

1 **Disentangling Nature from Nurture in Examining the Interplay Between**
2 **Parent-Child Relationships, ADHD, and Early Academic Attainment**

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23 **Abstract**

24 **Background:** Attention Deficit Hyperactivity Disorder (ADHD) is highly heritable and is
25 associated with lower educational attainment. ADHD is linked to family adversity, including
26 hostile parenting. Questions remain regarding the role of genetic and environmental factors
27 underlying processes through which ADHD symptoms develop and influence academic
28 attainment.

29 **Method:** This study employed a parent-offspring adoption design ($N=345$) to examine the
30 interplay between genetic susceptibility to child attention problems (birth mother ADHD
31 symptoms) and adoptive parent (mother and father) hostility on child lower academic
32 outcomes, via child ADHD symptoms. Questionnaires assessed birth mother ADHD
33 symptoms, adoptive parent (mother and father) hostility to child, early child
34 impulsivity/activation, and child ADHD symptoms. The Woodcock-Johnson test was used to
35 examine child reading and math aptitude.

36 **Results:** Building on a previous study (Harold et al., 2013), heritable influences were found:
37 birth mother ADHD symptoms predicted child impulsivity/activation. In turn, child
38 impulsivity/activation (4.5 years) evoked maternal and paternal hostility, which was
39 associated with children's ADHD continuity (6 years). Both maternal and paternal hostility
40 (4.5 years) contributed to impairments in math but not reading (7 years), via impacts on
41 ADHD symptoms (6 years).

42 **Conclusion:** Findings highlight the importance of early child behavior dysregulation evoking
43 parent hostility in both mothers *and* fathers, with maternal and paternal hostility contributing
44 to the continuation of ADHD symptoms and lower levels of later math ability. Early
45 interventions may be important for the promotion of child math skills in those with ADHD
46 symptoms, especially where children have high levels of early behavior dysregulation.

47 **Keywords:** ADHD, hostile parenting, reading, math, gene-environment correlation

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50 ADHD is a childhood-onset neurodevelopmental disorder characterized by symptoms
51 of hyperactivity-impulsiveness and inattention (American Psychological Association, 1994).
52 Early markers of behavioral and emotional dysregulation (e.g., impulsivity, reactivity,
53 regulation difficulties) in infancy and childhood have been associated with increased risk for
54 ADHD (Harold et al, 2013; Frick et al 2018). ADHD is highly heritable, with twin studies
55 estimating the heritability of ADHD to be around 70% (Thapar et al., 2018). Recent
56 molecular genetics studies have also evidenced the genetic underpinnings of ADHD
57 (DeMontis et al., 2018). However, the rearing environment, including parenting and parent-
58 child relationship quality, is also recognized as important with respect to modifying the
59 course of ADHD symptoms in children (Deault, 2010; Johnston & Mash, 2000), even when
60 genetic factors are considered (Thapar et al., 2006; Thapar et al., 2013).

61 A number of studies have found associations between symptoms and diagnosis of
62 ADHD and lower academic attainment in childhood, adolescence, and adulthood (Daley &
63 Birchwood, 2010; Greven et al., 2014; Greven et al., 2011; Plourde et al., 2015; Snowling &
64 Hulme, 2012; Tosto et al., 2015). Specifically, ADHD symptoms have been associated with
65 reduced reading, writing, and math attainment in both clinical and community samples
66 (Daley & Birchwood, 2010). Associated comorbid specific learning problems (e.g., dyslexia,
67 developmental coordination disorder) and poorer cognitive ability that are known to be
68 strongly associated with ADHD may be one route via which ADHD impacts on educational
69 attainment. The pathways and processes through which ADHD symptomology may influence
70 academic achievement are not clear. Genetic and environmental pathways are both
71 hypothesized to play a role in these associations (Hart et al., 2010; Kuntsi et al., 2004;
72 Paloyelis et al., 2010; Willcutt et al., 2007).

