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ORIGINAL RESEARCH

Twins' Rearing Environment Similarity and Childhood Externalizing Disorders: A Test of the Equal Environments Assumption

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Abstract The equal environments assumption (EEA) of the twin method posits that environmental influences that are etiologically relevant to a given phenotype are no more likely to be shared by monozygotic (MZ) than dizygotic (DZ) twin pairs. One method of testing the EEA is to evaluate whether increased rearing environment similarity in MZ twin pairs compared to DZ twin pairs is related to increased phenotypic correlation. In a sample of 885 twin pairs, we contrasted similarity in rearing environment between MZ and DZ twin pairs, examined the correlation between similarity in rearing environment and conduct disorder (CD), oppositional-defiant disorder (ODD), inattention, and hyperactivity-impulsivity symptom dimensions, and tested the effects of differential similarity in rearing environments between MZ and DZ twin pairs by testing whether rearing environment similarity moderated the correlations for the externalizing symptom dimensions. We found that MZ twins experienced substantially more similar rearing environments than DZ twins, but that there was little evidence that MZ and DZ correlations for the externalizing symptom dimensions varied by rearing environment similarity. Thus, these results constitute evidence for the validity of the EEA for childhood externalizing disorders.

Keywords Equal environments assumption · Childhood externalizing psychopathlogy · Rearing environment similarity

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Introduction

A critical assumption of traditional twin research is the equal environments assumption (EEA), which posits that the environmental factors that are etiologically relevant to a given phenotype are no more likely to be shared by monozygotic (MZ) twin pairs than dizygotic (DZ) twin pairs. This assumption allows researchers to infer that any differences in the magnitude of correlation on a trait between MZ and DZ twin pairs are due to differences in their genetic similarity, rather than a combination of genetic and environmental factors. The validity of this assumption has been a concern raised by critics of twin methods (e.g., Lewontin et al. 1984; Wyatt and Midkiff 2006) due to the fact that MZ twins are more likely to share physical features which lead to more similar treatment, share friends, be in the same class in school, and dress alike, among other aspects of environmental similarity (e.g., Loehlin and Nichols 1976). Nevertheless, an important omission in such critiques is that the presence of higher levels of physical and environmental similarity in MZ twins than in DZ twins is a violation of the EEA *only* if these aspects of the environment are etiologically relevant to the phenotype of interest. Twin researchers have used five methods to test the validity of the EEA across a variety of phenotypes (reviewed by Kendler et al. 1993).

One method of testing the EEA assumes that physical resemblance between twins leads to similarity of treatment by the social environment. If this is the case, physical similarity of twin pairs should be correlated with trait similarity after controlling for zygosity. Several studies have used this method to test the EEA for a variety of traits, including intelligence and personality (Matheny et al. 1976; Plomin et al. 1976), schizophrenia (Kendler 1983), eating attitudes and behaviors (Klump et al. 2000), major depressive disorder (MDD), generalized anxiety disorder

(GAD), phobias, alcoholism, and bulimia (Hettema et al. 1995). The majority of the evidence supports the validity of the EEA across traits and disorders, though one study found a significant correlation between trait similarity and physical similarity for bulimia (Hettema et al. 1995).

A second method of testing the EEA attempts to determine whether increased environmental similarity in MZ twins is due to the behavior of the twins themselves or is initiated by other individuals. In an observational study of parent–child interactions, Lytton (1977) found that the excess similarity in parental treatment of MZ twins compared to DZ twins was due to parental behavior in response to twin behavior, indicating that the EEA was not violated. Unfortunately, this study is the only investigation of the EEA using this method, perhaps due to the difficulty of observational studies.

A third method of testing the EEA is to compare the similarity of parent reports of their treatment of their twin children to the twins' trait similarity. Loehlin and Nichols (1976) used this method among others in their seminal study of adolescent twins and found support for the validity of the EEA, such that similarity of parental treatment was unrelated to vocational interests, personality, or cognitive ability. Further, researchers have used this method to find support for the EEA for traits or disorders such as MDD, GAD, phobia, alcoholism (Kendler et al. 1994; Kendler and Gardner 1998), nicotine dependence, and bulimia (Kendler and Gardner 1998).

A fourth method of testing the EEA compares the impact of twins' actual zygosity versus perceived zygosity on trait similarity. Occasionally, twins and parents of twins are misinformed about their twins' zygosity for a variety of reasons. If twins' families, social environments, or the twins themselves expect MZ twins to be more similar than DZ twins and this expectation influences trait similarity in the twins, then the EEA has been violated. Researchers have used this method to test the EEA for traits such as height, weight, academic achievement intelligence, attitudes, hyperactivity, and personality (Scarr 1968; Munsinger and Douglass 1976; Matheny 1979; Scarr and Carter-Saltzman 1979; Goodman and Stevenson 1989; Conley et al. 2013), as well as psychiatric disorders such as MDD, GAD, Attention-Deficit Hyperactivity Disorder (ADHD), phobia, bulimia, and alcoholism, nicotine dependence, and posttraumatic stress disorder (Kendler et al. 1993; Xian et al. 2000; Conley et al. 2013), and found that perceived zygosity had little influence on twins' trait similarity. Thus, studies using this method have largely supported the validity of the EEA.

