THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF PSYCHOLOGY

PRENATAL ANDROGEN EFFECTS ON RISKY BEHAVIOR: SENSATION SEEKING AND RISK-TAKING IN INDIVIDUALS WITH CONGENITAL ADRENAL HYPERPLASIA

TIMOTHY GROH
SPRING 2017

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Psychology
with honors in Psychology

Reviewed and approved* by the following:

Sheri Berenbaum
Professor of Psychology and Pediatrics
Thesis Supervisor

Frank Hillary
Associate Professor of Psychology
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

Abstract

There are sex differences in risk-taking and related personality traits. Boys and men engage in more risky behavior than do girls and women. Sex differences in risky behavior may be partly influenced by early hormones. This hypothesis was tested in this study using the natural experiment congenital adrenal hyperplasia (CAH), a genetic disorder that results in exposure to high levels of androgens in utero. The personality trait sensation seeking and an experimental measure of risk-taking were assessed as part of a long-term study. At Time 1, 61 adolescents and adults (ages 16 to 27 years), including 33 girls and women with CAH and 11 boys and men with CAH, completed a sensation seeking questionnaire. At Time 2, 28 adults (ages 18 to 37 years), including 13 women and 3 men with CAH, completed the same measure of sensation seeking and an experimental measure of risk-taking. Unaffected same-sex relatives were controls. Unaffected males were hypothesized to score higher than unaffected females, and females with CAH were hypothesized to score higher than unaffected females on sensation seeking and risk-taking. At Time 1, unaffected males scored higher than unaffected females on sensation seeking and on the thrill and adventure seeking and boredom susceptibility subscales of sensation seeking, but not on the other two subscales. Females with CAH scored higher than unaffected females on thrill and adventure seeking, but not on the other subscales. At Time 2, there were no sex differences and no differences between females with versus without CAH on sensation seeking or risk-taking. The results do not allow firm conclusions about prenatal androgen effects on sensation seeking or risk-taking, but suggest that prenatal androgens may masculinize thrill and adventure seeking. Failure to find hypothesized effects may be due to limited statistical power.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Primary thanks are due to the girls, boys, women, and men with CAH who made this work possible and helped advance scientific understanding of gender development through their participation. A special thanks to those who have participated in Dr. Berenbaum's research over many years and phases of investigation. This long-term involvement also highlights the crucial role played by the Berenbaum Lab. Everyone who has been part of the lab has been vital in maintaining relationships with participants and keeping operations running smoothly. I would like to thank in particular Tina Bryk, Adriene Beltz, and all the undergraduate students with whom I shared the pleasure of learning and the learned the pleasure of doing quality work. The resulting environment has been my academic and intellectual home base over the past four years. I would also like to acknowledge my honors advisor, Dr. Frank Hillary, the Department of Psychology, and the Schreyer Honors College for their support of my thesis. Funding for this work was provided in part by NIH grants HD19644 and MH099617 and a Schreyer Summer Research Grant. Lastly, Dr. Berenbaum, thank you for all that you have done to support not only my thesis but also my growth, development, and success. You have provided me with wonderful opportunities over the past four years, and I am grateful for your effort, challenge, patience, and guidance. You are forever ingrained in my scientific and intellectual conscience, and your influence will reverberate onward. Thank you.

Introduction

Why do some people willingly parachute out of planes while others refuse to climb the high diving board? What causes one person to gamble on uncertain investments and another person to eschew any chance of financial loss? Differences in risky behavior are the subject of much curiosity. They are also the subject of public concern: risky behaviors have been implicated in areas of social consequence ranging from health outcomes (Kann et al., 2016) to the stability of financial markets (Coates & Herbert, 2008; Kandasamy et al., 2014).

Risky behavior is characterized by uncertainty of outcome and the possibility of gain, offset by the possibility of loss. Risky behavior consists of both the personality traits that dispose an individual to take risks and the manifestation of those traits. Risk-taking is not driven by a single trait (Figner & Weber, 2011), but sensation seeking is one personality trait that is particularly useful for studying risky behavior (Lauriola, Panno, Levin, & Lejuez, 2014; Steinberg, 2010; Steinberg et al., 2008). Sensation seeking is "the seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experience" (Zuckerman, 1994, p. 27). High sensation seekers appraise risk as lower than do low sensation seekers (Horvath & Zuckerman, 1993; Zuckerman, 1979), and they are more likely to take risks (reviewed in Zuckerman, 2007). Furthermore, sensation seeking is suggested to be the common factor that accounts for associations among different types of risky behaviors (Zuckerman, 2007, p. 65).

In the context of the most popular conceptualization of personality, the Five Factor Model of personality (Block, 2010), high sensation seekers are characterized by higher levels of

Openness to Experience and Extraversion and lower levels of Conscientiousness and Agreeableness compared to low sensation seekers (Aluja, García, & García, 2003; Dahlen & White, 2006; Zuckerman, Kuhlman, Joireman, Teta, & Kraft, 1993). Neuroticism does not differ between high and low sensation seekers (Dahlen & White, 2006; Zuckerman et al., 1993). Sensation seeking correlates most strongly with the E5- Excitement Seeking facet of Extraversion (r = .58) (Aluja et al., 2003).