73 Parenting behaviors have been associated with child ADHD symptoms (Johnston &
74 Mash, 2001); the most consistent finding is an association with hostile parenting (Harold et
75 al., 2013; Ullsperger, Nigg, & Nikolas, 2016). Recent twin and adoption studies also suggest
76 that behaviours consistent with ADHD symptoms in the early years of life (e.g., child
77 impulsivity/activation) may evoke hostile parenting (Harold et al., 2013; Lifford et al, 2009).
78 Parenting processes, specifically hostile caregiving, also have been associated with reduced
79 academic attainment, including reading and math performance in middle childhood and
80 adolescence (Flouri and Buchanon, 2004; Eamon, 2005; Benner & Kim, 2010; Dotterer et al.,
81 2008; McCoy et al., 2013; Melby & Conger, 1996; Weymouth et al., 2016), with initial
82 evidence suggesting that youth adjustment may play a mediating role (e.g., Wentzel, 1994).
83 However, there is relatively limited examination of the parenting processes that may impact
84 on ADHD outcomes (Deault, 2010). Furthermore, when examining the role of the parent-
85 child relationship on child adjustment, research has primarily focused on the mother-child
86 relationship. The role of fathers is increasingly recognized as an important influence on risk
87 for child psychopathology and academic attainment (e.g., Cabrera et al., 2018). Although
88 evidence suggests that associations between parenting and child outcomes may vary across
89 the mother-child and father-child relationship (Harold et al., 2013; Lifford et al., 2009), this is
90 rarely considered in the context of child ADHD symptoms. Where studies examine maternal
91 and paternal parenting processes in relation to child ADHD symptoms, they have not usually
92 considered the *relative* role of maternal and paternal parenting processes (Lifford, Harold, &
93 Thapar, 2008; Kaiser et al., 2011).

94 A key challenge to establishing family processes as a salient environmental factor for
95 child outcomes is that most family studies rely on genetically related parents and children and
96 therefore it is difficult to disentangle environmental from genetic effects, also known as gene-
97 environment correlations (*r*GE; Plomin, DeFries & Loehlin, 1977; Harold, Leve & Sellers,

2017). The two most frequently examined forms of *r*GE are passive and evocative *r*GE. Passive *r*GE occurs when parents' and children's genes (which are shared) confound the association between family and child level variables (Plomin et al., 1977; Scarr & McCartney 1983). Evocative *r*GE occurs when genetically influenced characteristics in the child evoke particular responses from their environment (Plomin et al., 1977). Environmental main effects are those that cannot be attributed to *r*GE. To disentangle such effects, genetically informative designs, among others (Thapar & Rutter, 2019) are helpful for attempting to identify likely causal processes to target intervention and prevention strategies appropriately. To address this limitation, we utilized a longitudinal parent-offspring adoption design to examine the interplay between genetic susceptibility to child attention problems (birth mother ADHD symptoms) and adoptive parent (mother and father) hostility on child academic outcomes. This design examines the association between adopted children symptoms and characteristics of biologically related parents (the birth parents) and unrelated parents (the adoptive parents). Associations between adopted children and their adoptive parents are assumed to be due to rearing environmental influences, unconfounded by shared genes (i.e., removing the confound of passive *r*GE). In contrast, associations between adopted children and their biological parents are assumed to be attributable to shared genes (in addition to prenatal environmental effects for biological mothers). Employing this research design, we examined associations between adoptive mother and father hostile parenting (at child age 4.5 years), child ADHD symptoms (child age 6 years), and academic attainment (reading and math scores at age 7 years). We also examined associations between genetically influenced (via birth mother symptoms of ADHD) early child behaviors (impulsivity/activation, behavior consonant with early ADHD-type behaviors: Harold et al., 2013) on both maternal and paternal hostility (i.e., evocative *r*GE) as pathways associated with child ADHD symptom continuity, reading, and math achievement. It was hypothesized that biological

123 mother ADHD symptoms would be associated with adopted child impulsivity/activation (at
124 age 4.5 years), which in turn would predict maternal and paternal hostility, indicative of
125 evocative rGE, replicating prior findings for mothers. Additionally, it was hypothesized that
126 maternal and paternal hostile parenting (at age 4.5 years) would predict children's ADHD
127 symptom continuity at age 6 years and that child ADHD symptoms would predict poorer
128 academic achievement.