The fifth and most commonly used method of testing the EEA is to evaluate the association between reported similarity of aspects of the twins' environment and trait similarity. As noted earlier, some features of childhood and adult environments, such as sharing friends, sharing a room, dressing alike, and being in closer contact as adults (Loehlin and Nichols 1976; Kendler et al. 1986), tend to be more similar for MZ than for DZ twins. If similarity in these aspects of the environment leads to greater trait similarity then this would constitute a violation of the EEA. This method of evaluating the validity of the EEA also originated from Loehlin and Nichols (1976), who devised a brief questionnaire administered to parents that assesses observable similarities in the twin environment. This measure consists of the following questions: 'were the twins dressed alike?', 'as children did the twins tend to play together or separately?', 'as adolescents did the twins tend to spend time together?', 'did the twins have the same teacher at school?', 'did he twins sleep in the same room or separate rooms?', 'in raising the twins [how similarly have you treated them]?', and 'did the twins have the same friends?' (Loehlin and Nichols 1976). In their original study, Loehlin and Nichols (1976) found nonsignificant correlations between twin rearing environment similarity and trait similarity for personality or intellectual ability in adolescence. Following from this work, many researchers have tested the EEA using the Loehlin-Nichols measure or slightly modified versions thereof.

The majority of the evidence from studies that estimated the effects of environmental similarity on MZ and DZ correlations has supported the validity of the EEA across a wide variety of phenotypes. For example, no consistent relation has been found between childhood or adult environmental similarity and twin resemblance for social attitudes (Martin et al. 1986), alcohol consumption and dependence (Heath et al. 1989; Kendler et al. 1993; Kendler and Gardner 1998), self-reported symptoms of anxiety and depression (Morris-Yates et al. 1990; Kendler et al. 1986), diagnoses of MDD and GAD (Kendler et al. 1993; Kendler and Gardner 1998), phobias (Kendler et al. 1993), personality (Borkenau et al. 2002), bulimia (Kendler et al. 1993; Sullivan et al. 1998), separation anxiety, ADHD, conduct disorder (CD), Oppositional-Defiant Disorder (ODD) (Cronk et al. 2002), physical activity (Eriksson et al. 2006), or aggression (Derks et al. 2006). Some of these studies (e.g., Kendler et al. 1993; Sullivan et al. 1998; Cronk et al. 2002) also directly tested whether controlling for rearing environment similarity provided evidence for upwardly biased estimates of heritability or downwardly biased estimates of shared environmental influences obtained in twin studies, as would be predicted if the EEA were not valid. These studies found no evidence of bias in either case, again supporting the validity of the EEA. Further, a similar method has been used to support the validity of the EEA for Children of Twins designs, finding that higher levels of cotwin contact among MZ twins' children did not predict externalizing behavior in the children (Koenig et al. 2010). It is worth noting that in contrast, a few studies (Clifford et al. 1984; Kaprio et al. 1990) did find that the similarity of the adult environment influenced psychiatric symptoms or personality.

Though the validity of the EEA has been tested in adults somewhat extensively, as reviewed above, there have been only a few studies that have examined the validity of the EEA for twin studies of childhood psychopathology. It may be the case that rearing environment similarity does not have an effect on twin similarity for adult psychiatric disorders, but this may not be true for childhood psychopathology. In fact, only one study has examined the relation of rearing environment similarity of child and adolescent twins to their similarity for psychopathology (Cronk et al. 2002). Though these analyses were conducted in a relatively large sample of 1,093 twin pairs, only female twins were included, only three items were used to assess environmental similarity (sharing friends, dressing alike, and being in the same classes), and inattention and hyperactivity-impulsivity symptoms were not separated. Given that other aspects of rearing environment similarity may be relevant and that the etiology of psychopathology has been demonstrated to differ across sex (e.g., Eley et al. 1999; Rhee and Waldman 2002; Saudino et al. 2005) and across ADHD symptom dimensions (e.g., Greven et al. 2011; Larsson et al. 2013; Rhee et al. 1999), further investigation is warranted.

In the present study we tested the validity of the EEA for childhood externalizing disorders using the Loehlin and Nichols (1976) measure of rearing environment similarity in a sample of child and adolescent twins. We used male and female participants, *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR; American Psychiatric Association 2000) ODD, CD, ADHD Inattention, and ADHD hyperactivity-impulsivity psychiatric symptom dimensions, and all 7 questions from the Loehlin-Nichols measure in order to provide additional evidence to assess whether the EEA is valid for childhood psychopathology beyond the extant literature (i.e., Cronk et al. 2002). We first evaluated differences between MZ and DZ twins for each item and the mean across items on the environmental similarity measure. We hypothesized that MZ twins would be more similar than DZ twins for each item. We then calculated the zero-order correlations between MZ and DZ twins for the 4 symptom dimensions. Finally, we tested whether rearing environment similarity moderated the MZ and DZ twin correlations for the externalizing symptom dimensions to determine the degree to which the EEA is valid for childhood externalizing psychopathology.

