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Research article

The association between the 2D:4D ratio and psychopathic characteristics

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HIGHLIGHTS

- Psychopathy is higher for males compared to females.
- Males exhibit lower 2D:4D ratios compared to females.
- Low 2D:4D ratios were linked with higher levels of egocentricity in males compared to females.
- Findings provide evidence that testosterone, measured by the 2D:4D ratio, may be implicated in certain domains of psychopathy.

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ABSTRACT

Prior research has identified relations between prenatal testosterone exposure and various antisocial and criminal behaviors. However, less is known about the association between prenatal testosterone exposure and personality traits, such as psychopathy. This study used self-report and biometric data from a sample of undergraduates ($n = 491$) at a large southwestern university to examine the association between prenatal testosterone exposure (measured by the 2D:4D ratio) and three dimensions of psychopathy (i.e., callousness, egocentricity, and antisocial behavior). Analyses were stratified by sex to explore sex-specific biological underpinnings of psychopathy in young adulthood. Results showed that males scored significantly higher in psychopathic traits and reported significantly lower 2D:4D ratios, compared to females. Additionally, 2D:4D ratios were negatively associated with egocentricity in males, but not females. These findings contribute to a growing literature on the organizational effects that prenatal testosterone exposure may have on the development of different dimensions of psychopathy.

1. Introduction

Psychopathy includes a cluster of personality traits that have been associated with antisocial and violent criminal behavior. Research that has examined the etiology of psychopathic traits suggests that environmental and biological influences can interactively explain some of the variation in the expression of different dimensions of psychopathy (Forouzan and Nicholls, 2015; Perez, 2012). Hormones have been identified as one biological mechanism that may contribute to the onset and persistence of psychopathic traits (Glenn and Raine, 2014). Specifically, exposure to greater levels of testosterone during prenatal stages of development, often measured retrospectively via the relative lengths of the second and fourth finger (i.e., the 2D:4D ratio) (Manning, 2002), has been linked with increased levels of psychopathy and callous-unemotional (CU) traits (Blanchard and Centifanti, 2017; Blanchard et al., 2016).

Previous research has identified negative relations between digit ratios and psychopathy for women (i.e., greater prenatal testosterone being associated with greater psychopathy in women; Blanchard et al., 2016) and positive relations between digit ratios and callousness for men (i.e., greater prenatal estrogen being associated with greater callousness in men; Blanchard and Lyons, 2010). These findings suggest that the association between the 2D:4D ratio and psychopathic traits may present itself differently between males and females, particularly when looking at primary psychopathic characteristics. Evidence is mixed, however,

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regarding the direction of this association in males and females (Blanchard and Lyons, 2010; Blanchard et al., 2016; Marchegiani et al., 2018). As such, this study seeks to expand upon previous research by examining if exposure to prenatal testosterone, measured indirectly using the 2D:4D ratio, is associated with three distinct facets of psychopathy (i.e., egocentricity, callousness, and antisocial behavior).

1.1. Psychopathy and the 2D:4D ratio

Those who score higher on psychopathic dimensions tend to display atypical interpersonal, affective, and behavioral facets and are more likely to present increased levels of callousness, egocentricity, impulsivity, aggression, and risk-seeking behaviors (Hare, 2003; Hare and Neumann, 2008). Psychopathy has been conceptualized as a 3-factor model (Cooke and Michie, 2001; Sellbom, 2011) and includes dimensions of callousness (e.g., affective traits such as a lack of remorse), egocentricity (e.g., interpersonal traits such as narcissism), and antisociality (e.g., behavioral traits such as impulsivity). Research has consistently reported that males tend to score higher on measures of callousness, egocentricity, and antisocial behavior compared to females (de Vogel and Lancel, 2016; Kreis and Cooke, 2011).

The interplay between biological, environmental, and contextual factors may influence the etiology of psychopathy (Hare, 1999). Twin and adoptions studies have found that shared genetic components partly explain the presence of psychopathy across the population (Beaver et al., 2011; Blonigen et al., 2003). Environmental exposures may also partly contribute to the manifestation of psychopathic dimensions. Greater exposure to violence and neglect within the home and community, for example, has been associated with higher psychopathic traits among samples of adolescents and adults (Forouzan and Nicholls, 2015; Schraft et al., 2013). Callous unemotional traits are also reported to be higher among dyads of mothers and their children (i.e., closely shared psychological or biological relationships often predict personality traits; Loney et al., 2007), suggesting inherited genetics and/or parenting may concurrently influence psychopathy. A possible explanation for these findings is that children who are vulnerable to developing psychopathic traits evoke negative responses from their parents and the broader environment (e.g., peers; teachers) thereby increasing vulnerability to the continued expression of these nonnormative traits.

Only recently has research identified specific biological markers that may contribute to the development of psychopathy (Glenn and Raine, 2014). Converging evidence has implicated hormones (e.g., testosterone) as one important biological marker that may influence the development of psychopathy through its effects on neurobiological functioning and subsequent behaviors (Glenn, 2009). Specifically, early exposure to testosterone (e.g., prenatally) may organize the developing brain in such a way as to influence the manifestation of nonnormative behaviors and personality traits (Del Giudice and Angeleri, 2016), including psychopathy (Blanchard and Lyons, 2010; Blanchard et al., 2016; Marchegiani et al., 2018), later in life. The observed link between hormonal imbalances (e.g., greater testosterone) and psychopathy may also explain the tendency for males to exhibit a greater propensity for developing psychopathic traits compared to females (Yildirim and Derksen, 2012).