158 **Methods**

159 **Participants and study design**

160 The current sample comprised 361 linked sets of adopted children, adoptive parents,
161 and biological mothers from the Early Growth and Development Study (EGDS), a
162 longitudinal, multisite US parent-offspring adoption study (Leve et al., 2019). The median
163 lag-time to placement was child age of 2 days ($M = 6.2$; $SD = 12.45$; range = 0-91 days).
164 Participants were representative of the adoptive parent and birth parent populations that
165 completed adoption plans at the participating agencies during the same period. Mean age of
166 birth mothers and birth fathers at the time of placement was 23.84 and 25.61 respectively.
167 The majority of birth parents were Caucasian (birth mother = 75%; birth father = 79%). Birth
168 parents typically had high school education, and household incomes of <\$25,000. The
169 majority of adoptive parents were Caucasian (91%). Mean age of adoptive mothers and
170 adoptive fathers was 36.98 and 37.82 at the time of placement, respectively. Adoptive parents
171 were typically college educated with a median household income of \$100,000. Adoptive
172 parents had been married an average of 12 years. Additional details about the study design
173 and sample description are described elsewhere (Leve et al., 2019; Leve et al., 2007). Ethical
174 approval was provided by the University of Oregon Institutional Review Board (protocol
175 number: 04262013.036). Given our focus on maternal relative to paternal parenting

176 processes, we excluded same-sex couples from analyses, therefore 345 families were
177 available for the current analysis.

178 **Measures**

179 *Birth Mother ADHD symptoms*

180 Birth mother ADHD symptoms were assessed using maternal reports of both the
181 Adult Temperament Questionnaire (ATQ; $\alpha = .73$) at 18 months of child age (Rothbart,
182 Ahadi, & Evans, 2000) and the Barkley Adult ADHD scale ($\alpha = .90$) at child age 4.5 years
183 (Murphy & Adler, 2004). The scales were standardized and then summed into a single
184 measure of mother ADHD symptoms, with good internal consistency ($\alpha = .88$). See Harold et
185 al, 2013 for further details of the measure ($M = .08$, $SD = 1.75$).

186 *Adoptive parent-to-child hostility*

187 Adoptive parent-to-child hostility was assessed using parent self-reports on the Iowa
188 Family Interaction Rating Scales (Melby et al., 1993) at child age 4.5 years. Adoptive
189 mothers and fathers reported on their own hostile behaviors towards their child (maternal
190 reports $M = 11.04$, $SD = 3.08$; paternal reports $M = 10.29$; $SD = 2.89$). Higher scores were
191 indicative of higher hostility (maternal reports $\alpha = .91$; paternal reports: $\alpha = .94$).

192 *Child Impulsivity/Activation*

193 Child Impulsivity/Activation was assessed using adoptive mother report on the
194 Children's Behavior Questionnaire: CBQ (Rothbart, Ahadi, Hershey, & Fisher, 2001) and
195 adoptive mother reports on the Behavioral Inhibition Scale/Behavioral Activation Scale:
196 BIS/BAS (Blair, Peters, & Granger, 2004) at age 4.5 years, as used in Harold et al. (2013) .
197 Each of these subscales were standardized and then summed to create a single indicator of
198 early child impulsivity/ activation ($M = .02$, $SD = 3.19$).

199 *Child ADHD symptoms*

200 Child ADHD symptoms were assessed using adoptive mother and father reports on
201 the Conner's Abbreviated Parent Questionnaire, a 10-item scale regarding hyperactivity and
202 inattentive behaviors (Conners, 1997) at child age 6 years. A composite score of mother and
203 father reports was created ($r = .71$, $p < .001$), using a mean score of mother and father reports
204 ($M = 8.09$; $SD = 4.93$).

205 *Child academic achievement*

206 Child academic achievement was measured at age 7 years using z-scores of reading
207 ($M = .53$, $SD = 1.00$) and math fluency ($M = -.02$; $SD = 1.04$) subscales from the Woodcock-
208 Johnson III achievement test (Woodcock, McGrew, & Mather, 2001), which assessed reading
209 and math skills. Previous research suggests that the reliability for both reading and math
210 fluency show strong reliabilities of .90 (Schrank & McGrew, 2001). Scales were reverse
211 scored so that higher scores indicated greater levels of difficulty in attaining competence (i.e.,
212 poorer academic attainment).

213 *Covariates*

214 Earlier levels of academic achievement were assessed using the Test of Preschool
215 Early Literacy test (TOPEL) at age 4.5 years (Lonigan, Wagner, & Tokesen, 2007). The
216 present study combined two subscales (Print Knowledge and Definitional Vocabulary) to
217 create a composite score of children's emergent literacy skills. Previous research suggests
218 internal consistency for the TOPEL index is .96 (Lonigan et al., 2007).