Method

Sample

The sample consisted of 885 twin pairs born in Georgia between 1980 and 1991. Detailed information regarding sample recruitment and participant response rate has been described previously (Ficks et al. 2013). Table 1 shows the distribution of zygosity, sex, age, and ethnicity within the sample.

Table 1 Basic demographics and the means and standard deviations of externalizing dimensions

Mean age (SD)	10.6 (3.2)
% Male	49 %
Ethnicity	82 % Caucasian, 11 % African American
Zygosity	54 % DZ, 46 % MZ
DZ pair genders	26 % Male, 26 % female, 48 % opposite-sex
Mean ODD symptoms (SD)	MZ: .79 (.75), DZ: .88 (.81)
Mean CD symptoms (SD)	MZ: .14 (.22), DZ: .15 (.23)
Mean inattention symptoms (SD)	MZ: .75 (.91), DZ: .83 (.97)
Mean Hyp/Imp symptoms (SD)	MZ: .90 (1.10), DZ: 1.01 (1.17)

Measures

Zygosity determination

Twin pair zygosity was determined via parental responses to a mailed questionnaire on eight items regarding the twins' physical similarity (e.g., "Is it hard for strangers to tell your twins apart based on their physical appearance?"). Each response was coded as 1 or 0 to indicate similarity of difference within the dyad, respectively. One zygosity score per twin pair was obtained by computing the mean of all 8 items. Mean scores less than .5 were considered indicated of DZ status, and scores greater than or equal to .5 were considered indicative of MZ status, given that a score of .5 appeared to be the optimal threshold for separating the zygosity distributions for MZs and DZs. Zygosity determination via parent ratings of such items has been shown to result in a cost-effective yet highly accurate determination of twin zygosity (i.e., 96–99 % correct assignment) when compared with DNA-based methods (Jackson et al. 2001; Spitz et al. 1996).

Rearing environmental similarity

Twin similarity in childhood rearing environments was assessed using parental responses to the 7 items developed by Loehlin and Nichols (1976). Parents were asked to respond on a 5 point Likert scale to how well each item described their twins' childhood experiences between 0 ("not at all") and 4 ("very well"). The items included "They have dressed alike," "They have played together,"

"They have spent a lot of time together," "They have had the same teachers," "They have slept in the same room," "They have been treated alike by parents," and "They have had the same friends."

Externalizing symptom dimensions

Mothers rated their children's psychopathology by responding to the Emory Combined Rating Scale (ECRS) (Waldman et al. 1998), a parent-report questionnaire assessing symptoms of the major *DSM* childhood psychiatric disorders, including ADHD (inattention and hyperactive/impulsive symptom dimensions), ODD, CD, and the full range of internalizing disorders. Each item corresponds to a *DSM-IV-TR* symptom as rated on a 0–4 scale, with 0 meaning *not at all representative of the child* and 4 meaning *very much representative of the child*. Scores were averaged across items resulting in continuous symptom dimensions for Inattention, Hyperactivity-Impulsivity, ODD, and CD. Each of the externalizing symptom dimensions demonstrated high reliability, with Cronbach's α's of .95, .89, .91, and .82 for inattention, hyperactivity-impulsivity, ODD, and CD, respectively.

Analyses

Comparisons of rearing environment similarity between MZ and DZ twins

The mean score for each environmental similarity item as well as the mean of all 7 items was compared across MZ, same-sex DZ, and opposite-sex DZ twin pairs using a set of ANOVAs that incorporated two a priori orthogonal contrasts, the first comparing the similarity of MZs and DZs and the second comparing the similarity of same-sex DZs and opposite-sex DZs. Twins' sex and age were used as covariates in these analyses.

Twin correlations for externalizing symptom dimensions

In order to evaluate the degree of resemblance between twins on the childhood externalizing symptom dimensions, we calculated zero-order correlations between MZ and DZ twins for Inattention, Hyperactivity-Impulsivity, ODD, and CD.

Differential similarity in rearing environment as a moderator of twin correlations for the externalizing symptom dimensions

Finally, we used multiple regression to test whether rearing environment similarity moderated the MZ and DZ twin correlations for the externalizing symptom dimensions by regressing twin 2's symptom scores on twin 1's symptom scores, rearing environment similarity, and the product of twin 1's symptom scores and rearing environment similarity, thus providing an evaluation of the validity of the EEA or the degree of violation thereof. Due to considerable skewness and kurtosis of CD symptoms, analyses of twin resemblance for CD and its moderation by rearing environment similarity were conducted using Generalized Linear Models in which CD symptoms were modeled as ordinal.

