The Association Between Peer and Own Aggression is Moderated by the BDNF Val-Met Polymorphism

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Peer antisocial behavior robustly predicts adolescents’ own behavior, but not all adolescents are equally vulnerable to their peers’ influence and genetic factors may confer vulnerability. This study used data of \( n = 3,081 \) adolescents from the Avon Longitudinal Study of Parents and Children to examine whether brain-derived neurotrophic factor (BDNF), a polymorphism that affects psychological functioning, moderates the association between affiliation with aggressive peers at age 10 and own aggression at age 15. A significant gene–environment interaction was found, where those who affiliated with aggressive peers in childhood showed increased risk of being aggressive in adolescence if they carried the BDNF met-met variant compared with val-val carriers. Our findings underline the importance of both biological and social factors for adolescent development.

During adolescence, youths spend increasingly less time being supervised by adults (Paikoff & Brooks-Gunn, 1991) and more time interacting with peers (Larson & Richards, 1991). This is also the period when individuals are most vulnerable to the influence of their peers (Brechwald & Prinstein, 2011; Steinberg & Monahan, 2007). Studies provide ample evidence that affiliation with deviant friends increases own antisocial behavior, even after accounting for peer-related confounders such as peer rejection (e.g., Snyder et al., 2005, 2010) and family-related factors (Vitaro, Brendgen, & Tremblay, 2000). In fact, one of the strongest predictors of antisocial behavior in adolescence is peer behavior (Van Lier, Wanner, & Vitaro, 2007). Despite the crucial role of peers in adolescence, the influence of deviant peers on adolescent antisocial behavior is not uniformly strong. Individual differences in sensitivity to peer influence have been ascribed to relationship and individual factors such as impulsivity (Snyder et al., 2010).

Studies have also begun to examine the degree to which individual variation in genetic factors may elevate or attenuate the influence of deviant peers. Quantitative genetic studies have shown that sensitivity to friends’ influence is partly heritable (e.g., Van Lier, Boivin et al., 2007), and, more recently, studies have begun to identify the specific genes involved. For example, Lee (2011) used data from the National Longitudinal Study of Adolescent Health (Add Health) to examine the interplay between the monoamine-oxidase-A gene and deviant peer affiliation and reported that genotype moderated the association between affiliation with deviant peers and own aggressive behavior. Latendresse et al. (2011) used data from the Child Development Project to examine interaction effects between peer antisocial behavior measured at age 12 and CHRM2, a gene that had previously been linked to personality traits (e.g., Hendershot, Bryan, Feldstein, Claus, & Hutchinson, 2011) and alcohol-related disorders (e.g., Jung et al., 2011). Latendresse et al. showed that youths carrying the minor CHRM2 allele were more likely to report externalizing problems if they had associated with antisocial peers. Although research into biological moderation...
of peer effects is still scarce (Brendgen, 2012), these two studies clearly point to the necessity to take specific genetic effects into account when trying to understand how certain youth might be more likely to show antisocial behavior following affiliation with deviant peers, and support and extend a vast literature of gene–environment interactions.

This study adds to the above by examining the brain-derived neurotrophic factor (BDNF) gene, a polymorphism located on chromosome 11p13-14, which regulates the secretion of BDNF in the brain. The functional BDNF polymorphism consists of a valine to methionine substitution at position 66 (val66met) with BDNF secretion being reduced in met- compared with val-alleles (Hong, Liou, & Tsai, 2011). BDNF is a key mediator of neuronal plasticity in the prefrontal cortex and hippocampus in humans (Calabrese, Molteni, Racagni, & Riva, 2009). The polymorphism is implied in regulation of responses to stress through its effect on the hypothalamic-pituitary-adrenal (HPA) axis (Colzato, Van den Wildenberg, Van der Does, & Hommel, 2011; Gatt et al., 2009; Shalev et al., 2009). In detail, met-allele carriers showed greater HPA axis activity and higher levels of anxiety, nervousness, and insecurity, as well as increased substance abuse following stress induction (Colzato et al., 2011). BDNF also affects susceptibility to environmental stressors in the prediction of depressive symptoms (Wichers et al., 2008) and impulsive aggression (Wagner, Baskaya, Dahmen, Lieb, & Tadic, 2010). In both studies, met-allele carriers were more vulnerable to environmental risk than val-val carriers. Moreover, carriers of the met-allele score higher on introversion (Terracciano et al., 2010) and show an increased risk of psychopathological disorders related to and including aggression (e.g., Spalletta et al., 2010) and impulsivity (Oades et al., 2008).