Prenatal testosterone exposure has been measured retrospectively and indirectly by the relative distance between the second (index) and fourth (ring) finger, known as the 2D:4D ratio (Manning, 2002). Typically, research has found that increased exposure to testosterone in utero can result in longer ring fingers (4D) compared to index fingers (i.e., low 2D:4D ratios). Extant research has provided support for the 2D:4D ratio as a sexually dimorphic measure with males, on average, having lower digit ratios than females (Burton et al., 2013; Butovskaya et al., 2019; Hampson et al., 2008; Hönekopp and Watson, 2010; Hoskin and Ellis, 2015; Manning, 2002; Manning et al., 2004). Furthermore, a meta-analyses of 116 studies (Hönekopp and Watson, 2010) found significant sex differences in the 2D:4D ratio on the right hand, respectively. Thus, research has collectively found that males tend to have lower digit ratios, particularly on the *right hand*, compared to females.

Lower right-hand 2D:4D ratios have been linked to a multitude of nonnormative personality traits and behaviors including attention deficit disorder, aggression, risk taking, recklessness, assault, impulsivity, and crime (Hanoch et al., 2012; Hoskin and Ellis, 2015; McIntyre et al., 2007). A recent meta-analysis (Turanovic et al., 2017) reported a significant, albeit weak ($d = 0.036$), relation between the 2D:4D ratio and antisocial behavior. This association varied by sex, with lower 2D:4D ratios being significantly associated with increased verbal aggression in males ($d = 0.035$) but not in females ($d = -0.017$). The strength of this association is unsurprising given that the 2D:4D digit ratio is a marker of in utero testosterone exposure, hence it is expected to make small contributions to the development of nonnormative behaviors and personality traits later in life. Despite the relative size of the effect, evidence suggests the 2D:4D ratio may offer a potential explanation for observed sex specific variation in violent and aggressive behaviors (i.e., the gender ratio problem), with males being more likely to engage in aggressive behaviors and violence compared to females (Schwartz et al., 2009; Steffensmeier et al., 2005). Thus, as Ellis and Hoskin (2018) note, there is a continued need to examine potential explanatory variables, including sexually dimorphic measures of prenatal testosterone exposure (i.e., the 2D:4D ratio), to explain differences in male and female personality traits and behavioral patterns (e.g., psychopathy).

To our knowledge, only three studies have examined relations between prenatal testosterone exposure, as measured by the 2D:4D ratio, and psychopathic characteristics (Blanchard and Lyons, 2010; Blanchard et al., 2016; Marchegiani et al., 2018). In the first, Blanchard and Lyons (2010) found a positive association between right-hand 2D:4D ratios and psychopathy in a sample of 54 participants (30 men and 24 women). Their findings implicated prenatal estrogen, but not prenatal testosterone, as a hormonal biomarker associated with higher total psychopathy scores in females and higher callous affect in males. These findings contradicted what was expected, as low 2D:4D ratios are typically linked to increased sensation seeking, aggression, risk taking, and offending in male samples (Hönekopp, 2011; Hoskin and Ellis, 2015). Blanchard and Lyons (2010) suggest that estrogen may play a more important role in the development of psychopathy for females and callousness for males; however, their conclusions are limited by the size of the sample used in the analysis (i.e., 30 men and 24 women). This is a notable limitation, as previous works have indicated that correlations using measures of digit ratios on traits influenced by prenatal testosterone require larger samples to detect significant effects (Ellis and Hoskin, 2018).

Blanchard et al. (2016) build upon their previous study to examine relations between the 2D:4D ratio, primary psychopathy, and secondary psychopathy in a sample of 67 male and 81 female university students. Analyses revealed lower digit ratios were linked to higher levels of primary and secondary psychopathy in females. Unexpectedly, this association was not significant for males. Blanchard et al. (2016) suggest that these findings may be attributable to the female fetus being more responsive to fluctuations in testosterone levels during development compared to the male fetus. Alternatively, findings in the male sample could be due to a "ceiling effect." In other words, males, who are already more likely to be exposed to greater levels of prenatal testosterone, may exhibit an in-utero threshold that is more difficult to capture through the digit ratio measurement (Breedlove, 2010). Marchegiani et al. (2018) also found a positive link between higher digit ratios and primary psychopathy in a sample of 65 adult male volunteers.

Inconsistent findings from previous studies examining links between the 2D:4D ratio and psychopathy indicate a continued need to further examine the interplay between prenatal hormone exposure, sex, and different facets of psychopathy. As a proxy measure of the level of prenatal testosterone, the 2D:4D ratio may explain some of the differences in male and female personality traits that lead to outwardly directed

aggression and violence. However, research assessing the digit ratio and psychopathy to this point remains limited. It is critical for future works to utilize larger sample sizes to examine male and female differences in the 2D:4D ratio that may contribute to sex differences in psychopathic traits.

1.2. Current study

Psychopathy is a personality construct defined by a host of antisocial personality characteristics including superficial charm, callousness and a lack of remorse, self-centeredness, and antisocial tendencies that increase the likelihood of criminal propensity (Hare and Neumann, 2008). A wealth of research has documented differences in the display of psychopathy across sex, with research showing that males score significantly higher on dimensions of psychopathy compared to females. Differences in the manifestation of psychopathy between males and females may be attributable to in utero exposure to testosterone. The 2D:4D ratio has been used as a retrospective proxy measure of in utero testosterone exposure. Conditional evidence has reported weak yet significant associations between the *right hand* 2D:4D ratio and psychopathic personality traits. Moreover, prior works have reported that the relation between the 2D:4D ratio and nonnormative personality traits, like psychopathy, may vary across sex (Blanchard and Lyons, 2010; Blanchard et al., 2016; Marchegiani et al., 2018). Yet most of the research in this area has analyzed small samples with limited capacity for multivariate analyses. The current study seeks to extend this line of research by examining the association between the right hand 2D:4D ratio and callousness, egocentricity, and antisocial behavior in a large sample of undergraduate males and females while accounting for relevant confounds including age, race/ethnicity, parental arrest, and child physical and sexual abuse. We expect to find a negative relation between the right hand 2D:4D ratio and each dimension of psychopathy. We also explore the relative association between the right hand 2D:4D ratio and psychopathy separately for males and females.