Results

Rearing environmental similarity comparisons

Figure 1 shows differences across MZ, same-sex DZ, and opposite-sex DZ twin pairs in the average similarity for each of the 7 Loehlin and Nichols (1976) rearing environment similarity items, as well as for the average of those 7 items. MZ twins were greater than DZ twins in their overall similarity of rearing environment (Wald $\chi^2 = 141.8$, df $= 1$, $p < .001$, $\eta^2 = .16$), and in the extent to which they were dressed alike (Wald $\chi^2 = 77.8$, df $= 1$, $p < .001$, $\eta^2 = .09$), played together (Wald $\chi^2 = 50.6$, df $= 1$, $p < .001$, $\eta^2 = .06$), spent time together (Wald $\chi^2 = 54.1$, df $= 1$, $p < .001$, $\eta^2 = .06$), slept in the same room (Wald $\chi^2 = 172.2$, df $= 1$, $p < .001$, $\eta^2 = .20$), were treated alike by parents (Wald $\chi^2 = 14.6$, df $= 1$, $p < .001$, $\eta^2 = .02$), and had the same friends (Wald $\chi^2 = 66.7$, df $= 1$, $p < .001$, $\eta^2 = .08$). MZ and DZ twins did not differ in the extent to which they had the same teachers, however (Wald $\chi^2 = 2.0$, df $= 1$, $p = .162$, $\eta^2 = .00$). Figure 2 shows back-to-back histograms of the distribution of average rearing environmental similarity for MZ and DZ twin pairs.

Similarly, we contrasted the average similarity for each of the 7 rearing environmental similarity items, as well as for the average of those 7 items, across same- and opposite-sex DZ twin pairs. The results differed across the 7 items, such that same-sex DZ twins were greater than opposite-sex DZ twins in their overall similarity of rearing environment (Wald $\chi^2 = 43.7$, df $= 1$, $p < .001$, $\eta^2 = .05$), and in the extent to which they were dressed alike (Wald $\chi^2 = 57.4$, df $= 1$, $p < .001$, $\eta^2 = .07$), played together (Wald $\chi^2 = 3.8$, df $= 1$, $p = .050$, $\eta^2 = .004$), slept in the same room (Wald $\chi^2 = 132.0$, df $= 1$, $p < .001$, $\eta^2 = .15$), and had the same friends (Wald $\chi^2 = 66.7$, df $= 1$, $p < .001$, $\eta^2 = .08$). Same- and opposite-sex DZ twins did not differ in the extent to which they had the same teachers (Wald $\chi^2 = 1.6$, df $= 1$, $p = .209$, $\eta^2 = .00$), spent time together (Wald $\chi^2 = .9$, df $= 1$, $p = .330$, $\eta^2 = .00$), or were treated alike by parents (Wald $\chi^2 = 1.0$, df $= 1$, $p = .323$, $\eta^2 = .00$), however.