219 To control for similarities between birth and adoptive families resulting from contact
220 and knowledge between birth parents and children, secondary analyses considered the
221 association with the level of openness in the adoption (Ge et al., 2008). We also examined
222 associations with prenatal complications to attempt to disentangle genetic influences from
223 prenatal environment (Marceau et al., 2016). However, neither of these covariates was

224 significantly associated with any variables in the model and therefore neither was considered
225 further in analyses.

226 **Analyses**

227 Path analysis was used to examine the role of biological mother ADHD as a predictor
228 of adopted children's early impulsivity/activation behaviors, and to examine associations
229 between child impulsivity/activation and both adoptive mother and father hostility, thereby
230 allowing examination of evocative *r*GE processes. It simultaneously allowed the examination
231 of processes through which parental hostility and child ADHD symptoms may be associated
232 with later child academic outcomes (reading and math). The full theoretical model is shown
233 in Figure 1. Analyses were conducted using LISREL (Joreskog & Sorbom, 2006). Fit
234 statistics were used to examine model fit using the chi square, Confirmatory Fit Index (CFI),
235 and the Root Mean Square Error of Approximation (RMSEA). Good model fit is indicated by
236 a non-significant chi square test, $CFI \geq .98$, $TLI \geq .80$, and $RMSEA \leq .05$ (Kline, 2005).

237 Missing data ranged from 21% (72/345 for math achievement at age 7) to 34%
238 (117/345 father hostility at age 4.5 years). The Little's test indicated that data were missing
239 completely at random ($\chi^2(253) = 281.54, p = .105$). Analyses were conducted using Full
240 Information Maximum Likelihood estimation, which makes use of all available data,
241 therefore 345 cases were included in the current analyses.

242 **Results**

243 **Correlational analyses**

244 As previously demonstrated (Harold et al., 2013), birth mother ADHD symptoms
245 were correlated with early child impulsivity/activation ($r = .18, p < .001$); see Table 1. In
246 addition, early child impulsivity was correlated with maternal and paternal hostility toward
247 the child ($r = .20, p < .001$; $r = .21, p < .001$ respectively), as well as later child ADHD
248 symptoms ($r = .42, p < .001$), but not with later reading ($r = .09, p = .184$) or math scores ($r =$

249 .05, $p > .250$). Maternal and paternal hostility toward the child were correlated with each other
 250 ($r = .33, p < .001$), and with later levels of child ADHD symptoms ($r = .27, p < .001$; $r = .26, p$
 251 $< .001$ respectively). Parent hostility was not correlated with child reading (maternal hostility:
 252 $r = .10, p = .138$; paternal hostility: $r = .12, p = .107$) or math scores (maternal hostility: $r = -$
 253 $.01, p > .250$; paternal hostility: $r = .08, p = .245$). Child ADHD symptoms were correlated
 254 with lower math ($r = .22, p < .001$) but not reading achievement ($r = .11, p = .118$).

255 **Path analysis**

256 Figure 1 shows the full model. Fit indices indicated a satisfactory fit to the data ($\chi^2 (9)$
 257 $= 26.66, p = .002$; CFI = .96; TLI = .87; RMSEA = .07 (.04, .10), SRMR = .05).

258 [Figure 1]

259 Birth mother ADHD symptoms predicted child early impulsivity/activation ($\beta = .17, p$
 260 $= .005$). Child impulsivity/activation (at age 4.5 years) in turn predicted both adoptive mother
 261 and father hostility ($\beta = .20, p = .002$; $\beta = .21, p = .001$ respectively), as well as child ADHD
 262 symptoms at age 6 years ($\beta = .35, p < .001$). Adoptive mother hostility predicted later child
 263 ADHD symptoms ($\beta = .13, p = .015$), as did adoptive father hostility ($\beta = .16, p = .006$).
 264 Neither maternal hostility nor father hostility directly predicted later poorer child math ($\beta = -$
 265 $.10, p = .093$; $\beta = -.03, p > .250$) or reading ($\beta = .03, p > .250$; $\beta = .04, p > .250$) achievement.
 266 However, there was a significant indirect effect of maternal and paternal hostility on later
 267 math aptitude via the continuity in child ADHD symptoms (both $\beta = .03, p < .05$). Early levels
 268 of poorer reading in the child predicted later poorer math ($\beta = .29, p < .001$) and reading ($\beta =$
 269 $.46, p < .001$) achievement. Child symptoms of ADHD predicted later poorer child math
 270 achievement ($\beta = .16, p = .007$), but not reading ($\beta = -.03, p > .250$). There was a significant
 271 indirect effect of early child impulsivity/activation on later child poorer math ability via child
 272 ADHD symptoms ($\beta = .05, p < .05$). Additional analyses compared this full model to a model
 273 which set non-significant associations to zero. A non-significant chi-square difference test