Associations between genetic factors and complex behaviors are increasingly studied from a neurological perspective. Raine’s (2008) observation that BDNF is important for expressing conduct problems under conditions of (social) stress is supported by studies in this realm. For instance, stressful social environments have been linked to neural processes, including functioning of the neural stress response system as well as brain regions involved in emotion regulation (Meyer-Lindenberg & Tost, 2012). Peer groups are of particular importance in adolescence, and high levels of aggression within them may constitute a source of pressure and social stress. Supporting this assumption, Paus et al. (2008) observed differences in brain morphology in children with high versus low resistance to peer influence. The expression of BDNF was discussed as a potential force driving these differences, which underlines the hypothesis that the BDNF polymorphism may modulate adolescents’ peer experiences and the effects of deviant peer affiliation.

Building on previous studies of genetic factors in vulnerability to peer influence and of associations between the BDNF polymorphism and psychopathology, the current study tested whether adolescents carrying one, and particularly two, met-alleles would be more vulnerable to the influence of aggressive peers, and hence at increased risk of aggression themselves, controlling for their own childhood aggression.

**EFFECTS OF GENDER**

Gender was included as a potential moderator for several reasons. First, boys use physical aggression more than girls (Card, Stucky, Sawalani, & Little, 2008; Hyde, 1984; Lahey et al., 2000). While it is not clear whether gender moderates peer influence on aggressive behavior (e.g., Mears, Ploeger, & Warr, 1998), our study focuses on peer aggression in pre-adolescence, a life stage in which peer relations are largely gender-segregated (Rose & Rudolph, 2006). Girls may be assumed to spend time mainly with other girls and may therefore be less exposed to (and affected by) aggressive behavior in their peer environment. In addition, gender moderates to some extent the social function of aggression in the peer context, that is, the use of aggressive behavior as a means to achieve popularity and status (Prinstein & Cillessen, 2003; Salmivalli, Kaukiainen, & Lagerspetz, 2000; Vaillancourt & Hymel, 2006). Finally, differences between males and females have been reported with respect to the effects of BDNF on psychopathology (e.g., Verhagen et al., 2010), including the role this polymorphism plays as a moderator of stressful life experiences. For instance, Van Oostrom et al. (2012) showed that BDNF interacted with stressful life events in childhood in the prediction of affective memory bias, a measure related to depression; however, this association was only found in males and not in females. Taking into account gender-specific patterns in use of aggressive behavior and effects of BDNF and responding to calls for attending to gender specificity in gene–environment interaction studies in the prediction of psychopathology (Caspi & Moffitt, 2006; Dunn et al., 2011), we examined potential effects of gender.

Our analyses were guided by the following hypotheses: First, we assumed that own mid-adolescent aggression is positively predicted by
affiliation with aggressive peers in childhood. Second, we hypothesized this association to be moderated by BDNF genotype. Consistent with previous conceptualization of BDNF, we assumed an additive model, that is, increasing risk with every met-allele (Lipsky & Marini, 2007). The results of this study would support a diathesis-stress model if BDNF met-allele carriers were found to be more vulnerable to the effects of affiliating with aggressive friends than carriers of the val-val homozygous variant. This should be especially the case for carriers of the met-met variant. Third, we tested gender differences in an exploratory manner.