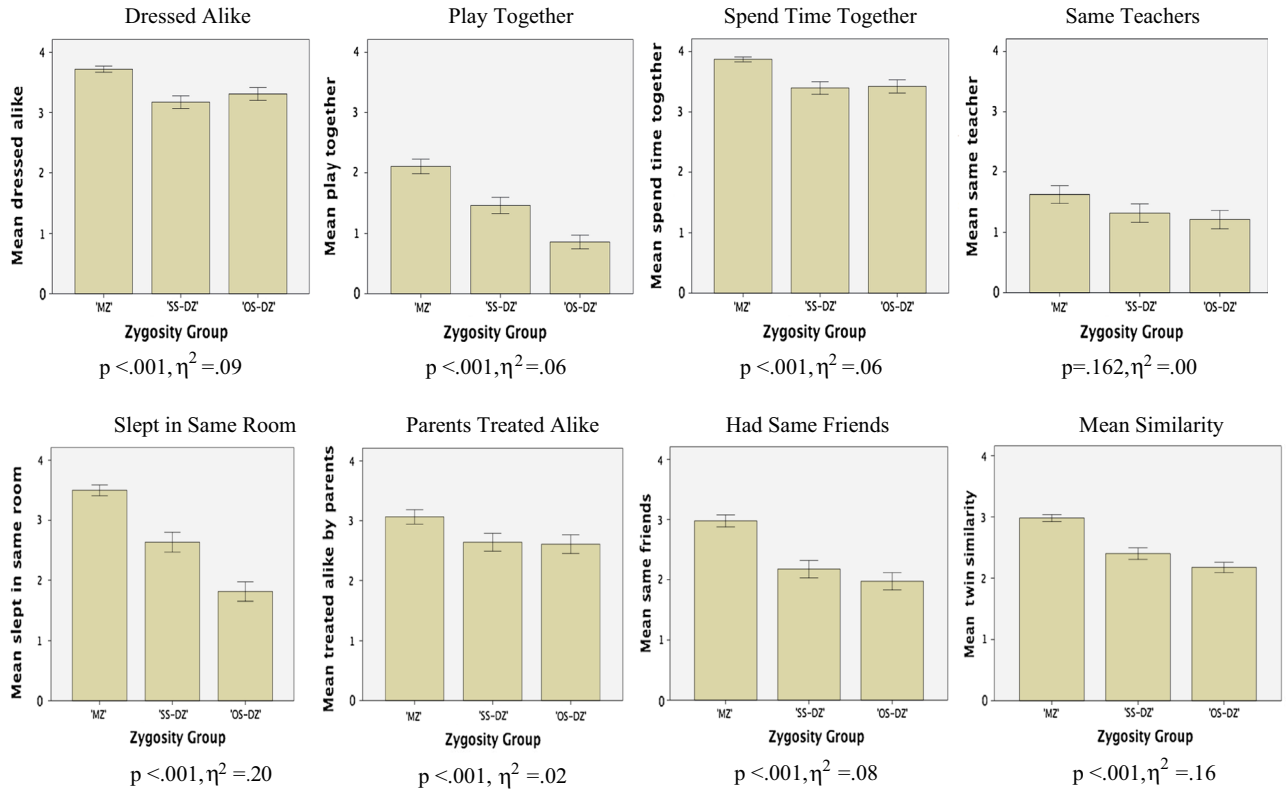

Fig. 1 Zygosity differences in rearing environment similarity

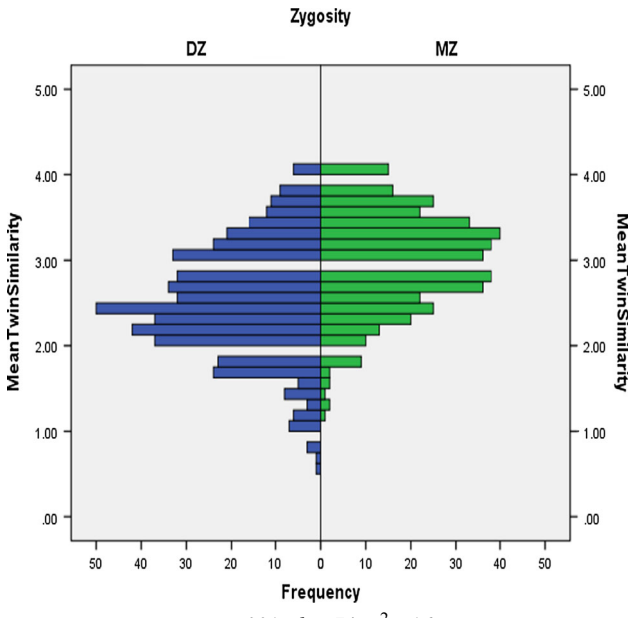

Fig. 2 Histograms of MZ-DZ differences in rearing environment similarity

Twin correlations for externalizing symptom dimensions

Table 2 shows the zero-order correlations for each externalizing symptom dimension. Specifically, for Inattention these correlations were .573 for MZs and .064 for DZs, for Hyperactivity-Impulsivity these correlations were .725 for MZs and .169 for DZs, for ODD these correlations were .620 for MZs and .344 for DZs, and for CD these correlations were .780 for MZs and .262 for DZs. Also shown in this table are the correlation between average similarity in rearing environment and each of the externalizing symptom dimensions separately for MZ and DZ twins. These correlations were negative and low for each of the symptom dimensions. Specifically, for Inattention these correlations were −.10 and −.12 for MZs and DZs, for Hyperactivity-Impulsivity these correlations were −.02 and −.09 for MZs and DZs, for ODD these correlations were −.12 and −.14 for MZs and DZs, and for CD these correlations were −.11 and −.12 for MZs and DZs.

Table 2 Twin correlations for the externalizing symptom dimensions

Symptom dimension	$r_{MZ/DZ}$	MZs	DZs
Inattention	−.10/−.12	.573	.064
Hyperactivity-impulsivity	−.02/−.09	.725	.169
ODD	−.12/−.14	.620	.344
CD	−.11/−.12	.780	.262

$r_{MZ/DZ}$ refers to the correlation between average rearing environment similarity and each of the externalizing symptom dimensions for MZs (before the slash) and DZs (after the slash)

Moderation of the correlations of externalizing symptom dimensions by similarity in rearing environment

Table 3 shows the results of tests of interactions between average similarity in rearing environment and twin 1's externalizing symptom dimension scores in explaining variation in twin 2's externalizing symptom dimension scores separately for MZ and DZ twins. Given that there are 8 tests of interactions the critical p value threshold = .006 (i.e., .05/8). Tests of the interaction between similarity in rearing environment and twin 1's externalizing symptom dimension scores were non-significant for Inattention (MZs: $R^2 = .001$, $p = .472$; DZs: $R^2 = .002$, $p = .343$), Hyperactivity-Impulsivity (MZs: $R^2 = .008$, $p = .012$; DZs: $R^2 = .003$, $p = .250$), and ODD (MZs: $R^2 = .001$, $p = .346$; DZs: $R^2 = .000$, $p = .874$). Due to considerable skewness and kurtosis of CD symptoms, analyses of twin resemblance for CD and its moderation by rearing environment similarity were conducted using Generalized Linear Models in which CD symptoms were modeled as ordinal. Nonetheless, tests of the interaction between similarity in rearing environment and twin 1's CD symptom dimension scores also were non-significant (MZs: $R^2 = .000$, $p = .897$; DZs: $R^2 = .001$, $p = .476$).