There is a moderate-sized sex difference in sensation seeking. Across the lifespan, boys and men score higher than girls and women (Cross, Cyrenne, & Brown, 2013). Developmental changes in sensation seeking involve increasing levels from age 9 to a peak around age 15, followed by steadily declining levels thereafter. The size of the sex difference in sensation seeking remains relatively stable across much of development (Ball, Farnill, & Wangeman, 1984; De Moor, Beem, Stubbe, Boomsma, & De Geus, 2006; Roth, Schumacher, & Brähler, 2005; Russo et al., 1993; Steinberg et al., 2008; Zuckerman, Eysenck, & Eysenck, 1978).

As would be expected, some individual subcomponents of sensation seeking show sex differences. The four subscales of the main measure of sensation seeking are thrill and adventure seeking (TAS), disinhibition (DIS), boredom susceptibility (BS), and experience seeking (ES) (Zuckerman et al., 1978). Across the lifespan, boys and men score higher than girls and women on TAS, DIS, and BS, and the differences are small-to-moderate (d = .42, d = .46, and d = .35, respectively); there is not a significant sex difference on ES (Cross et al., 2013). Developmental changes in the subscales follow the same pattern as total sensation seeking, increasing from age 9 to 15 followed by steady decline thereafter, and the size of the sex differences in the subscales remains relatively stable across development (Ball et al., 1984; De Moor et al., 2006; Zuckerman et al., 1978).

Consistent with evidence about personality, boys and men also engage in more risk-taking behavior across the lifespan than do girls and women, though this difference is typically small (Byrnes, Miller, & Schafer, 1999; Charness & Gneezy, 2012; Morrongiello & Matheis, 2007; Zuckerman & Kuhlman, 2000). There are low base rates for some risky behaviors (e.g., problem gambling; Welte, Barnes, Tidwell, & Hoffman, 2008), but not all (e.g., risky driving, risky sexual activity; Kann et al., 2016). The size of the sex difference is not consistent across development for all forms of risk-taking. For example, the size of the sex difference for physical risk-taking remains constant from early to late childhood (Morrongiello & Matheis, 2007), whereas the size of the sex difference for risky driving increases from adolescence into young adulthood, and the size of the sex difference for gambling remains constant from adolescence into young adulthood (Byrnes et al., 1999). Changes in the size of the sex difference in different risky behaviors across development has been attributed to asynchronous increases and decreases in multiple risk-related personality traits between males and females (Shulman, Harden, Chein, & Steinberg, 2015).

Understanding the causes of the sex difference in risky behavior is important and can shed light onto the causes of individual differences in risky behavior since factors that contribute to differences between the sexes often also contribute to variation within the sexes (Blakemore, Berenbaum, & Liben, 2009, p. 151). In general, sex differences in behavior have been seen to result from many factors, including gendered socialization, gender cognitions, and sex-related biology. Gendered socialization explanations typically emphasize learning and social learning theories, hypothesizing that some sex differences in behavior result from reinforcement, punishment, imitation, and modeling of gender-appropriate behavior (e.g., Bussey & Bandura, 1984). Gender cognitive explanations, such as gender schema theory, emphasize the importance

of gender identity and gender stereotypes in schematic processing of sex-related information, resulting in sex differences in behavior (e.g., Martin & Halverson, 1981). Sex-related biological explanations consider sex-typed behaviors to result from the same factors that produce physical sex differences, that is, genes on the sex chromosomes and sex hormones (e.g., Arnold, 2009).

The focus of this work concerns sex hormone effects on the sex difference in sensation seeking and risk-taking. Sex hormones are endogenous steroids that differ in concentration between males and females and are involved in sexual differentiation and reproduction. The two classes of sex hormones are estrogens and androgens. Both estrogens and androgens are found in both sexes, but estrogens are found in higher concentration in females than in males (beginning at puberty), and androgens, including the hormone testosterone, are found in higher concentration in males than in females (between weeks 8-24 of gestation, between postnatal months 2-3, and after puberty) (Achermann & Hughes, 2016).

Sex hormones are generally seen to affect behavior in two ways. First, sex hormones during sensitive periods early in life can cause permanent changes in neural development, thus altering subsequent behavior; these effects are termed "organizational." Second, circulating hormones throughout life can temporarily alter some brain structures, thus temporarily modifying behavior; these effects are termed "activational." Notably, however, this distinction is not as clear as originally hypothesized. The cellular effects of sex hormones do not differ between organizational and activational effects on behavior (Arnold & Breedlove, 1985), and the brain may remain sensitive to organizational effects up through puberty (Berenbaum & Beltz, 2011; Schulz, Molenda-Figueira, & Sisk, 2009; Sisk & Zehr, 2005) and at other periods (e.g., pregnancy; Kinsley et al., 1999).

The organizational effects of early androgens on the sex difference in sensation seeking and risk-taking are the focus of this work. In nonhuman animals, exposure to sex hormones early in development has been shown to have permanent effects on sex-typed behaviors. In particular, early androgens have been shown to masculinize and defeminize sexual behavior, aggression, and rough play in species ranging from rodents to nonhuman primates (for reviews, see de Vries, Fields, Peters, Whylings, & Paul, 2014; McCarthy, 2011; Ryan & Vandenbergh, 2002; Thornton, Zehr, & Loose, 2009; Wallen, 2005, 2009). There is also some evidence from rodents that early androgens affect risky behaviors such as exploration (Ray & Hansen, 2004) and novelty seeking (Palanza, Morley-Fletcher, & Laviola, 2001), though the direction of the sex difference in rodent novelty seeking is not consistent throughout the literature (Davis, Clinton, Akil, & Becker, 2008; Hughes, 1968; Laviola, Macrì, Morley-Fletcher, & Adriani, 2003; Palanza et al., 2001; Ray & Hansen, 2004; Russell, 1977; Toledo-Rodriguez & Sandi, 2011). The study of early androgen effects on sex-typed human behaviors is predicated on this work, and results generally confirm it.