**METHOD**

**Participants**

Participants for the current study represent a subsample of the Avon Longitudinal Study of Parents and Children (ALSPAC), an ongoing population-based study designed to investigate the effects of a wide range of influences on the health and development of children. Pregnant women residing in the southwest of England who had an estimated date of delivery between April 1, 1991, and December 31, 1992, were invited to participate. The initial study cohort consisted of 14,541 pregnancies and 13,971 singletons or twins still alive at 12 months study cohort consisted of 14,541 pregnancies and ber 31, 1992, were invited to participate. The initial date of delivery between April 1, 1991, and December 31, 1992, were invited to participate. The initial study cohort consisted of 14,541 pregnancies and 13,971 singletons or twins still alive at 12 months of age. A total of $n = 9,244$ individuals were genotyped for BDNF, of which $n = 3,081$ also had data on measures of socioeconomic status, single-parent status, peer, and own antisocial behavior at ages 10 and 15. When compared with the 1991 UK National Census Data, the ALSPAC sample was found to be similar to the UK population as a whole, except that the sample showed a slightly higher proportion of married or cohabiting mothers and families who were house owner-occupiers, and (consistent with the area where the study is based) a smaller proportion of mothers from ethnic minorities (4.1% vs. 7.6%). Note that only participants of British ancestry were included in the present analyses. Ethical approval for the study was obtained from the ALSPAC Law and Ethics Committee and the local Research Ethics Committee. Detailed information about ALSPAC is available from the study by Boyd et al. (2013) and online (http://www.bris.ac.uk/alspac). Parents gave written consent for children in this study.

It should be noted that due to the design of ALSPAC, not all adolescents participated in each assessment (Boyd et al., 2013), resulting in varying numbers of cases for the different measures. Moreover, as is common in longitudinal studies, cases lost to attrition were disadvantaged in contrast to those who continued to participate in the study, particularly with regard to a variety of sociodemographic indicators. Compared with adolescents who did not participate in the age 15 assessment, adolescents with data present at age 15 were less likely to come from single-parent families ($\chi^2 = 43.39, p < .001$) or families with a higher socioeconomic status (SES) as assessed through occupational classification ($\chi^2 = 59.94, p < .001$). We further compared cases with information on age 15 aggression to those without on all other study measures and found that data presence was more likely for girls ($\chi^2 = 42.16, p < .001$), for those who were not involved in aggressive behavior at age 10 ($\chi^2 = 29.06, p < .001$), and those who did not affiliate with aggressive peers ($\chi^2 = 28.16, p < .001$). No differences in data presence at age 15 were found for BDNF. Extensive information on attrition within the ALSPAC study is provided by Boyd et al. (2013).

**Assessment**

**Aggressive behavior.** Adolescents reported on their engagement in aggressive activities at ages 10 and 15. At age 15, a 5-item scale (“threatened to hurt someone they know,” “hit, spat, or thrown stones at someone they know,” “hit, kicked, or punched someone,” “stolen money or property that someone was carrying,” and “hurt or injured animals on purpose”) was used. This measure reflects the different forms of physically aggressive behaviors in a diagnosis of Conduct Disorder as suggested by the American Psychiatric Association in the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; American Psychiatric Association, 1994). For each item, adolescents indicated how often they had engaged in it in the past 12 months, with response categories ranging from $0 = never$, $1 = just once$, $2 = 2–4$ times, and $3 = 5$ or more times. The internal reliability of the scale was acceptable, Cronbach’s $\alpha = .72$. The majority of adolescents reported no engagement at all (59% of adolescents), but 10% of adolescents reported engaging in several forms of aggressive behavior. A sum score ($M = 1.37, SD = 2.29$, range $= 0–15$) was used as dependent variable in subsequent analyses.

At age 10, two items were used to assess aggression ("getting into fights" and "being cruel to animals"), rated in yes/no format and assessing lifetime occurrence (e.g. "have you ever..."). Because of the
small number of items, we dichotomized sums into 0 (no engagement) versus 1 (engagement in one or more behaviors). Ten percent of adolescents reported aggressive behavior at age 10 (10.12% got into fights, 0.6% had been cruel to animals).

**Aggressive behavior in peers.** Also at age 10, participants rated their peer’s aggression using the same 2-item measure. Participants were asked about their peers’ behavior in a collective manner (e.g., “have your friends been in a fight?”). Twenty-nine percent of children reported their peers having been in fights and 6.25% reported peer cruelty to animals. As for adolescents’ age 10 self-reports, we dichotomized sum scores into 0 (no peer aggression) and 1 (any peer aggression). This resulted in 31% of peers being assigned a score of 1.