Table 3 Moderation of twin correlations for externalizing symptoms by twin similarity

Symptom dimension	MZs		DZs	
	R^2	p	R^2	p
Inattention				
Interaction with similarity	.001	.472	.002	.343
Hyperactivity-impulsivity				
Interaction with similarity	.008	.012	.003	.250
ODD				
Interaction with similarity	.001	.346	.000	.874
CD[a]				
Interaction with similarity	.000	.897	.001	.476

[a] Due to considerable skewness and kurtosis of CD symptoms, analyses of twin resemblance for CD and its moderation by rearing environment similarity were conducted using generalized linear models in which CD symptoms were modeled as ordinal

Discussion

In this study we tested the EEA for childhood externalizing disorders, specifically the Inattentive and Hyperactive-Impulsive symptom dimensions of ADHD, ODD, and CD. We used a particular method to test the EEA, namely contrasting average similarity in rearing environment and its component 7 indices between MZ and DZ twin pairs, examining the correlation between average similarity in rearing environment and the four externalizing symptom dimensions, and finally examining the effects of differential similarity in rearing environments between MZ and DZ twin pairs by testing whether rearing environment similarity moderated the twin correlations for the Inattentive, Hyperactive-Impulsive, ODD, and CD symptom dimensions.

Our analyses showed that MZ twins were greater than DZ twins in their average similarity of rearing environments and in the extent to which they dressed alike, played together, spent time together, slept in the same room, were treated alike by parents, and had the same friends, but did not differ in the extent to which they had the same teachers. These findings are consistent with Loehlin and Nichols's (Loehlin and Nichols 1976) original findings along with the findings of virtually all other studies that have examined environmental similarity among twins. Our analyses also showed that same-sex DZ twins were greater than opposite-sex DZ twins in their average similarity of rearing environments and in the extent to which they were dressed alike, played together, slept in the same room, and had the same friends, but did not differ in the extent to which they had the same teachers, spent time together, or were treated alike by parents. Thus, the similarity or difference in the sex of DZ twin pairs seems to influence differences in their rearing environment similarity, though not uniformly. These findings highlight that other factors beyond zygosity and gender must influence rearing environment similarity, yet we are not aware of any research that has attempted to identify particular genetic or environmental influences on rearing environment similarity. Quantifying and identifying the etiological influences on rearing environment similarity is a worthy pursuit and researchers should investigate these issues to provide a more informed understanding of the EEA and sibling dynamics. Relatedly, no research has differentiated aspects of rearing environment similarity that are likely beyond the control of the twins themselves (e.g., sharing a teacher) versus aspects over which twins likely do have some control (e.g., playing together). It could be the case that these aspects have

differential etiologies and thus indicate separable processes through which rearing environment similarity is produced.

Despite the substantial differences between MZ and DZ twin pairs in their average similarity of rearing environments and most of the component indices thereof, average similarity of rearing environment was only weakly related to the four externalizing symptom dimensions. These correlations ranged from −.02 to −.12 for MZs and from −.09 to −.14 for DZs. In addition, based on the results of the moderated multiple regression analyses, there was little evidence that MZ and DZ correlations for the externalizing symptom dimensions varied by rearing environment similarity. The evidence from this study, along with research that has examined the validity of the EEA in studies of psychopathology (e.g., Cronk et al. 2002; Kendler et al. 1993) among other phenotypes (Eriksson et al. 2006; Martin et al. 1986), provides assurance that the estimates of etiological influences obtained through twin methods are not biased due to the increased rearing environment similarity of MZ twins compared with DZ twins. This study in particular has provided additional evidence for the validity of the EEA in childhood samples, an area which has only been examined once prior to these analyses (Cronk et al. 2002). Further, this study provides the first evidence that the EEA is valid in male children and across ADHD symptom dimensions in childhood.

Several limitations of this study should be considered. First, all ratings were based on the retrospective report of parents about their children's functioning. This study did not include the self-report of twins about their own externalizing behavior. Parents and children often disagree on reports of the child's psychopathology, particularly during adolescence (e.g., Herjanic and Reich 1982). Thus, these results may not generalize to adolescent twin self-reports of externalizing psychopathology. Further, the measure of rearing environment similarity used in these analyses included only seven environmental characteristics out of the virtually countless characteristics that could potentially be measured. Though the characteristics included in Loehlin and Nichols's (1976) measure are those often cited by critics of the twin method as clearly discrepant between MZ and DZ twins, the EEA assumes that *any* environmental characteristic that is etiologically relevant to the trait of interest is found equally in MZ and DZ twins. A less commonly performed test of the EEA would be to determine whether confirmed etiologically relevant environmental conditions differ in frequency between MZ and DZ twins. If such differences do exist, these environmental conditions should be taken into account analytically when performing biometric model fitting.