In human beings, male fetuses experience a surge of testosterone production between approximately weeks 8 to 24 of gestation, resulting in large sex differences in testosterone during this period (Abramovich , 1974; Abramovich & Rowe, 1973; Dattani & Gevers, 2016; Reyes, Boroditsky, Winter, & Faiman, 1974; Rodeck, Gill, Rosenberg, & Collins, 1985). This causes sexual differentiation of the external genitalia, reproductive system, and likely also the brain and subsequent behavior (Blakemore et al., 2009, p. 47; Collaer & Hines, 1995). Critically, however, experimental manipulation of hormones in human fetuses is not possible, thus creating challenges for studying the effects of prenatal androgens on sex-typed behaviors. Fortunately, several methods have been developed to address this question (for reviews, see Berenbaum & Beltz, 2016; Blakemore et al., 2009; Cohen-Bendahan, van de Beek, & Berenbaum, 2005b).

Organizational effects of prenatal androgens on sex-typed human behaviors have been studied in individuals with endocrine disorders where only one component of sexual differentiation has been "manipulated" by nature (e.g., a genetic mutation), producing a dissociation among aspects of sexual differentiation. Such natural experiments can provide strong evidence for a causal effect of the manipulated component of sexual differentiation on sex-typed behavior; this assumes that there is control for other factors that might influence the behavior of interest and rule out alternative explanations.

The most studied natural experiment is congenital adrenal hyperplasia (CAH), a condition that results in exposure to high levels of androgens beginning early in gestation due to a genetic mutation causing an enzyme deficiency in the cortisol biosynthesis pathway. When individuals are diagnosed with CAH after birth, they are treated with glucocorticoids to normalize androgen levels (Speiser et al., 2010). If high levels of prenatal testosterone contribute to sexual differentiation of the human brain, then subsequent behavior in girls and women with CAH should be more male-typical and less female-typical than that of unaffected girls and women. Critically, girls and women with CAH are reared and identify as female, so any behavioral masculinization or defeminization can be attributed to their increased prenatal androgen exposure. Extensive evidence has shown that females with CAH are more male-typical and less female-typical than unaffected females in several behavioral domains including toy play, activity and career interests and participation, and spatial ability (for reviews, see Berenbaum & Beltz, 2016; Berenbaum & Beltz, 2011; Cohen-Bendahan et al., 2005b; Hines, 2011; Hines, 2010; Hines, Constantinescu, & Spencer, 2015). To date, sensation seeking and risk-taking have not been examined in girls and women with CAH, though some related characteristics (e.g., sex-typed personality traits) have been; this evidence is reviewed later.

Nevertheless, CAH is not a perfect experiment. Females with CAH differ from females without CAH in several ways beyond increased prenatal androgens, and these might affect behavior in girls and women with CAH. First, girls with CAH have masculinized genitalia that may elicit more male-typical socialization. However, girls with CAH have been shown to play more with boys' toys regardless of whether or not one of their parents is in the same room; in fact, the presence of their parent may actually decrease their play with boys' toys (Nordenström, Servin, Bohlin, Larsson, & Wedell, 2002; Servin, Nordenström, Larsson, & Bohlin, 2003). Furthermore, parents have been shown to give more positive feedback for playing with girls' toys to daughters with CAH than to unaffected daughters (Pasterski et al., 2005). In contrast, one study found that parents offer more encouragement for play with boys' toys to daughters with CAH than to unaffected daughters, but this was suggested to be in response to their increased interest in boys' toys relative to unaffected daughters (Wong, Pasterski, Hindmarsh, Geffner, & Hines, 2013). Parental socialization is unlikely to fully account for masculinized behavior of girls with CAH, though it may contribute.

Second, hormones other than androgens (e.g., cortisol and aldosterone) are also abnormal in CAH (Speiser & White, 2003) and might affect behavior. For example, cortisol may affect memory which could impact behavior (Het, Ramlow, & Wolf, 2005). However, boys and men with CAH are generally behaviorally similar to unaffected boys and men, suggesting that behavior in girls and women with CAH is unlikely influenced by these other hormones (Berenbaum, 1999; Berenbaum & Hines, 1992; Berenbaum & Resnick, 1997; Hines et al., 2015; Leveroni & Berenbaum, 1998). Third, living with a chronic disease may affect behavior. Again, however, the lack of sex-typed behavioral effects in boys and men with CAH compared to unaffected boys and men does not support this. Additionally, girls with diabetes scored similarly

to control girls on measures of sex-typed behavior, whereas the scores of girls with CAH were more masculine and less feminine than the girls with diabetes (Hall et al., 2004). Fourth, imperfect disease control may result in increased postnatal androgen exposure, which could affect behavior. However, women treated for CAH are more likely to have low rather than high postnatal androgen levels (Helleday, Siwers, Ritzen, & Carlström, 1993b). Additionally, masculinized toy play has been shown to relate to indicators of prenatal but not postnatal androgen excess (Berenbaum, Duck, & Bryk, 2000). Furthermore, masculinized toy play and gender-role behavior have been shown to relate positively to degree of prenatal androgen exposure inferred from genotype (Hall et al., 2004; Nordenström et al., 2002). In sum, these factors do not offer compelling alternative explanations for findings in CAH.