In addition, we controlled for single-parent status and socioeconomic status in all analyses. Both demographic indicators were assessed from mothers in the beginning of the study and have been used in other studies using the same sample (e.g., Barker, 2012). Both covariates were dichotomized and indicated whether or not a mother was a single parent (4.9%) and whether or not a child grew up in a family of low SES according to the Registrar General’s social class scale. Families in classes IV and V were considered to have a low SES (12.1%).

**Genotyping for BDNF.** DNA extraction and genotyping in this sample are described in detail in Jones et al. (2000). The frequencies for the val-val, val-met, and met-met genotypes were 66.2% (n = 1,135), 29.1% (n = 499), and 4.7% (n = 81) for boys and 67.0% (n = 1,294), 29.5% (n = 569), and 3.6% (n = 69) for girls. The BDNF polymorphism was in Hardy–Weinberg equilibrium for both boys (χ² = .582, p = .45) and girls (χ² = .147, p = .70). Supporting an additive risk model, val-homozygotes were assigned a score of 0, val-met heterozygotes were assigned a score of 1, and met-met homozygotes were assigned a score of 2. Thus, each met-allele was assumed to add to individual genetic risk as has been found with regard to other phenotypes, including aggression (Spalletta et al., 2010) and in interplay with maternal care on personality traits (Suzuki et al., 2011).

**Analytic Strategy**

Analyses were carried out using negative binomial regression models to account for skew in aggressive behavior at age 15, and results were confirmed using the bootstrapping procedure in Stata 12. The regression models proceeded in two steps. In the first step, we examined the main effects of BDNF genotype and peer aggressive behavior on adolescent own aggressive behavior, controlling for gender, own aggression at age 10, low SES, and single-parent status. We estimated main effects both in a combined and in separate models to clarify the independent contributions of peer aggression and genotype. In the second step, the interaction between genotype and friends’ behaviors was added to the model to test whether the effect of peer aggressive behavior differed by BDNF genotype. Main effect of BDNF and its interaction with peer aggression were estimated as contrast between val-val (baseline) and val-met and val-val and met-met variants. Significant interactions were followed up using simple slope models (Aiken & West, 1991). That is, we reestimated the association between peer aggression at age 10 and own mid-adolescent aggression on different levels of BDNF, while controlling for all covariates that were part of the original model.

Finally, we examined whether gender further moderated the interaction between BDNF genotype and peer behavior by testing whether a three-way interaction term would reach statistical significance while also estimating all main effects (covariates and predictors) and all potential two-way interaction effects.

Regression coefficients are presented in unstandardized form and as incidence rate ratios (IRR). IRR refer to the risk of higher (or chance of lower) levels of aggression at age 15 given an increase or decrease in the predictor. In other words, IRR indicate a one-unit increase or decrease in outcome (e.g., engaging in two aggressive acts instead of one) given a one-unit increase in the predictor variable. Because our main predictors are categorically coded, a one-unit increase in peer aggression means that this behavior is present versus absent in peers. For BDNF, each unit increase refers to an additional met-allele. The interpretation of IRR is similar to odds ratio, that is, a coefficient of 1.20 indicates a 20% elevated risk to increase by one unit in the outcome, whereas an IRR of 0.85 indicates a 15% lower score on the outcome variable given a one-unit increase in the predictor variable.

**RESULTS**

**Associations Between Study Measures**

We first examined frequency differences between BDNF genotype variants for peer aggression and
covariates. These analyses were conducted to identify potential gene–environment correlations, which indicate that exposure to an environmental risk is associated with genotype (e.g., risk of affiliation with aggressive peers at age 10 would differ as a function of BDNF). Frequency differences such as these need to be tested prior to examining gene–environment interaction effects. No differences were found, thus ruling out the possibility that adolescents selected themselves into aggressive peer context as a function of their genotype. Table 1 shows bivariate correlations among all study measures. As expected, participants’ aggression was fairly stable and at both measurement waves associated with peer aggression. Own and peer aggression at age 10 overlapped considerably. Boys were more aggressive than girls and reported higher peer aggression.