In conclusion, these results suggest that the EEA is met for childhood externalizing disorders, at least according to the method of testing used herein. This study also highlights the importance of testing each of the distinct components of the EEA, as although MZ and DZ twin pairs differed substantially in their average similarity of rearing environments, this environmental similarity was only minimally related to the childhood externalizing symptom dimensions. In addition, MZ and DZ correlations for the externalizing symptom dimensions varied little by rearing environment similarity. Critics of twin studies as a basis for inferring the etiology of traits and disorders (e.g., Lewontin et al. 1984; Wyatt and Midkiff 2006) have all too frequently focused on the first part of the EEA (i.e., differential similarity in rearing environments between MZ and DZ twin pairs) to the exclusion of the latter components of the EEA (i.e., the relation of similarity in rearing environments to the target trait/disorder and the impact of differential similarity in rearing environments for MZ and DZ twin pairs on the twin correlations for the target trait/disorder). Future researchers should continue to use this and other methods of testing for violations of the EEA to safeguard against criticism as well as against biases in estimates obtained from biometric model fitting.

Conflict of interest Devon LoParo and Irwin Waldman declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent All procedures were followed in accordance with the ethical standards of the Emory University IRB committee and with the Helinski Declaration of 1975, as revised in 2000. Informed consent was obtained from all participants for being included in the study.

References

American Psychiatric Association (2000) Diagnostic and statistical manual of mental disorders (text rev), 4th edn. APA, Washington DC

Borkenau P, Riemann R, Angleitner A, Spinath FM (2002) Similarity of childhood experiences and personality resemblance in monozygotic and dizygotic twins: a test of the equal environments assumption. Personal Individ Differ 33(2):261–269

Clifford CA, Hopper JL, Fulker DW, Murray RM, Rao DC (1984) A genetic and environmental analysis of a twin family study of alcohol use, anxiety, and depression. Genet Epidemiol 1(1):63–79

Conley D, Rauscher E, Dawes C, Magnusson PK, Siegal ML (2013) Heritability and the equal environments assumption: evidence from multiple samples of misclassified twins. Behav Genet 43(5):415–426

Cronk NJ, Slutske WS, Madden PA, Bucholz KK, Reich W, Heath AC (2002) Emotional and behavioral problems among female twins: an evaluation of the equal environments assumption. J Am Acad Child Adolesc Psychiatry 41(7):829–837

Derks EM, Dolan CV, Boomsma DI (2006) A test of the equal environment assumption (EEA) in multivariate twin studies. Twin Res Hum Genet 9(03):403–411

Eley TC, Lichtenstein P, Stevenson J (1999) Sex differences in the etiology of aggressive and nonaggressive antisocial behavior: results from two twin studies. Child Dev 70(1):155–168

Eriksson M, Rasmussen F, Tynelius P (2006) Genetic factors in physical activity and the equal environment assumption–the Swedish young male twins study. Behav Genet 36(2):238–247

Ficks CA, Lahey BB, Waldman ID (2013) Does low birth weight share common genetic or environmental risk with childhood disruptive disorders? J Abnorm Psychol 122(3):842

Goodman R, Stevenson J (1989) A twin study of hyperactivity—II. The aetiological role of genes, family relationships and perinatal adversity. J Child Psychol Psychiatry 30(5):691–709

Greven CU, Rijsdijk FV, Plomin R (2011) A twin study of ADHD symptoms in early adolescence: hyperactivity-impulsivity and inattentiveness show substantial genetic overlap but also genetic specificity. J Abnorm Child Psychol 39(2):265–275

Heath AC, Jardine R, Martin NG (1989) Interactive effects of genotype and social environment on alcohol consumption in female twins. J Stud Alcohol Drugs 50(01):38

Herjanic B, Reich W (1982) Development of a structured psychiatric interview for children: agreement between child and parent on individual symptoms. J Abnorm Child Psychol 10(3):307–324

Hettema JM, Neale MC, Kendler KS (1995) Physical similarity and the equal-environment assumption in twin studies of psychiatric disorders. Behav Genet 25(4):327–335

Jackson RW, Snieder H, Davis H, Treiber FA (2001) Determination of twin zygosity: a comparison of DNA with various questionnaire indices. Twin Res 4(1):12–18

Kaprio J, Koskenvuo M, Rose RJ (1990) Change in cohabitation and intrapair similarity of monozygotic (MZ) cotwins for alcohol use, extraversion, and neuroticism. Behav Genet 20(2):265–276

Kendler KS (1983) Overview: a current perspective on twin studies of schizophrenia. Am J Psychiatry 140(11):1413–1425