Another natural experiment to study prenatal androgen effects on sex-typed behaviors and corroborate findings from CAH is complete androgen insensitivity syndrome (CAIS). Individuals with CAIS have a 46,XY karyotype and, therefore, develop normal testes that produce male-typical levels of androgens; however, due to defective or absent androgen receptors, they cannot respond to androgens, so have no effective androgen exposure. This results in female-typical physical development and female-typical rearing. If androgens affect sex-typed behaviors, individuals with CAIS should be female-typical because they cannot respond to their androgens (Hines, Ahmed, & Hughes, 2003; Wisniewski et al., 2000). Although there are few behavioral studies of CAIS (because it is very rare; Achermann & Hughes, 2016), the evidence is consistent with this hypothesis. Individuals with CAIS have female-typical gender identity, sexual orientation, and gender-role behavior (Hines et al., 2003; Mazur, 2005; Wisniewski et al., 2000); they perform worse than control men and women on some spatial abilities (Imperato-McGinley, Pichardo, Gautier, Voyer, & Bryden, 1991); and they show

female-typical brain activation for mental rotation (van Hemmen et al., 2016) and in response to sexual stimuli (Hamann et al., 2014). CAIS is not a perfect experiment either, because effective androgen exposure is confounded with female-typical rearing and circulating hormones. Nevertheless, the evidence from CAIS is consistent with prenatal androgenic organization of sex-typed behaviors and converges with evidence from CAH and from studies of typical samples, discussed next.

Organizational effects of prenatal androgens on sex-typed human behaviors have also been studied in typically-developing individuals. This approach circumvents the challenges of studying rare populations, and it provides valuable information about the influence of normal variation in prenatal androgens on normal variation in sex-typed behaviors. In these studies, levels of prenatal androgens are either assayed directly (i.e., by sampling amniotic fluid) or inferred indirectly (i.e., from physical characteristics related to prenatal androgen exposure, such as aspects of genital anatomy or gestation with a co-twin, or from testosterone levels in maternal blood) and analyzed in relation to individual differences in sex-typed behavior, separately by sex (Berenbaum & Beltz, 2016; Constantinescu & Hines, 2012). Limitations of directly assaying fetal androgen levels are practical, ethical, and theoretical. Performing amniocentesis to obtain amniotic fluid is a risk to the fetus, so it is limited to women who undergo the procedure for medical purposes (Constantinescu & Hines, 2012), and it is not clear how amniotic testosterone levels relate to fetal plasma testosterone levels (Abramovich, 1974; Gitau, Adams, Fisk, & Glover, 2005; Rodeck et al., 1985). Limitations of indirectly inferring prenatal androgen levels from physical markers mainly concern which markers accurately reflect normal variation in prenatal androgens (e.g., Berenbaum, Bryk, Nowak, Quigley, & Moffat, 2009). Likewise, it is not clear how testosterone levels in maternal blood relate to fetal testosterone levels

(Abramovich, 1974; Cohen-Bendahan, van Goozen, Buitelaar, & Cohen-Kettenis, 2005c; Gitau et al., 2005; Rodeck et al., 1985). Nevertheless, studies of normal variation in prenatal androgens in typically-developing individuals have provided convergent evidence that prenatal androgens affect sex-typed toy play and activity interests (Auyeung et al., 2009; Hines et al., 2002; Pasterski et al., 2015) and spatial ability (Auyeung et al., 2012; Heil, Kavšek, Rolke, Beste, & Jansen, 2011; Vuoksimaa et al., 2010), though some studies have failed to find effects (e.g., Auyeung et al., 2012; Grimshaw, Sitarenios, & Finegan, 1995; Knickmeyer et al., 2005; van de Beek, Goozen, Buitelaar, & Cohen-Kettenis, 2009).

In sum, robust and consistent evidence from natural experiments, along with converging evidence from studies of natural variation in prenatal androgen exposure, strongly supports the hypothesis that prenatal androgens masculinize and defeminize some sex-typed human behaviors, most prominently toy play, activity and career interests and participation, and spatial ability (Berenbaum & Beltz, 2016). There is relatively little evidence regarding prenatal androgen effects on sensation seeking and risk-taking, but there is some suggestive evidence from natural experiments and studies of natural variation in prenatal androgen exposure in typically-developing individuals, discussed next.

There is evidence that prenatal androgens affect sex-typed personality traits. Compared to unaffected females, girls and women with CAH are less empathic and maternal (Helleday, Edman, Ritzén, & Siwers, 1993a; Mathews, Fane, Conway, Brook, & Hines, 2009), less interested in infants (Leveroni & Berenbaum, 1998), and more physically aggressive (Berenbaum & Resnick, 1997; Mathews et al., 2009; Pasterski et al., 2007). However, not all personality traits that show sex differences differ between girls and women with CAH and unaffected females. One study did not find a difference on dominance between girls and women

with CAH and unaffected females, but this may have been due to low statistical power (Mathews et al., 2009). One study of individuals with CAIS found them to score lower on assertiveness and higher on tender-mindedness than control men, in parallel with the sex difference on these traits (Hines et al., 2003). Another natural experiment in which children were prenatally exposed to androgenic hormones for medical purposes found that they were more likely than their unexposed, sex-matched siblings to be aggressive (Reinisch, 1981). Studies of typically-developing children have found that amniotic testosterone relates negatively to empathy among boys (Chapman et al., 2006; Knickmeyer, Baron-Cohen, Raggatt, Taylor, & Hackett, 2006).