274 ($\Delta df = 5$; $\Delta\chi^2 = 6.16$, $p = .292$) suggested that these non-significant associations did not
275 substantially contribute to the model indicating that a more parsimonious model can be
276 accepted.

277 Stacked modelling procedures examined whether pathways from child impulsivity to
278 maternal and paternal hostility differed in magnitude. Constraining the path from child
279 impulsivity to adoptive mother hostility and to adoptive father hostility to be equal did not
280 result in a significantly worse model fit ($\Delta df = 1$; $\Delta\chi^2 = 0.98$, $p > .05$), suggesting that the
281 association between early child impulsivity on father hostility was not significantly different
282 than its association with mother hostility. We also examined whether pathways differed in
283 magnitude between maternal and paternal hostility to child ADHD symptoms. Constraining
284 the path from adoptive mother hostility and father hostility to child ADHD symptoms to be
285 equal did not result in a significantly worse model fit ($\Delta df = 1$; $\Delta\chi^2 = .78$, $p > .05$), suggesting
286 that the associations between maternal and paternal hostility on child ADHD symptoms was
287 not significantly different.

288 Discussion

289 The current study examined the interplay between genetic susceptibility and both
290 maternal and paternal hostility in the persistence of ADHD symptoms and academic
291 achievement in childhood with child impulsivity/activation as an early marker of risk for
292 ADHD symptoms (Frick et al., 2018). We examined associations between early child
293 attributes (impulsivity/activation), parent hostility and academic attainment (specifically
294 math) via child ADHD symptoms in a research design that removes the confound of passive
295 rGE (adoptive parents and their adopted children do not share genes). Our findings first
296 replicate previous findings in this sample suggesting that genetically influenced (measured by
297 birth mother ADHD symptoms) early child impulsivity/activation evoke adoptive mother
298 hostility (Harold et al., 2013). We also extended findings, demonstrating evocative effects on

299 adoptive father hostility. Second, child ADHD symptoms were associated with later
300 academic attainment. We found that child ADHD symptoms were specifically associated
301 with lower math but not reading attainment. This is surprising given that ADHD and reading
302 ability are known to be strongly associated (e.g., Willcutt et al., 2007; Snowling & Hulme,
303 2012; Adams & Snowling, 2001), with evidence suggesting shared genetic liability (Plourde
304 et al., 2015; Stergiakouli et al., 2017; Barry, Lyman, & Klinger, 2002; Daley & Birchwood,
305 2010). The null finding on ADHD symptoms and reading is in contrast to previous research
306 that finds associations between ADHD and reading/literacy (Rabiner, Coie, & Conduct
307 Problems Prevention Group, 2000; Frazier, Youngstrom, Glutting & Watkins, 2007). There
308 are several explanations for why the current study found no association between child ADHD
309 symptoms and reading. First, the current sample consists of primarily middle-class, college-
310 educated adoptive parents and evidence suggest that parents with higher educational
311 qualifications read to their children more frequently (Kuo, Franke et al, 2004). Second,
312 parents place an increased importance on literacy learning and spend more time supporting
313 children's reading compared to math (Cannon & Ginsberg, 2008). This results in math being
314 a relatively novel subject at school entry. Third, we were able to control for prior reading
315 abilities using the TOPEL, but we did not have an earlier measure of children's math
316 abilities. This methodological artefact may have resulted in more available variance to predict
317 in math as compared to reading achievement. Together, these three factors could have
318 contributed to reading being less influenced by ADHD symptoms in the current study.
319 Nevertheless, these findings have implications for the understanding of child development
320 and long-term math attainment where there are indicators of signs of early ADHD.