2. Methods

2.1. Participants

This study uses data drawn from undergraduate students attending a large southwestern university during the fall of 2016. Participants were selected based on enrollment in introductory criminal justice courses. The procedure and data collection were approved by the Institutional Review Board at Sam Houston State University. The data were collected in a two-step process following obtainment of informed consent. The first step included an in-class paper and pencil survey. A total of 862 participants completed the in-class self-report survey. The second step involved a separate laboratory portion of data collection. Students were verbally notified, followed by an email from their course instructor, to attend a follow-up lab portion of the survey. Consent was re-obtained prior to engaging with the lab portion of the study. Participants were awarded extra credit and a custom koozie for their participation in the lab study.

Approximately 66% of students who completed the in-class survey scheduled a time to come to the lab ($N = 567$). The laboratory researchers collected participants' heart rate, skin conductance, saliva samples, facial symmetry, and information on various types of dietary, exercise, and sleep habits. Additionally, researchers obtained hand scans to measure digit length on both the right and left hand. A total of 491 participants provided reliable hand scans and relevant demographic variables. Discrepancies between the total number of lab participants and the recorded right-hand digit ratio were the result of some students declining to give their digit ratio measure. Preliminary data analyses showed no significant differences between key variables and covariates in the sample of participants who participated in the lab portion of the data collection and those who did not, including those who provided hand scans during the laboratory portion of data collection and those who did not (preliminary analyses can be provided upon request). The final analytical sample ($n = 491$; Table 1) consisted of approximately 67% female ($n = 327$) and 33% male ($n = 164$) participants who identified as Caucasian (37.1%), African American (13.2%), Hispanic (39.5%), or Other race/ethnicity (10.1%). The age of the participants ranged from 18 to 27 years, with a mean of 20 years of age ($SD = 1.79$).

Table 1. Descriptive Statistics for Analytic Sample (N = 491).

	Mean/%	SD	Range	t-test/χ^2 (df)^{sig}
Egocentricity	8.98	4.57	0–25	4.99 (458) **
Males	10.46	4.49	0–25	
Females	8.26	4.44	0–22	
Callousness	3.60	2.11	0–12	4.08 (485) **
Males	4.14	2.19	0–10	
Females	3.33	2.02	0–12	
Antisociality	5.22	2.52	0–13	2.12 (480) *
Males	5.56	2.41	0–12	
Females	5.04	2.57	0–13	
Right hand 2D:4D ratio	.97	.03	.88–1.09	−3.39 (489)**
Males	.97	.03	.91–1.05	
Females	.98	.03	.88–1.09	
Childhood sexual abuse	8.92%	–	0–1	5.41 (439)**
Males	1.32%	–	0–1	
Females	12.54%	–	0–1	
Childhood physical abuse	7.42%	–	0–1	1.78 (387)
Males	4.61%	–	0–1	
Females	8.75%	–	0–1	
Paternal arrest	25.45%	–	0–1	.539 (374)
Males	17.81%	–	0–1	
Females	29.25%	–	0–1	
Maternal arrest	7.56%	–	0–1	1.53 (478)
Males	4.64%	–	0–1	
Females	8.97%	–	0–1	
Age	20.00	1.79	18–27	
Female^0	66.60%	–	0–1	
White^0	37.07%	–	0–1	

Notes: ^{0}Reference group for non-stratified analyses. $^{**}p < .01$; $^{*}p < .05$.

2.2. Measures

2.2.1. Psychopathy

The Levenson Self-Report Psychopathy (LSRP) scale was used to measure psychopathic traits. While the LSRP was originally designed for a 2-factor model of psychopathy (Levenson et al., 1995), research has suggested the LSRP may be better suited as a 3-factor model used to capture latent psychopathy dimensions related to egocentricity, callousness, and antisocial behavior (Sellbom, 2011). Accordingly, the current study used the 3-factor construct of psychopathy as measured by the LSRP. Decisions involving model fit and testing of the 3-factor model compared to the two-factor model as well as invariance across sex can be found in the Analysis and Results sections. Unlike the two-factor model of the LSRP, which uses all the original 26 items, the 3-factor model (Sellbom, 2011) relies on 19 of these items (see Appendix A) and reflects the three factors of egocentricity (10 items, $M = 8.98$, $SD = 4.57$), callousness (4 items, $M = 3.60$, $SD = 2.11$), and antisocial behavior (5 items, $M = 5.22$, $SD = 2.52$) with responses measured on a 4-point scale (0 = *Strongly disagree*, 1 = *Disagree somewhat*, 2 = *Agree somewhat*, 3 = *Strongly agree*).