The only data on androgen effects on sensation seeking and risk-taking are indirect, coming from studies of fraternal twins. Females with a male co-twin are thought to be exposed to increased androgens compared to females with a female co-twin (Miller, 1994; Resnick, Gottesman, & McGue, 1993). This hypothesis is based on evidence from nonhuman animals. In rodents and swine, females positioned between two male fetuses in utero show masculinized aspects of postnatal anatomy, physiology, and behavior due to the transfer of androgens from the adjacent males (Clark & Galef, 1998; Even, Dhar, & vom Saal, 1992; Rohde Parfet et al., 1990; Ryan & Vandenbergh, 2002; vom Saal, 1989). Fraternal twin studies are not perfect experiments. First, human female twins may not receive as much prenatal androgen exposure as females in nonhuman species that are flanked by males. Nonhuman females that gestate next to only one male are typically not as masculinized as those that gestate between two males (Ryan & Vandenbergh, 2002). Second, androgen transfer between co-twins has not been directly demonstrated, though it is possible (Meulenberg & Hofman, 1991; Ross & Beall, 2013). This likely occurs by diffusion of androgens across the amniotic sacs, rather than transfer through maternal circulation (Cohen-Bendahan et al., 2005). Consistent with the hypothesized transfer of

androgens from the male to the female twin, girls and women with a male co-twin have been found to be masculinized on several physical, cognitive, and gender-role traits and sex-related psychiatric symptoms compared to girls and women with a female co-twin, but several studies have failed to see such effects (reviewed in Berenbaum & Beltz, 2016; Cohen-Bendahan et al., 2005b).

Two studies have found girls and women with a male co-twin to be masculinized on sensation seeking compared to girls and women with a female co-twin (Resnick et al., 1993; Slutske, Bascom, Meier, Medland, & Martin, 2011). Importantly, one study also controlled for postnatal socialization effects by showing that women with a female co-twin did not differ from women with a female co-twin and a close-in-age older brother, ruling out sibling imitation as a potential confound (Slutske et al., 2011). However, another study failed to find a difference between girls with a boy versus a girl co-twin on sensation seeking (Cohen-Bendahan, Buitelaar, van Goozen, Orlebeke, & Cohen-Kettenis, 2005a). This may reflect methodological issues such as small sample size and potentially confounding activational hormone effects. The two studies that found an effect of co-twin sex on sensation seeking had a sample size of 4,355 (Resnick et al., 1993) and 844 (Slutske et al., 2011), whereas the study that did not find an effect had a sample size of 203 (Cohen-Bendahan et al., 2005a). Furthermore, positive findings were seen in adults, but negative ones in children (Cohen-Bendahan et al., 2005a). There is variation in the timing and sequence of pubertal changes (Dahl, 2004), and sensation seeking has been positively associated with pubertal development when controlling for age (Martin et al., 2002; Steinberg et al., 2008), so variation in pubertal development among the children (all of whom were age 13) may have confounded the results.

The two studies of fraternal twins that found an effect of co-twin sex on sensation seeking also found sex differences and co-twin effects on some of the sensation seeking subscales. One found that boys and men scored higher than girls and women on TAS, DIS, and BS, and girls with a boy co-twin scored higher than girls with a girl co-twin on DIS and ES, despite ES not showing a sex difference (Resnick et al., 1993). The other found that men scored higher than women on all four subscales, and women with a male co-twin scored higher than women with a female co-twin on TAS and ES (Slutske et al., 2011).

Other fraternal twin studies of related personality traits and risky behaviors are consistent with prenatal androgen masculinization of sensation seeking and risk-taking. Relative to women with a female co-twin, women with a male co-twin have been found to be masculinized on conservatism (Miller & Martin, 1994), which has been moderately to strongly negatively correlated with sensation seeking (all *r*s < -.45; Glasgow, Cartier, & Wilson, 1985; Kish, Netterberg, & Leahy, 1973; Pearson & Sheffield, 1975). Compared to girls and women with a female co-twin, girls and women with a male co-twin have also been found to be masculinized on willingness to break social rules, consistent with increased sensation seeking (Loehlin & Martin, 1999). Another risky behavior, pathological alcohol use, also shows effects of co-twin sex. Women with a male co-twin report more alcohol use disorder symptoms than do women with a female co-twin when postnatal socialization effects are controlled (Ellingson, Slutske, Richmond-Rakerd, & Martin, 2013), and this has been supported by the finding that co-twin sex moderates the genetic risk for pathological drinking in girls (Meyers et al., 2014).