Effects of Peer Aggression and Genotype on Mid-Adolescence Own Aggression

As presented in Step 1 in Table 2, peer aggression in late childhood predicted aggressive behavior in mid-adolescence, above and beyond the effects of own aggression, gender, single-parent status, and SES. The IRR suggests that the presence of aggressive peers increased the risk of a one-unit increase in own mid-adolescent aggression by 1.43 times or 43%. Contrasts between the different genotype variants revealed no differential risk. We also conducted separate main effect models in which either BDNF or peer aggression constituted the focal predictor while controlling for all covariates. These separate models confirmed the effects found in the combined model. In detail, after controlling for all covariates used in the combined model, BDNF did not significantly predict aggression at age 15 (with val-val variant as comparison group: IRR val-met = 0.92, p = .23; IRR met-met = 0.82, p = .24). The main effect model for peer aggression, in contrast, yielded a significant effect (IRR = 1.41, p < .001) similar in size to the combined model.

We next estimated a model in which BDNF, peer aggression, and the interaction term of BDNF and peer aggression predicted adolescents’ aggression in mid-adolescence, again controlling for adolescents’ own prior aggression, single-parent status, SES, and gender (Step 2 in Table 2). As noted above, the effect of BDNF was assessed by contrasting the val-val variant with val-met and met-met variants, both for main genotype effect and as part of the interaction with aggressive peers. As depicted in Table 2, genotype interacted with peer aggression such that a significant contrast was yielded between val-val and met-met carriers. To probe this interaction, we computed simple slope

TABLE 1
Bivariate Spearman Rho Correlations Between Study Measures

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Own aggression age 15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Own aggression age 10</td>
<td>.19***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Peer aggression age 10</td>
<td>.21***</td>
<td>.43***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. BDNF (5)</td>
<td>-.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Gender (6)</td>
<td>-.26***</td>
<td>-.24***</td>
<td>-.28***</td>
<td>-.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Low SES</td>
<td>.02</td>
<td>.03*</td>
<td>.06**</td>
<td>-.02</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>7. Single parent</td>
<td>.06***</td>
<td>.04***</td>
<td>.02</td>
<td>-.02</td>
<td>.02</td>
<td>.05***</td>
</tr>
</tbody>
</table>

Note. BDNF = brain-derived neurotrophic factor. BDNF is coded as follows: 0 = val-val, 1 = val-met, 2 = met-met; gender is coded as follows: 1 = male, 2 = female. 
***p < .001. Low SES is coded according to Standard Occupational Classification Table; participants coded as Class IV and V were coded 1 = low SES group. Single parent was coded 1 when mothers indicated not having a partner. Coefficients in the table represent Spearman ρ coefficients for correlations of nonparametric data.

TABLE 2
Regression Model Predicting Aggressive Behavior at age 15

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>IRR</th>
<th>p</th>
<th>B</th>
<th>IRR</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>-.78</td>
<td>.46</td>
<td>&lt;.001</td>
<td>-.79</td>
<td>.46</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Own aggression age 10</td>
<td>.41</td>
<td>1.51</td>
<td>&lt;.001</td>
<td>.42</td>
<td>1.53</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Low SES</td>
<td>.16</td>
<td>1.17</td>
<td>.181</td>
<td>.16</td>
<td>1.17</td>
<td>.175</td>
</tr>
<tr>
<td>Single parent</td>
<td>.28</td>
<td>1.32</td>
<td>.173</td>
<td>.28</td>
<td>1.32</td>
<td>.173</td>
</tr>
<tr>
<td>Peer aggression age 10</td>
<td>.36</td>
<td>1.43</td>
<td>&lt;.001</td>
<td>.27</td>
<td>1.32</td>
<td>.003</td>
</tr>
<tr>
<td>BDNF (val-val baseline)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Val-met</td>
<td>-.10</td>
<td>.91</td>
<td>.178</td>
<td>-.16</td>
<td>.86</td>
<td>.085</td>
</tr>
<tr>
<td>Met-met</td>
<td>-.25</td>
<td>.78</td>
<td>.127</td>
<td>-.59</td>
<td>.55</td>
<td>.010</td>
</tr>
<tr>
<td>Peer aggression age 10 × BDNF (val-val baseline)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Val-met</td>
<td>.16</td>
<td>1.18</td>
<td>.276</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Met-met</td>
<td>.73</td>
<td>2.07</td>
<td>.035</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Note. All models are based on negative binomial regressions. Coefficients are presented in unstandardized (B) and standardized (IRR) form. Gender is coded as follows: 1 = male, 2 = female. Low SES is coded according to Standard Occupational Classification Table; participants coded as Class IV and V were coded 1 = low SES group. Single parent was coded 1 when mothers indicated not having a partner. BDNF = brain-derived neurotrophic factor; IRR = incidence rate ratios.
models (Aiken & West, 1991). These analyses showed a more pronounced effect of peers on adolescent’s aggression in met-met carriers ($IRR = 2.11, p < .004$) than in val-val carriers ($IRR = 1.30, p = .004$). The risk for val-met carriers lay between both homozygous variants ($IRR = 1.66, p < .001$) but did not differ significantly from the risk for val-val variant carriers as shown in Step 2 in our regression model. To illustrate this effect, the different levels of own aggression in presence versus absence of aggressive peers are depicted separately by genotype in Figure 1.