321 We were able to examine pathways implicated in the development of ADHD
322 symptomatology and subsequent academic attainment in a study that removed the confound
323 of passive *r*GE. Any associations between adoptive parent characteristics and adopted

324 children cannot be explained by common genes, and likely reflect environmental
325 associations, providing evidence of the importance of environmental factors, specifically
326 parent hostility for child ADHD symptom continuity, and later math attainment. In line with
327 previous research, we found evidence of an association between child ADHD symptoms and
328 maternal hostility (e.g., Harold et al., 2013); however, we extend current understanding,
329 demonstrating the importance of the relative role of father hostility for child ADHD symptom
330 persistence. The current study suggests that the associations between parental hostility and
331 later child ADHD symptoms do not differ in magnitude for mothers or fathers. This has
332 implications for recognizing the potential of father involvement in interventions. In addition,
333 we were also able to examine evocative *rGE*, specifically examining genetically informed
334 attributes of the child (impulsivity/activation) on both maternal and paternal parenting
335 processes. Consistent with previous research examining evocative *rGE*, early
336 impulsivity/activation evoked hostile parenting in mothers with maternal hostility in turn
337 predicting later ADHD symptoms (Harold et al., 2013). We found similar processes for
338 paternal parenting, with child impulsivity/activation evoking hostile paternal parenting,
339 which in turn predicted later child ADHD symptoms. These findings have implications for
340 the understanding of child development, with both genetic (measured by birth mother ADHD
341 symptoms) and environmental processes (adoptive mother and father hostile parenting)
342 predicting child outcomes (child ADHD symptoms and later math attainment).

343 **Limitations and future directions**

344 It is important to interpret these findings in the light of limitations. First, potential
345 bidirectional effects between early impulsivity/activation and parent hostility may be present,
346 however, in the current study, early child impulsivity/activation was measured at the same
347 period as adoptive parent hostility. However, findings from the current study are consistent
348 with a number of studies that have found evidence of evocative *rGE* for parenting behaviors

349 using molecular genetic (Elam et al., 2016) and family-based genetic research designs (Elam
350 et al., 2014; Harold et al., 2013). Further research is needed to examine the direction of
351 effects between early impulsivity and parenting processes. Second, birth father ADHD
352 symptoms were not included in the measure of the child's inherited risk because of limited
353 data available from birth fathers. ADHD diagnoses are more common in males than females
354 (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). We also relied on adult self-reports
355 of ADHD symptoms rather than diagnoses of ADHD in birth mothers as an index of genetic
356 risk for impulsivity in childhood. Together, these factors may have underestimated (or
357 overestimated) the magnitude of the association between birth parent ADHD symptoms and
358 child impulsivity. Third, although the findings in the current study are consistent with Harold
359 and colleagues (2013) which examined associations between adoptive mother hostility and
360 child ADHD symptoms using a cross-rater approach, it is important to note that, for some
361 measures there was a reliance on a single reporter (adoptive mother). Where available, we
362 utilized multiple informants to reduce the potential risk for shared method variance, for
363 example, both mother and father reports of child ADHD symptoms were used. We also used
364 standardized assessments of child reading and math achievement. However, future research
365 should consider alternative approaches to assessing child achievement, symptoms, and
366 parenting (e.g., teacher reports or clinical assessments of child ADHD symptoms;
367 observational parenting assessments). Fourth, in the current study, child ADHD symptom
368 levels were relatively low and therefore do not necessarily constitute mental health
369 'difficulties'. However, ADHD can be conceptualized as a continuum: both in terms of
370 associated outcomes, and because heritability estimates have been shown to be similar across
371 the continuum as well as in 'high scores' (Stergiakouli et al., 2015). Therefore, non-clinical
372 samples can be useful to examine the etiology of ADHD and related outcomes. Fifth, whilst
373 both inattentive and hyperactive-impulsive symptoms of ADHD have been evidenced to

374 contribute to the prediction of reading and math, evidence suggests that inattentiveness may
375 be a significantly stronger predictor of reading and math than hyperactive-impulsive
376 symptoms of ADHD (e.g., Greven et al., 2011; Greven et al., 2014). Therefore, it is possible
377 that different domains of ADHD may differentially impact on child reading and math
378 outcomes. However, in the current study, child ADHD symptoms were assessed using the
379 Conners' Parent Rating Scale – Revised, a unidimensional measure of ADHD symptoms.
380 Therefore it was not possible to examine these domains separately.