The bulk of evidence from fraternal twin studies suggests that sensation seeking and related personality traits and risky behaviors are affected by prenatal androgens. This is consistent with the evidence for prenatal androgen effects on other sex-typed personality traits

and behaviors seen in individuals with CAH and CAIS. Nevertheless, these data are inadequate to conclude that prenatal androgens affect sensation seeking and risk-taking for several reasons. First, fraternal twin studies are not perfect experiments. Second, not all personality traits and behaviors that show sex differences show differences between girls and women with CAH and unaffected females (Hines, 2010), so it is possible that sensation seeking and risk-taking are not affected by prenatal androgens. Third, the evidence from fraternal twin samples lacks convergent support from natural experiments. Causal inferences would be most strongly supported if girls and women with CAH are found to score higher on these characteristics than unaffected girls and women, in parallel with the sex difference.

Therefore, the purpose of this study was to evaluate the effect of prenatal androgens on sensation seeking and risk-taking in adolescents and adults with CAH. I hypothesized that girls and women with CAH would score higher on sensation seeking and risk-taking than unaffected girls and women. I also hypothesized that girls and women with CAH would score higher on the TAS, DIS, and BS subscales of sensation seeking than unaffected girls and women. Boys and men with CAH were also studied and not expected to differ from unaffected boys and men, as they have been shown not to differ on most aspects of behavior examined (Berenbaum, 1999; Berenbaum & Hines, 1992; Berenbaum & Resnick, 1997; Hines et al., 2015; Leveroni & Berenbaum, 1998); they also provide a control for other hormone abnormalities in CAH and the effects of living with a chronic disease.

Method

Participants

Participants were part of a longitudinal study of early hormonal influences on sex-typed behavior and were initially recruited through pediatric endocrine clinics or a family support group. Self-reported sensation seeking was assessed during the longitudinal study (Time 1), along with other measures reported elsewhere (Beltz, Swanson, & Berenbaum, 2011; Berenbaum, 1999; Berenbaum & Bailey, 2003; Berenbaum, Bryk, & Beltz, 2012; Berenbaum, Bryk, Duck, & Resnick, 2004; Berenbaum et al., 2000; Berenbaum & Hines, 1992; Berenbaum & Resnick, 1997; Berenbaum & Snyder, 1995; Leveroni & Berenbaum, 1998; Resnick, Berenbaum, Gottesman, & Bouchard, 1986). A subset of 13 of these individuals participated in a follow-up neuroimaging and behavioral study (Time 2) in which self-reported sensation seeking was assessed again, along with an experimental measure of risk-taking. At Time 1, data on sensation seeking were available for 61 adolescents and adults ranging in age from 16.2 to 26.5 years, *M* (*SD*) = 20.0 (2.6) years. At Time 2, data on sensation seeking and risk-taking were available for 28 adults ranging in age from 18.4 to 37.0 years, *M* (*SD*) = 27.4 (4.7) years. Table 1 shows the number and age of participants at Time 1 and Time 2 by sex and status (CAH, control). Groups did not differ significantly in age at Time 1 nor at Time 2. Control participants are unaffected same-sex siblings and first cousins, providing a control for general genetic and environmental effects on behavior.

Measures

Zuckerman's Sensation Seeking Scale Form V (ZSSS-V). All participants completed the ZSSS-V, a self-report measure of sensation seeking. It consists of 40 items presented as a forced choice between two options, one sensation seeking option (e.g., "I would like to take up the sport of water skiing;" "I get bored seeing the same old faces.") and one lower sensation option (e.g., "I would not like to take up water skiing;" "I like the comfortable familiarity of everyday friends."). Participants were asked to select the action or preference that that better describes their feelings. If the sensation seeking option is selected, the item is scored as a 2; if the lower sensation option is selected, the item is scored as a 1. The items are summed to produce a total score (minimum score of 40 and maximum score of 80). The total score is composed of four subscales, each consisting of ten items (each with a minimum score of 10 and maximum score of 20): thrill and adventure seeking (TAS), disinhibition (DIS), boredom susceptibility (BS), and experience seeking (ES). For the total and the four subscales, higher scores reflect more of the trait (Zuckerman, 1994). Most studies use this original scoring method (e.g., Aluga et al., 2003; Dahlen & White, 2006; Trimpop, Kerr, & Kirkcaldy, 1999; Zuckerman et al., 1978).

In this study, the total score and the four subscale scores were computed by averaging; the relevant items for the total and the four subscales were summed and divided by the total number of items present for each, as done by Slutske et al. (2011). Averaging produces a total score and subscale scores ranging from 1 to 2, with higher scores reflecting more of the trait. This also standardizes scores since some participants did not respond to some items. Subscales were considered missing if more than three of the ten items were missing, as done by Slutske et

al. (2011). At Time 1, 98% of participants had complete data for all four subscales; at Time 2, all participants had complete data.

The ZSSS-V is a valid and reliable measure of a real-world sensation seeking behaviors. Higher ZSSS-V scores relate negatively to risk perception (moderate-sized relationship) and predict more risk-taking (small-to-moderate sized relationship for some risky behaviors, e.g., financial risk-taking, ranging to large relationship for other risky behaviors, e.g., risky criminal behavior) (Zuckerman, 2007, p. 57). High scorers have more permissive attitudes toward sex, more varied sexual experiences, are more willing to try novel and unusual foods, and have more interest in complex, ambiguous, and intense stimuli than do low scorers (Zuckerman, 1994). A review of published data found that the mean internal reliability for the ZSSS-V total score is .76 and the mean internal reliabilities for the subscales are .75 for TAS, .69 for DIS, .62 for BS, and .69 for ES (Deditius-Island & Caruso, 2002). The ZSSS-V total score has high test-retest reliability (.94 for a three-week interval; Zuckerman, Buchsbaum, & Murphy, 1980). A meta-analysis showed that boys and men score higher than girls and women on ZSSS-V total sensation seeking (d = .46) and on three of the four subscales: TAS (d = .42), DIS (d = .46), and BS (d = .35); the difference on ES is not significant (d = .04) (Cross et al., 2013).