Finally, we examined whether the interaction between genotype and peer aggression worked differently for boys and girls. For this model, all main effects (i.e., $BDNF$, peer aggression, gender) as well as all two-way interaction effects ($BDNF \times Peer\text{ Aggression}$, Gender $\times Peer\text{ Aggression}$, $Gender \times Peer\text{ Aggression}$) were entered into the model simultaneously with the three-way interaction term ($BDNF \times Peer\text{ Aggression} \times Gender$). The three-way interaction effect failed to reach significance, and all other estimates were similar to prior analyses.

Given that a dominant effect of the met-allele has been reported in some studies (e.g., Wagner et al., 2010), we additionally computed regression models in which we combined both met-allele carrier groups. No significant main or interaction effect was found (results not tabulated but available from first author).

**DISCUSSION**

This study is one of only a handful of studies in genetic moderation of the link between peer aggressive behavior and later own aggression. In this context, we examined $BDNF$, a candidate gene with effects on a wide range of personality and psychopathological measures. In line with our hypothesis, we found that affiliation with aggressive peers in late childhood bore greater risk for adolescent aggressive behavior when individuals carried the met-met variant of the $BDNF$ genotype compared with val-val homozygote carriers. We hypothesized a diathesis–stress model, assuming an additive effect for $BDNF$ in which carriers of the val-met, and particularly met-met variants were assumed to be at linearly increasing risk of mid-adolescent aggression if they had affiliated with aggressive peers in late childhood. Our analyses partly supported this hypothesized significant interaction between genotype and exposure to aggressive peers.

In detail, we found that the regression of own aggression on earlier peer aggression was steeper for carriers of two met-alleles compared with carriers of two val-alleles. Although our measure of own aggression was not the same for assessments at age 10 and 15 and we thus only partly capture the increase in aggression, this pattern suggests that particularly carriers of two met-alleles are vulnerable to the effects of affiliation with aggressive peers. Noting that we computed an additive model while some previous studies combined val-met and met-met carriers for sample size reasons, our results nonetheless show similarity to previous findings. Wichers et al. (2008) showed that childhood adversity predicted later depression more strongly in met carriers than in individuals who did not carry this low-functioning allele. Similarly, Aguilera et al. (2009) found met-allele carriers to be at higher risk of depressive symptoms following sexual abuse in childhood than was the case for carriers of the val-val genotype. These results suggest that $BDNF$, although in our study not linked to aggression directly, may be a marker for sensitivity to environmental effects.

