behaviours in a low-density neighbourhood.

There was no significant association between CAR_{AUCg} and neighbourhood density in this study, thus it is rather unlikely that there would be a bidirectional process whereby certain adolescents develop higher CAR_{AUCg} as a result of living in high density neighbourhoods, or vice versa. Hence, the interaction effects between CAR_{AUCg} and neighbourhood density were not likely to be confounded by any bidirectional effects between the independent and moderating variables.

Our study showed significant main effects of SES on aggressive behaviours, with adolescents from low SES families reporting higher levels of parent- and self- reported aggression. These results are consistent with findings from a large body of previous studies (see Bradley & Corwyn, 2002 for a review). However, despite these main effects, the only significant SES by CAR_{AUCg} interaction effect was on the slope of self-reported delinquency. These findings suggest that the moderating effects of CAR_{AUCg} on the link between neighbourhood density and externalizing problems cannot be explained by the potential overlap between neighbourhood density and SES. These results further highlight the importance of investigating the interaction effects between neighbourhood density and CAR_{AUCg}.

4.4. Moderating role of CAR_{AUCi} on the association between neighbourhood density and development of adolescent externalizing problem behaviours

We found significant interaction effects between cortisol reactivity CAR_{AUCi} neighbourhood density in predicting adolescents' self-reported delinquent and aggressive behaviours. The interaction pattern suggests that adolescents with a higher CAR_{AUCi} (i.e., a bigger change in cortisol levels post-awakening) might be more likely to be negatively influenced by a high density neighbourhood and therefore they develop higher externalizing problem behaviours. These findings in general seem to be consistent with the interaction patterns between neighbourhood density and cortisol activity CAR_{AUCg} in predicting externalizing problem behaviours, providing further support for the biological sensitivity theory (Ellis & Boyce, 2011).

4.5. Limitations and strengths

Several limitations of the current study have to be noted. First, findings might be limited to youths from middle to late adolescence, the age period covered by this study. The effects of basal cortisol levels on externalizing problem behaviours were found to be age dependent (Alink et al., 2008). It is possible that the interaction effects between CAR_{AUCg} and neighbourhood density in predicting externalizing problem behaviours are also dependent on individuals' developmental stages. Second, this study focuses on a general population sample. Thus, results reflect normative levels of aggressive and delinquent behaviours. Therefore, the results cannot be generalized to clinically referred youths with conduct disorders or oppositional disruptive disorders. Third, in our study CAR was measured on a single day instead of over multiple days. Although a recent review has shown that the cortisol awaking response has relatively high between-visit reliabilities (r = 0.33–0.67; Golden, Wand, Malhotra, Kamel, & Horton, 2011), factors such as substance use, time of awakening, and stressful experiences could potentially affect CAR (e.g., Williams, Magid, & Steptoe, 2005). In our study, we partially address the limitation of one single measurement by testing the effects of some potential covariates and including the significant predictors in our analyses. However, to further increase the reliabilities of CAR measurement, future studies are encouraged

to use repeated measures over multiple days (Hellhammer, Fries, Schweisthal, Schlotz, Stone, & Hagemann, 2007).

This study has also several strengths. It is the first attempt investigating interaction effects between neighbourhood density and individuals' CAR on the development of adolescent externalizing problem behaviours. The multiple informant approach (i.e., both self- and parent-report) adopted in this study provided a more comprehensive picture of the interaction processes between neighbourhood density and CAR. Moreover, the longitudinal design allowed us to investigate whether the interaction between neighbourhood density and CAR predicts changes in externalizing problem behaviours within individuals. Furthermore, the present study controlled for the property value of the neighbourhood as well as family SES. As it is possible that neighbourhoods with a high density are on average poorer than those with low density, controlling for both family SES and neighbourhood wealth value could preclude this selection bias which could obscure the independence of the effects of neighbourhood density (Hipp, Butts, Acton, Nagle, & Boessen, 2013). Finally, the focus on neighbourhood density rather than general neighbourhood deprivation provides more specific information on the contribution of neighbourhood characteristics on adolescents' externalizing problem behaviours, which is called for in a recent review (Van Vuuren, Reijneveld, Van der Wal, & Verhoeff, 2014).

5. Conclusion

The present study revealed significant interaction effects between neighbourhood density and CAR in predicting adolescent aggressive and delinquent behaviours. In general it indicates that individuals' biological sensitivity to environmental context plays an important role in moderating the effects of neighbourhood density on adolescents' adjustment. Findings highlight the complexities that contribute to adolescents' externalizing problem behaviours and support the theoretical idea of interactive processes between environmental context and individuals characteristics contributing to adolescents' developmental outcomes.

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