2.2.2. 2D:4D ratio

Digit ratios were measured continuously with the lowest ratios representing the greatest level of prenatal testosterone exposure (Ellis and Hoskin, 2015a; Manning, 2002). Prior research has highlighted the

effects of prenatal testosterone when measuring the right-hand digit ratio on personality characteristics, suggesting there may be a stronger association with a range of traits that may be more sensitive to prenatal testosterone with the right hand compared to the left hand (Fink et al., 2004; Manning, 2002). Specifically, greater testosterone exposure during fetal development may affect the growth of the left hemisphere, affecting the right-hand digit ratio (Geschwind and Galaburda, 1985). In support of this idea, Hönekopp and Watson (2010) conducted a meta-analysis of 116 studies and found that the right hand may be a more robust indicator of prenatal testosterone because it is more sensitive to prenatal testosterone, resulting in greater sex differences (see also Coates et al., 2009; Manning et al., 2007). As such, this study uses the right hand 2D:4D ratio when examining relations between digit ratio and psychopathy. The right hand 2D:4D ratio ($M = 0.97$, $SD = 0.03$) was obtained by scanning the participants' hand and measured by finding the difference between the 2nd digit with the 4th digit. The right hand 2D:4D ratio was obtained and measured through ImageJ, a computer-assisted software program that calculates angles and distances for precision (Ferreira and Rasband, 2012). Individuals with equal lengths on the 2nd and 4th digit would have a ratio of 1.00.

2.2.3. Covariates

Childhood abuse, history of parental arrest, age, and race/ethnicity were included as theoretical and demographic covariates. Childhood abuse was measured using two dichotomous variables that included child sexual abuse and child physical abuse. Participants were asked if they were ever sexually abused prior to 17 years of age (0 = *no*, 1 = *yes*; 8.92%), and if they were ever physically abused prior to 17 years of age (0 = *no*, 1 = *yes*; 7.42%). History of parental arrest was separated into two dichotomous variables of paternal arrest and maternal arrest. Participants were asked if their father had ever been arrested (0 = *no*, 1 = *yes*), and if their mother had ever been arrested (0 = *no*, 1 = *yes*). Participants reported both paternal arrest (25%) and maternal arrest (8%), respectively. Lastly, demographic control variables included race/ethnicity (0 = white, 1 = person of color) since previous research suggests differences in digit ratio length may exist among racial and ethnic groups (Manning et al., 2007), and age ($M = 20.00$, $SD = 1.79$).

2.3. Analytic strategy

Analyses were performed in a series of four linked steps. First, Confirmatory Factor Analysis (CFA) was used to test the validity of the 2-factor and 3-factor models of psychopathy. Goodness-of-fit criteria (see Hu and Bentler, 1999) included the root mean square error of approximation (RMSEA < .08), the Comparative Fit Index (CFI > .90), and the Tucker Lewis Index (TLI > .90). Analyses were conducted using the weighted least squares means and variances estimator (WLSMV) in M*plus* Version 8.6 (Muthén and Muthén, 1998 – 2017). Syntax is available in the Supplementary Material.

After identifying the best fitting model for psychopathy, multi-group CFA was used to examine gender invariance (i.e., equivalence) for this model in males and females. Invariance tests using the WLSMV estimator in M*plus* require the use of the DIFFTEST option (syntax available in the Supplementary Material). Fit indices were assessed using the Satorra-Bentler Chi-Square difference test which estimates the change in χ^2 ($\Delta\chi^2$). It should be noted that χ^2 remains sensitive to sample size and, therefore, heavy reliance on χ^2 may result in incorrectly rejecting well-fitting and invariant models (Cheung and Rensvold, 2002; Kline, 2015; Pendergast et al., 2017). As such, model invariance was also evaluated via change in CFI (ΔCFI > 0.01) and RMSEA (ΔRMSEA > 0.015). These change indices are ideal for assessing model fit in samples where the sizes are greater than 150 per group (Pendergast et al., 2017).

After identifying the best fitting factor structure of psychopathy and examining invariance of this structure across sex, the analysis proceeded by estimating associations between the right hand 2D:4D ratio and relevant covariates in the full and sex stratified samples via Pearson correlations, *t*-tests, and chi-square tests in IBM SPSS Statistics (Version 27). Finally, the right hand 2D:4D ratio, childhood sexual abuse, childhood physical abuse, paternal and maternal arrest, age, and race/ethnicity were regressed onto the latent factors of egocentricity, callousness, and antisocial behavior in the full sample and in stratified groups of males and females. Regressions were conducted in M*plus* Version 8.6 (Muthén and Muthén, 1998 – 2017) using the robust maximum-likelihood (MLR) estimator.

3. Results

Results from the CFA (Table S1 in the Supplementary Material) indicated that the 3-factor (RMSEA = .06; CFI = .93; TLI = .92) solution (i.e., egocentricity, callousness, and antisociality) was the best fitting factor structure for psychopathy compared to the 2-factor model (RMSEA = .07; CFI = .84; TLI = .83). Internal reliability analyses for egocentricity ($\alpha = .81$, $\omega = .81$), callousness ($\alpha = .55$, $\omega = .56$), and antisocial behavior ($\alpha = .63$, $\omega = .64$), along with the results from the CFA, suggest the model is capturing three different dimensions of psychopathy. Additionally, results from the multi-group CFA indicated that the 3-factor model was invariant (i.e., equivalent) across sex. Configural (RMSEA = .06; CFI = .92; TLI = .91), metric (RMSEA = .06; CFI = .92; TLI = .91; $\Delta\chi^2 = 16.91$; ΔCFI = .001; ΔRMSEA = .002), and threshold RMSEA = .06; CFI = .92; TLI = .92; $\Delta\chi^2 = 28.79$; ΔCFI = .002; ΔRMSEA = .004) invariance were achieved. Notably, the Satorra-Bentler Chi-Square difference tests indicated a significant $\Delta\chi^2$. However, this is likely attributable to the group specific sample sizes.