Kendler KS, Gardner CO (1998) Twin studies of adult psychiatric and substance dependence disorders: are they biased by differences in the environmental experiences of monozygotic and dizygotic twins in childhood and adolescence? Psychol Med 28(03):625–633

Kendler KS, Heath A, Martin NG, Eaves LJ (1986) Symptoms of anxiety and depression in a volunteer twin population: the etiologic role of genetic and environmental factors. Arch Gen Psychiatry 43(3):213–221

Kendler KS, Neale MC, Kessler RC, Heath AC, Eaves LJ (1993) A test of the equal-environment assumption in twin studies of psychiatric illness. Behav Genet 23(1):21–27

Kendler KS, Neale MC, Kessler RC, Heath AC, Eaves LJ (1994) Parental treatment and the equal environment assumption in twin studies of psychiatric illness. Psychol Med 24(03):579–590

Klump KL, Holly A, Iacono WG, McGue M, Willson LE (2000) Physical similarity and twin resemblance for eating attitudes and behaviors: a test of the equal environments assumption. Behav Genet 30(1):51–58

Koenig LB, Jacob T, Haber JR, Xian H (2010) Testing the equal environments assumption in the children of twins design. Behav Genet 40(4):533–541

Larsson H, Asherson P, Chang Z, Ljung T, Friedrichs B, Larsson JO, Lichtenstein P (2013) Genetic and environmental influences on adult attention deficit hyperactivity disorder symptoms: a large Swedish population-based study of twins. Psychol Med 43(01): 197–207

Lewontin RC, Rose SPR, Kamin LJ (1984) Not in our genes: biology, ideology, and human nature. Pantheon Books, New York

Loehlin JC, Nichols RC (1976) Heredity, environment, and personality: A study of 850 sets of twins. University of Texas Press, Austin

Lytton H (1977) Do parents create, or respond to, differences in twins? Dev Psychol 13(5):456–459

Martin NG, Eaves LJ, Heath AC, Jardine R, Feingold LM, Eysenck HJ (1986) Transmission of social attitudes. Proc Natl Acad Sci 83(12):4364–4368

Matheny AP Jr (1979) Appraisal of parental bias in twin studies. Ascribed zygosity and IQ differences in twins. Acta Geneticae Medicae et Gemellologiae 28(2):155–160

Matheny AP Jr, Wilson RS, Dolan AB (1976) Relations between twins' similarity of appearance and behavioral similarity: testing an assumption. Behav Genet 6(3):343–351

Morris-Yates A, Andrews G, Howie P, Henderson S (1990) Twins: a test of the equal environments assumption. Acta Psychiatr Scand 81(4):322–326

Munsinger H, Douglass A (1976) The syntactic abilities of identical twins, fraternal twins, and their siblings. Child Dev 47(1):40–50

Plomin R, Willerman L, Loehlin JC (1976) Resemblance in appearance and the equal environments assumption in twin studies of personality traits. Behav Genet 6(1):43–52

Rhee SH, Waldman ID (2002) Genetic and environmental influences on antisocial behavior: a meta-analysis of twin and adoption studies. Psychol Bull 128:490–529

Rhee SH, Waldman ID, Hay DA, Levy F (1999) Sex differences in genetic and environmental influences on DSM-III-R attention deficit hyperactivity disorder (ADHD). J Abnorm Psychol 108:24–41

Saudino KJ, Ronald A, Plomin R (2005) The etiology of behavior problems in 7-year-old twins: substantial genetic influence and negligible shared environmental influence for parent ratings and ratings by same and different teachers. J Abnorm Child Psychol 33(1):113–130

Scarr S (1968) Environmental bias in twin studies. Biodemogr Soc Biol 15(1):34–40

Scarr S, Carter-Saltzman L (1979) Twin method: defense of a critical assumption. Behav Genet 9(6):527–542

Spitz E, Moutier R, Reed T, Busnel MC, Marchaland C, Roubertoux PL, Carlier M (1996) Comparative diagnoses of twin zygosity by SSLP variant analysis, questionnaire, and dermatoglyphic analysis. Behav Genet 26(1):55–63

Sullivan PF, Bulik CM, Kendler KS (1998) The epidemiology and classification of bulimia nervosa. Psychol Med 28(3):599–610

Waldman ID, Rowe DC, Abramowitz A, Kozel ST, Mohr JH, Sherman SL et al (1998) Association and linkage of the dopamine transporter gene and attention-deficit hyperactivity disorder in children: Heterogeneity owing to diagnostic subtype and severity. Am J Hum Genet 63(6):1767–1776

Wyatt WJ, Midkiff DM (2006) Biological psychiatry: a practice in search of a science. Behav Soc Issues 15(2):132–151

Xian H, Chantarujikapong SI, Scherrer JF, Eisen SA, Lyons MJ, Goldberg J et al (2000) Genetic and environmental influences on posttraumatic stress disorder, alcohol and drug dependence in twin pairs. Drug Alcohol Depend 61(1):95–102