At Time 1, participants completed a modified version of the ZSSS-V with only 36 items; four items were removed because they queried drug use and sexual behavior, and Time 1 participants included minors. At Time 2, participants were all adults and completed the full questionnaire.

Balloon Analogue Risk Task (BART). At Time 2, participants also completed the Balloon Analogue Risk Task (BART), a behavioral measure of risk-taking. The BART is a computer game and consists of 30 trials of virtual balloon pumping. Participants click a mouse to

add pumps of air to a balloon, earning money for each pump. They decide when to stop adding pumps and collect the total money earned for the trial. If the balloon pops, all the money for the trial is lost. Riskiness on the BART is assessed as the adjusted average number of pumps (i.e., the average number of pumps on balloons that did not pop), with higher averages reflecting more riskiness (Lejuez et al., 2002).

The BART has high test-retest reliability (r = .82) and predicts real-world risk-taking behavior. For example, riskiness on the BART was moderately-to-strongly correlated with a variety of real-world addictive, health, and safety risk behaviors (e.g., smoking, pathological drinking, polydrug use, gambling, unsafe sex, infrequent seatbelt use), with BART scores explaining variance in these behaviors beyond that explained by demographics and risk-related personality traits (Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Lejuez et al., 2002). Men take more risks on the BART than do women (d = .63) (Lejuez et al., 2002).

Data Analysis Plan

Data from Time 1 and Time 2 were analyzed separately. The subset of participants who participated at both Time 1 and Time 2 had sensation seeking data from both time points, and their scores were analyzed separately at each time. The following hypotheses were tested in the main analyses with group comparisons: unaffected boys and men will score higher than unaffected girls and women on sensation seeking and the BART; girls and women with CAH will score higher than unaffected girls and women on sensation seeking and the BART. In exploratory analyses, the same group differences were hypothesized for the TAS, DIS, and BS subscales of sensation seeking. No hypotheses were made regarding differences between boys

and men with CAH versus unaffected boys and men, but these groups were compared as a control for other hormone abnormalities in CAH and the effects of living with a chronic disease.

Main Analyses. The main analyses proceeded in several steps. First, a correlation analysis was performed to assess whether sensation seeking or BART scores at either time point was related to participant age. Sensation seeking was hypothesized to correlate negatively with age, given that sensation seeking levels decline steadily after approximately age 15 up through age 70 (Ball et al., 1984; De Moor et al., 2006; Roth et al., 2005; Russo et al., 1993; Shulman et al., 2015; Steinberg, 2010; Steinberg et al., 2008; Zuckerman et al., 1978) and all participants are 16 or older. I had no hypothesis for the BART, given that age-related changes in risk-taking are not as uniform as sensation seeking (Byrnes et al., 1999). This study had statistical power of .65 to detect a moderate size correlation (r = -.3) between age and sensation seeking at Time 1 and power of .34 to detect a moderate size correlation between age and sensation or the BART at Time 2.

Second, group differences were examined with either an analysis of covariance (ANCOVA) or analysis of variance (ANOVA). If there was a significant correlation between age and the outcomes of interest, then age was covaried in subsequent analyses, using an ANCOVA with between-subjects factors of sex and status (CAH, control). If there was not a significant correlation between age and the outcomes, then an ANOVA was used, with between-subjects factors of sex and status. Exploratory t tests were conducted to probe group differences with greater statistical power, and effect sizes are reported in standard deviation units, d = mean difference/average standard deviation (Cohen, 1988). 95% confidence intervals are reported for effect sizes.

Statistical power for group comparisons was limited. A small difference in sensation seeking (d = .2) was expected between girls and women with CAH versus unaffected girls and women, based on the moderate size of the sex difference reported in a recent meta-analysis (d = .46; Cross et al., 2013). At Time 1, there was power of .15, and at Time 2, there was power of .12 to detect such a difference. A small-to-moderate size difference on the BART (d = .35) was expected between girls and women with CAH versus unaffected girls and women, based on the moderate-to-large size of the sex difference (d = .63; Lejuez et al., 2002). There was power of .19 to detect such a difference at Time 2. In addition to limited power, Type I error was increased as an effect of conducting multiple comparisons. To compensate, the significance level α was set at .05.

Exploratory Analyses. The exploratory analyses followed the same procedure as the main analyses. First, a correlation analysis was performed to assess whether TAS, DIS, or BS at either time point were related to participant age. These three subscales were hypothesized to correlate negatively with age, given that they have been shown to decline steadily after approximately age 15 up through age 70 (Ball et al., 1984; De Moor et al., 2006; Zuckerman et al., 1978) and all participants are 16 or older. This study had statistical power of .65 to detect a moderate size correlation (r = -.3) between age and the subscales at Time 1 and power of .34 to detect a moderate size correlation between age and the subscales at Time 2.