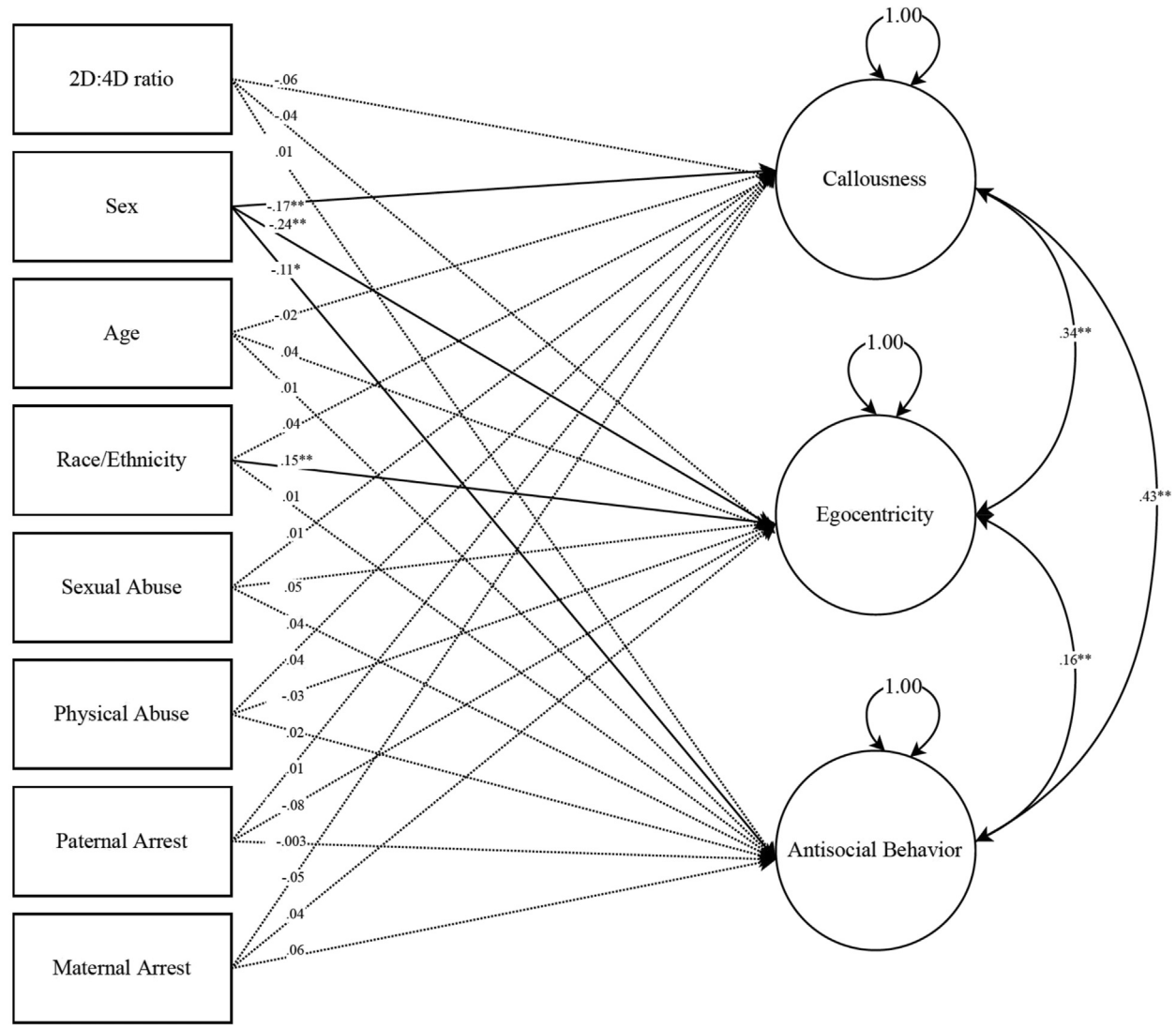
Males reported significantly higher levels of the egocentric ($t = 4.99$; $p < .001$), callous ($t = 4.08$; $p < .001$), and antisocial ($t = 2.12$; $p = .03$) facets of psychopathy compared to females (Table 1). Additionally, males had significantly lower right hand 2D:4D ratios ($t = -3.39$; $p < .001$) compared to females. Among females (Table S2), egocentricity was positively correlated with callousness ($r = .63$, $p < .01$), antisocial behavior ($r = .66$, $p < .01$), and race/ethnicity ($r = .14$, $p < .05$) while callousness was positively correlated with antisocial behavior ($r = .40$, $p < .01$). Among males (Table S2), egocentricity was positively correlated with callousness ($r = .64$, $p < .01$), antisocial behavior ($r = .67$, $p < .01$), and race/ethnicity ($r = .22$, $p < .01$). Finally, the right hand 2D:4D ratio was negatively correlated with egocentricity ($r = -.17$, $p < .05$) and race/ethnicity ($r = -.20$, $p < .05$) in males.

Figure 1 shows results for the regression analysis in the full sample. Although the 2D:4D ratio was not significant ($p = .295$), significant sex differences were found for egocentricity ($p < .001$), callousness ($p = .001$), and antisocial behavior ($p = .025$). Therefore, regressions were estimated again across sex.

The 2D:4D ratio was negatively associated with egocentricity in males ($\beta = -.14$, *95% CI* = −.28 to −.01, $p = .046$) while controlling for covariates (Figure 2). Specifically, lower right hand 2D:4D ratios were significantly associated with greater egocentricity in male respondents. There were no significant associations between the right hand 2D:4D ratio and psychopathy for females (Figure 3). Among females, egocentricity was negatively associated with paternal arrest ($\beta = -.11$, *95% CI* = −.22 to −.01, $p = .042$) and positively associated with race/ethnicity ($\beta = .06$, *95% CI* = .04–.27, $p = .007$).

