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

3   Sellers, R.,[1,2] Harold, G.T.,[1,2,3] Smith, A. F.,[1] Neiderhiser, J.M.,[4] Reiss, D.,[5] Shaw, D.,[6]

4   Natsuaki, M.N.,[7] Thapar, A.,[2] Leve, L.D.[8]

5   [1] School of Psychology, Andrew and Virginia Rudd Centre for Adoption Research and

6   Practice, University of Sussex, Brighton, UK

7   [2] Institute of Psychological Medicine and Clinical Neurosciences, School of Medicine, MRC

8   Centre for Neuropsychiatric Genetics and Genomics, Cardiff University, Cardiff, UK

9   [3] School of Psychology, Trinity College Dublin, The University of Dublin, Ireland

10   [4] Department of Psychology, The Pennsylvania State University, University Park, PA, USA

11   [5] Yale Child Study Center, New Haven, CT, USA

12   [6] University of Pittsburgh, Pittsburgh, PA, USA

13   [7] University of California, Riverside, CA, USA

14   [8] Prevention Science Institute, University of Oregon, Eugene, USA

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16   **Conflict of interests:** None

17   **Word count:** 4381 (excluding references & abstract)

18   **Corresponding Author:** Gordon T Harold, School of Psychology, Andrew and Virginia

19   Rudd Centre for Adoption Research and Practice, University of Sussex, Brighton.

20   *Phone*: +44 (0)1273 877102

21   E*mail*: G.Harold@sussex.ac.uk

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Abstract

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

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

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

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

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

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

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

A number of studies have found associations between symptoms and diagnosis of ADHD and lower academic attainment in childhood, adolescence, and adulthood (Daley & Birchwood, 2010; Greven et al., 2014; Greven et al., 2011; Plourde et al., 2015; Snowling & Hulme, 2012; Tosto et al., 2015). Specifically, ADHD symptoms have been associated with reduced reading, writing, and math attainment in both clinical and community samples (Daley & Birchwood, 2010). Associated comorbid specific learning problems (e.g., dyslexia, developmental coordination disorder) and poorer cognitive ability that are known to be strongly associated with ADHD may be one route via which ADHD impacts on educational attainment. The pathways and processes through which ADHD symptomology may influence academic achievement are not clear. Genetic and environmental pathways are both hypothesized to play a role in these associations (Hart et al., 2010; Kuntsi et al., 2004; 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 (rGE; Plomin, DeFries & Loehlin, 1977; Harold, Leve & Sellers,

98   2017). The two most frequently examined forms of *r*GE are passive and evocative *r*GE.

99   Passive *r*GE occurs when parents' and children's genes (which are shared) confound the

100   association between family and child level variables (Plomin et al., 1977; Scarr & McCartney

101   1983). Evocative *r*GE occurs when genetically influenced characteristics in the child evoke

102   particular responses from their environment (Plomin et al., 1977). Environmental main

103   effects are those that cannot be attributed to *r*GE. To disentangle such effects, genetically

104   informative designs, among others (Thapar & Rutter, 2019) are helpful for attempting to

105   identify likely causal processes to target intervention and prevention strategies appropriately.

106   To address this limitation, we utilized a longitudinal parent-offspring adoption design to

107   examine the interplay between genetic susceptibility to child attention problems (birth mother

108   ADHD symptoms) and adoptive parent (mother and father) hostility on child academic

109   outcomes. This design examines the association between adopted children symptoms and

110   characteristics of biologically related parents (the birth parents) and unrelated parents (the

111   adoptive parents). Associations between adopted children and their adoptive parents are

112   assumed to be due to rearing environmental influences, unconfounded by shared genes (i.e.,

113   removing the confound of passive *r*GE). In contrast, associations between adopted children

114   and their biological parents are assumed to be attributable to shared genes (in addition to

115   prenatal environmental effects for biological mothers). Employing this research design, we

116   examined associations between adoptive mother and father hostile parenting (at child age 4.5

117   years), child ADHD symptoms (child age 6 years), and academic attainment (reading and

118   math scores at age 7 years). We also examined associations between genetically influenced

119   (via birth mother symptoms of ADHD) early child behaviors (impulsivity/activation,

120   behavior consonant with early ADHD-type behaviors: Harold et al., 2013) on both maternal

121   and paternal hostility (i.e., evocative *r*GE) as pathways associated with child ADHD

122   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.

Measures

179   *Birth Mother ADHD symptoms*

180   Birth mother ADHD symptoms were assessed using maternal reports of both the

181   Adult Temperament Questionnaire (ATQ; α = .73) at 18 months of child age (Rothbart,

182   Ahadi, & Evans, 2000) and the Barkley Adult ADHD scale (α = .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 (α = .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 α = .91; paternal reports: α = .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, & Togesen, 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.

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 rGE 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 (χ^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.

Results

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 (χ^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 (β = .17, *p*

260 = .005). Child impulsivity/activation (at age 4.5 years) in turn predicted both adoptive mother

261 and father hostility (β =.20, *p* = .002; β = .21, *p* = .001 respectively), as well as child ADHD

262 symptoms at age 6 years (β = .35, *p* <.001). Adoptive mother hostility predicted later child

263 ADHD symptoms (β = .13, *p* = .015), as did adoptive father hostility (β = .16, *p* = .006).

264 Neither maternal hostility nor father hostility directly predicted later poorer child math (β =-

265 .10, *p* = .093; β =-.03, *p* >.250) or reading (β = .03, *p* >.250; β = .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 β = .03, *p* <.05). Early levels

268 of poorer reading in the child predicted later poorer math (β = .29, *p* <.001) and reading (β =

269 .46, *p* <.001) achievement. Child symptoms of ADHD predicted later poorer child math

270 achievement (β = .16, *p* = .007), but not reading (β = -.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 (β = .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 (Δdf = 5; $\Delta\chi2$ = 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 (Δdf = 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 (Δdf = 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 rGE. 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 at., 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.

Author contributions

428

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.

435

Acknowledgements

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