381 Finally, ADHD commonly co-occurs with other neurodevelopmental problems (e.g.
382 language, motor co-ordination difficulties; DuPaul et al. 2013; Martin et al., 2015) as well as
383 mental health problems (e.g. conduct disorder, anxiety; Jensen et al., 1997; Thapar & van
384 Goozen, 2018; Schatz & Rostain, 2006) so we cannot rule out that the link between ADHD
385 and parent hostility and its links with math attainment is explained by these factors.

386 To further understand the pathways and processes influencing the developmental
387 course of ADHD symptomatology and academic outcomes, future research should consider
388 additional mediators and moderators of the pathways to child ADHD symptoms and
389 academic outcomes. For example, additional aspects of parenting that were included in the
390 current study but not in the current report (e.g., monitoring, engagement) could also be
391 important for the development of child mental health difficulties (including symptoms of
392 ADHD) and later academic functioning (Daley & Birchwood, 2010; Rogers et al., 2009a,
393 2009b). In addition, parent academic ability is associated with child academic ability, with
394 the association due to both genetic and environmental influences (Friend et al., 2009). Future
395 research should examine how adoptive and birth parent measures of academic ability impact
396 on these processes. In addition, adoptive parent mental health may be important to consider:
397 parental symptoms of ADHD have been associated with aspects of parenting (Harvey,
398 Danforth, McKee, Ulaszek, & Friedman, 2003), as have symptoms of antisocial behaviour

399 (Harold et al., 2012; Harold et al., 2011). Therefore, it will be important for future research to
400 examine how other aspects of parental mental health affect the processes through which
401 children develop psychopathology, and difficulties in reading and math achievement.

402 Notwithstanding these caveats, results provide evidence of an environmental effect of
403 adoptive father-to-child and mother-to-child effects on child ADHD symptom continuity, and
404 later math ability in children to whom they were not genetically related (i.e., removing
405 passive *r*GE). In addition, adoptive mother-to-child *and* father-to-child hostility was evoked
406 by genetically informed child impulsivity/activation which also predicted child ADHD
407 symptoms. The current data help advance understanding of the interplay between genetic
408 susceptibility and environmental risk in the development of ADHD symptoms and academic
409 achievement in childhood. Genetic risk for ADHD symptoms served as a risk factor for
410 disrupted mother-to-child and father-to-child relationships. These findings suggest a cascade
411 of risk through which genetic risk for ADHD symptoms influence later math achievement,
412 with indirect effects via both mother and father hostility contributing to the developmental
413 course of ADHD. Early interventions targeting hostility in *both* parents may be important,
414 especially where children have high levels of impulsivity, not for treating ADHD per se (as
415 per NICE guidance) but for influencing its developmental course and associated outcomes
416 and attainment. There is evidence that parenting programs can be an effective intervention for
417 those with ADHD who have comorbid conduct disorder (NICE 2018), which is known to
418 also be associated with learning problems (Erskine et al., 2016). Recent review evidence
419 suggests that parenting interventions targeting ADHD alone (without comorbid presence of
420 conduct disorder) do not appear efficacious (Lange et al, 2018; Daley et al, 2018; see meta-
421 analysis Sonuga-Barke et al., 2013) but may help other outcomes. Notwithstanding these
422 observations, the present results are among the very first in this area to highlight the role of
423 maternal and paternal parenting as significant in relation to ADHD symptoms - a potential

424 consideration for future intervention program design and development. In addition, child
425 ADHD symptoms were associated with later academic ability, specifically math ability.
426 Interventions that assist with the development of math skills, particularly those with high
427 levels of early manifestations of ADHD symptoms, may also be particularly beneficial.

428 Author contributions

429 Harold, Leve, and Sellers developed the study research question. Sellers performed the data
430 analysis under the supervision of Harold and Leve. Sellers and Harold contributed to the
431 interpretation of the study findings. Sellers drafted the manuscript. Reiss, Leve, Neiderhiser,
432 Shaw and Natsuaki designed and carried out the original study and data collection activities
433 All authors provided critical revisions, and all authors approved the final version of the
434 manuscript for submission.

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