4. Discussion

This study investigated relations between the right hand 2D:4D ratio and psychopathy facets in males and females. The right hand 2D:4D ratio was significantly associated with the egocentric dimension of psychopathy for males but not females. Additionally, results from the univariate analyses are consistent with prior research and suggest that males are more likely to score higher on egocentricity, callousness, and antisocial behaviors compared to females (de Vogel and Lancel, 2016; Kreis and



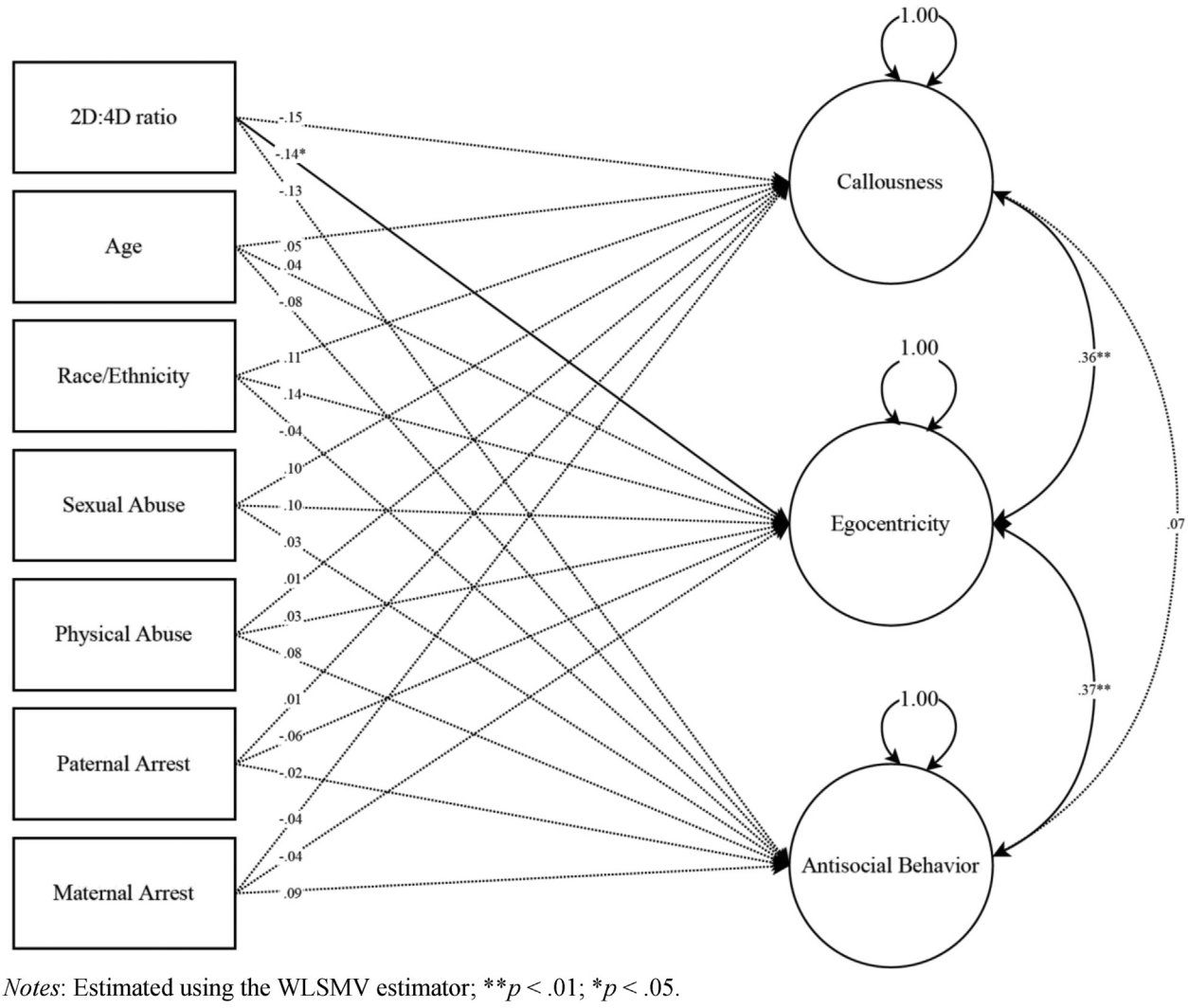
Notes: Estimated using the WLSMV estimator; $^{**}p < .01$; $^{*}p < .05$.

Figure 1. Standardized Regression Results for the 3-Factor Model for the Full Sample.

Cooke, 2011; Lee and Salekin, 2010). One implication from these findings, which aligns with Lee and Salekin (2010), is that psychopathy may be a sexually dimorphic personality construct. Hence, androgenic differences may explain some of the observed variance in the development of psychopathy between males and females. This study provides additional evidence that males have lower 2D:4D ratios compared to females (Burton et al., 2013; Hoskin and Ellis, 2015; Manning, 2002).