A potential mechanism through which $BDNF$ affects sensitivity to the environment is by influencing the experience of stressful conditions. $BDNF$ has been discussed as moderator of the HPA axis, the pathway that regulates responses to stress (Colzato et al., 2011; Gatt et al., 2009; Shalev et al., 2009). Peer aggression may be perceived as stressful for different reasons: (1) it may be threatening and induce fear (i.e., of being the target of aggressive behavior), (2) it can induce pressure to show behavioral conformity and put individuals at increased risk of ostracism by normative peers and punishment by adults, and (3) it can induce competition and negative hierarchy among peer groups (Prinstein & Cillessen, 2003; Salmivalli

![FIGURE 1 Mean levels of aggression at age 15 by brain-derived neurotrophic factor (BDNF) genotype and presence or absence of peer aggression at age 10. The scale refers to actual scores and represents over 90% of all values in the sample.](Image)
et al., 2000; Vaillancourt & Hymel, 2006). With regard to specific biological pathways, BDNF may act in two ways: genotypic variation may affect individual sensitivity to stress caused by aggression in peers and it may also affect cortisol levels which then translate into individual differences in own use of aggression. BDNF plays an important role in cortisol stress response (e.g., Colzato et al., 2011); hence, on experience of aggressive peers, some youths may experience greater arousal as a function of BDNF variant and more inclination to comply with (aggressive) peer norms. Indeed, prior studies have discussed associations between HPA axis functioning, cortisol levels, and aggression (for a review see Pavlov, Chistiakov, & Chekhonin, 2012). Thus, future studies that track instances of peer aggression, collect real-time cortisol level measures, and assess participants’ perceived susceptibility to peer influence in conjunction with differential genotype are complex but needed to understand the exact biological and psychological pathways that we tentatively discuss here.

LIMITATIONS AND FUTURE DIRECTIONS

Despite the insight into the interplay of peer environment and BDNF in the prediction of aggression in adolescence, our results need to be interpreted with several limitations in mind. Our study is based on self-reports that refer to adolescents’ own accounts of their peers’ aggressive behaviors, which biases the validity of this measure. Notably, the moderate overlap between adolescents’ own and their peers behavior at age 10 is in line with other studies that assessed deviant peer group affiliation in a general sense (e.g., Weerman, 2011). Main effects of peer on adolescents’ own later aggressive behavior were modest, but it should be noted that these measures were assessed with a time difference of approximately 5 years and spanning life stages with potentially very different peer contexts (i.e., primary school in late childhood vs. secondary school and considerably more spare time contact to peers outside of school). The measures of aggressive behavior at age 10 (both own and peer) were limited in their variance, a consequence of small number of items. Moreover, although we were able to control for own prior behavior, the measures of aggression at ages 10 and 15 differed and thus prevented us from examining actual change. A more similar control would have been highly desirable for a more rigorous research design.

In addition to using more refined measures of the environment, future studies that go beyond single candidate genotypes are necessary. We are not alone in finding negligible main effects of genotype on a phenotype of sizable heritability (Maher, 2008), and it is possible that inclusion of additional markers will increase the size of this effect. In addition, the interplay between genotypes and environmental factors may function via endophenotypes such as personality factors. Future studies are encouraged to include measures that are more proximally associated with specific genetic factors and also with distal outcomes to illuminate the pathways through which candidate genes moderate environmental factors.

Other unmeasured factors may have accounted for the association between childhood peer and mid-adolescent own aggression. A range of demographic features (school environment, neighborhood) or individual factors that promote affiliation with aggressive peers and also own aggressive behavior are feasible confounders of the associations described here. Furthermore, this study was based on a cohort sample, and aggression both in peers and in adolescents themselves was not very common. It is possible that the additive effect of BDNF would have been more pronounced and statistically significant in a clinical sample.

Similar to many other longitudinal studies, ALSPAC has faced attrition over time. Because predictors of attrition (see Boyd et al., 2013) are also predictors of deviant peer affiliation and aggression in adolescence, our sample almost certainly underrepresents adolescents who show severe problem behavior. This, however, also means that risk associations found in the current study are likely to have been attenuated. We also note that simulation studies suggest that, while attrition inevitably affects estimates of prevalence, it is less likely to impact associations among variables (Wolke et al., 2009).

Notwithstanding these limitations, this study contributed to the continuous effort to understand how social and biological factors work together to impact adolescents’ behavioral development. We showed that young people who affiliate with aggressive peers in late childhood are at particular risk for engaging in such behavior themselves, but that this association was even more pronounced for met-met variant carriers of the BDNF gene compared with val-val carriers. Thus, genetic markers play a nonnegligible role in the search for factors that make some adolescents more vulnerable to peer effects on aggressive behavior.
REFERENCES


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