Negative relations were observed between the right hand 2D:4D ratio and egocentricity in males after accounting for several covariates. This finding diverges from previous literature reporting positive relations between digit ratios and psychopathy (Blanchard and Lyons, 2010; Marchegiani et al., 2018), but is consistent with the overall hypothesis that there may be sex differences in neurodevelopmental pathways and endocrine systems which influence the development of psychopathic traits (Marchegiani et al., 2018). Specifically, we provide conditional, yet non-causal, evidence that greater testosterone exposure in utero, indicated by low right hand 2D:4D ratios, may increase egocentricity for males but remains largely unrelated to other dimensions of psychopathy within the sample. While speculative, the findings suggest that males may be more susceptible to developing behavioral features related to the egocentric facet of psychopathy due to increased exposure to testosterone in utero. Prenatal testosterone may act as a neurohormonal antecedent for behaviors that promote reproductive success (Ellis and Hoskin, 2015b; Hoskin and Ellis, 2015). Thus, males exposed to greater prenatal testosterone, indicated by lower right hand digit ratios, may be more likely to demonstrate personality characteristics that reflect the egocentric facet of psychopathy, including deceit and manipulation, to obtain their own reproductive goals despite the effect it may have on others.

Although the current study did not observe a significant relation between the 2D:4D ratio and psychopathy for females, prior research has shown that the 2D:4D digit ratio may influence different types of personality characteristics in females (Burton et al., 2013; Fink et al., 2004), including the 'Big Five' personality traits (e.g., neuroticism, conscientiousness, agreeableness, openness, and extroversion). Therefore, it may be that the digit ratio is more strongly associated with other personality characteristics for females rather than characteristics associated with psychopathy. Given these divergent findings, future research should continue to examine the role that prenatal hormone exposure has on personality traits in females, such as psychopathy. Additionally, it should also be noted that no significant associations were observed between



Notes: Estimated using the WLSMV estimator; $^{**}p < .01$; $^{*}p < .05$.

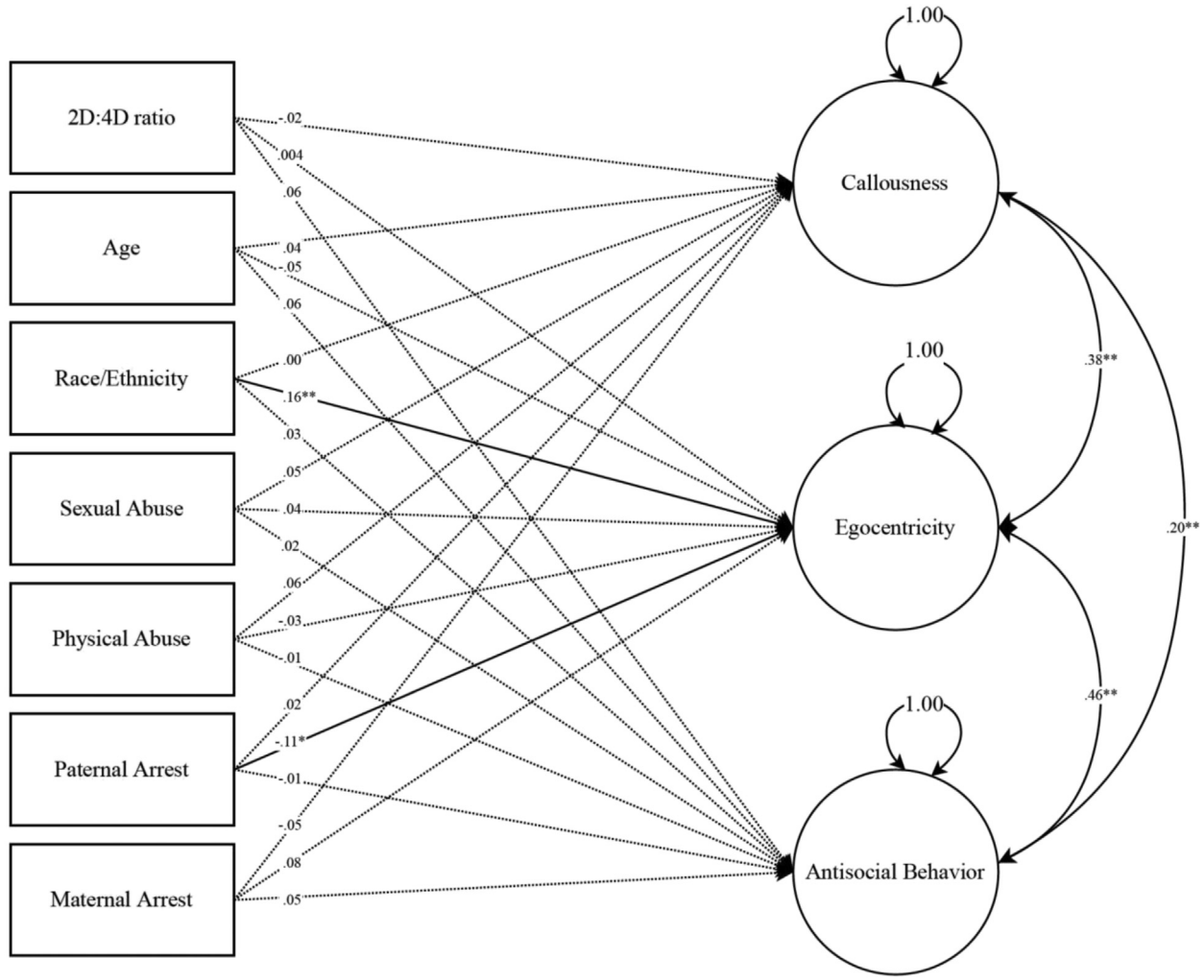
Figure 2. Standardized Regression Results for the 3-Factor Model for Males.

psychopathy and physical and sexual abuse within the study. Null findings may be the result of the small sample of individuals who indicated prior sexual and physical abuse, where roughly 44 and 36 individuals reported sexual and physical abuse respectively.

The current study has several strengths. First, it is the largest study, to date, to analyze relations between the 2D:4D ratio and psychopathy across sex while controlling for a host of covariates. It also the only study that incorporates a 3-factor model of psychopathy to further assess the association between the digit ratio and separate core primary psychopathic characteristics (i.e., egocentricity and callousness). Despite these major strengths, there are several limitations. First, the main unit of analysis in this study consisted of college students enrolled in introductory criminal justice courses. Examining psychopathy in college samples is not unusual (Blanchard et al., 2016; Lee and Salekin, 2010; Levenson et al., 1995), but the findings are limited in utility and generalizability. Only a handful of studies have investigated the role of the 2D:4D ratio and personality, in particular, psychopathy, with one using a community sample (Marchegiani et al., 2018) and two using university samples (Blanchard and Lyons, 2010; Blanchard et al., 2016). Therefore, replication is needed as current research is limited in sample size and populations. Future studies should examine relations between 2D:4D ratios and psychopathy in other samples, including forensic and incarcerated samples of adolescents and adults. Additionally, given the continued debate on how best to operationalize psychopathy, future works replicating these findings should consider additional measures of psychopathy including the Psychopathy Checklist-Revised (PCL-R; Hare, 2003) or the Self-Report Psychopathy Scale-III (SRP-III; Neumann et al., 2012).

A second limitation involves the use of digit ratios as a proxy measure for prenatal testosterone (Yildirim and Derksen, 2012). Consistent with the use of proxy measures of hormones, the 2D:4D ratio as a biomarker for precise levels of prenatal testosterone should be interpreted with caution (Turanovic et al., 2017). One criticism to using the digit ratio as a measurement for prenatal testosterone is that digit ratios may not only be affected by prenatal androgens, but rather genetics, suggesting heritability rather than an androgenic effect in fetal development (Breedlove, 2010; Gobrogge et al., 2008). Researchers should consider using other forms of indirect measures for prenatal testosterone exposure, including adult facial features (i.e., facial masculinity; Whitehouse et al., 2015) and/or anogenital distance (AGD) to measure early hormonal influences on behavior (Swan et al., 2005). Furthermore, this study did not ask respondents to report their handedness (i.e., if they are left- or right-handed). Handedness may be a product of neurobiological lateralization and may be an important indicator to consider in future works.

Finally, the digit ratio had a small effect within the entire model. This is unsurprising given the biological measurement used. Although statistically significant, the digit ratio represents a measurement for hormone exposure during utero, which is expected to only account for a small



Notes: Estimated using the WLSMV estimator; $^{**}p < .01$; $^{*}p < .05$.

Figure 3. Standardized Regression Results for the 3-Factor Model for Females.

portion of the variance between prenatal hormone exposure and psychopathic characteristics while controlling for other relevant covariates.

5. Conclusion

This study provides additional evidence that the right hand 2D:4D ratio is associated with the egocentricity domain of psychopathy among males. This finding possibly indicates that greater exposure to prenatal testosterone in males may be associated with an increased likelihood of developing interpersonal traits centered on the drive to manipulate and take advantage of others, lie, control, or blame others. This may help explain the development of psychopathy as it pertains to personality and behaviors in males through neurohormonal and prenatal androgenic influences observed within a sexually dimorphic construct and provides evidence of the importance in assessing the 2D:4D ratio among males and females separately. Findings also highlight the importance of assessing relations between the digit ratio and individual (primary) psychopathic characteristics separately as the digit ratio may be associated with specific personality characteristics. Rather, different components within the psychopathy construct may be differentially affected by prenatal testosterone as a result of sex, further supporting possible endocrine influence of prenatal androgens on personality.

Declarations

Author contribution statement

Katherine Perez; Eric Connolly: Analyzed and interpreted the data; Wrote the paper.

Danielle Boisvert; Todd Armstrong: Conceived and designed the experiments: Contributed reagents, materials, and analysis tools; Analyzed and interpreted the data.

Eric Cooke; Jessica Wells; Richard Lewis; Matthias Woeckener: Conceived and designed the experiments; Performed the experiments, contributed reagents, materials, and analysis tools; Analyzed and interpreted the data; Wrote the paper.

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The data that has been used is confidential.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

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Appendix A

Three-Factor Model of Psychopathy
Callousness

1. Even if I were trying very hard to sell something, I wouldn't lie about it.
2. Cheating is not justifiable because it is unfair to others.
3. I feel bad if my words or actions cause someone else to feel emotional pain.
4. I make of point of trying not to hurt others in pursuit of my goals.

Egocentricity

5. In today's world, I feel justified in doing anything I can get away with to succeed.
6. My main purpose in life is getting as many goodies as I can.
7. I enjoy manipulating other people's feelings.
8. I tell other people what they want to hear so that they will do what I want them to do.
9. For me, what's right is whatever I can get away with.
10. Success is based on survival of the fittest; I am not concerned about the losers.
11. Making a lot of money is my most important goal.
12. I let others worry about higher values; my main concern is with the bottom line.
13. I often admire a really clever scam.
14. People who are stupid enough to get ripped off usually deserve it.

Antisocial

15. I am often bored.
16. I quickly lose interest in tasks I start.
17. I have been in a lot of shouting matches with other people.
18. I find myself in the same kinds of trouble, time after time.
19. When I get frustrated, I often "let off steam" by blowing my top.

Response Categories: 4-Point Likert scale (0 = *Strongly Disagree*, 1 = *Disagree Somewhat*, 2 = *Agree Somewhat*, 3 = *Strongly Agree*).

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