Second, group differences on the subscales were examined with an ANOVA or an ANCOVA with age as the covariate if there was a significant correlation between age and the subscale. Exploratory t tests were conducted to probe group differences with greater statistical power. Since the effect sizes of the sex differences on TAS, DIS, and BS are small-to-moderate (d = .42, d = .46, and d = .35, respectively; Cross et al., 2013), I expected the differences

between girls and women with CAH versus unaffected girls and women to be small (d = .2). At Time 1, there was power of .15, and at Time 2 there was power of .12 to detect such differences. The significance level α was set at .05 to adjust for multiple comparisons.

Additionally, correlation analysis was performed to examine test-retest reliability of the ZSSS-V and to determine the relationship between Time 2 participants' ZSSS-V scores and BART scores. Test-retest reliability was expected to be good, based on previous findings (Zuckerman et al., 1980). A small-to-moderate positive correlation was expected between Time 2 ZSSS-V and BART scores, based on previous findings (r = .14; Lauriola et al., 2014).

Results

Main Analyses

The aim of the main analyses was to test group differences in sensation seeking at Time 1 and group differences in sensation seeking and the BART at Time 2. On both sensation seeking and the BART, unaffected boys and men were hypothesized to score higher than unaffected girls and women, girls and women with CAH were hypothesized to score higher than unaffected girls and women, and no hypotheses were made for the comparison of boys and men with CAH versus unaffected boys and men. Neither sensation seeking nor the BART was significantly correlated with age (as detailed below), so group differences were tested using analyses of variance (ANOVAs) with between-subjects factors of sex and CAH status (affected, unaffected).

Exploratory *t* tests were conducted to probe group differences with greater statistical power, and Type I error was set at .05. One-tailed *t* tests were used to compare controls and to compare girls and women with versus without CAH, and two-tailed *t* tests were used to compare boys and men with versus without CAH. Effect sizes were calculated in standard deviation units, *d* = mean difference/average standard deviation. 95% confidence intervals were calculated around effect sizes. Descriptive statistics and effect sizes of group comparisons are reported in Table 2, and the results of statistical tests of group differences are reported in Table 3.

Time 1: Sensation Seeking. There was not a significant correlation between total sensation seeking and age, $r(59) = .03$, $p > .05$. There was a main effect of sex such that males scored higher than females on sensation seeking. There was not a significant main effect of CAH

status. There was a significant interaction between sex and CAH status such that there was a larger effect of sex among unaffected individuals than among individuals with CAH.

Exploratory *t* tests revealed that scores on sensation seeking were significantly higher for unaffected males than unaffected females, and the difference is large (see Table 2). Girls and women with CAH also scored higher than unaffected girls and women, but the difference was not significant; however, the 95% confidence interval for the sex difference spans small to large effects. Boys and men with CAH scored lower than unaffected boys and men, but the difference was not significant.

Time 2: Sensation Seeking and the BART. There was not a significant correlation between total sensation seeking and age, $r(26) = -.23$, $p > .05$. There was not a significant main effect of sex or CAH status, nor was there a significant interaction on sensation seeking. Exploratory *t* tests revealed that scores on sensation seeking were significantly lower for men with CAH than unaffected men, and the difference is large (see Table 2). There were no other significant group differences on sensation seeking. The 95% confidence interval for the sex difference on sensation seeking spans small to large effects.

There was not a significant correlation between adjusted average number of pumps on the BART and age, $r(26) = -.05$, $p > .05$. There was not a significant main effect of sex or CAH status, nor was there a significant interaction on the BART. Exploratory *t* tests revealed no significant group differences on the BART. The 95% confidence interval for the sex difference on the BART spans small to large effects.

Exploratory Analyses

The primary aim of the exploratory analyses was to examine group differences on the four subscales of sensation seeking (TAS, DIS, BS, and ES) at both Time 1 and Time 2. On TAS, DIS, and BS, unaffected boys and men were hypothesized to score higher than unaffected girls and women, girls and women with CAH were hypothesized to score higher than unaffected girls and women, and no hypotheses were made for the comparison of boys and men with CAH versus unaffected boys and men. The analysis procedure was the same as the main analyses. Descriptive statistics and effect sizes of group comparisons at Time 1 are reported in Table 4, and the results of statistical tests of group differences are reported in Table 5. Descriptive statistics and effect sizes of group comparisons at Time 2 are reported in Table 6, and the results of statistical tests of group differences are reported in Table 7.

Additionally, several correlations were examined. To determine test-retest reliability of the ZSSS-V, the correlation between ZSSS-V scores of the subset of participants who participated at both Time 1 and Time 2 was examined. To determine the relationship between sensation seeking and risk-taking, the correlation between Time 2 participants' ZSSS-V scores and BART scores was examined.

Time 1. The correlations between age and the sensation seeking subscales TAS, $r(59) = .06$, DIS, $r(59) = -.08$, BS, $r(59) = .02$, and ES, $r(59) = .09$, were not significant (all ps $> .05$). There was a significant main effect of sex on BS such that males scored higher than females. There was a significant interaction between sex and CAH status on ES such that there was a larger effect of sex among unaffected individuals than among individuals with CAH. There were no other significant main effects or interactions.

As shown in Table 4, exploratory *t* tests revealed that, on TAS, unaffected males scored higher than unaffected females and the difference is large; girls and women with CAH also scored higher than unaffected females on TAS and the difference is moderate-to-large. The sex difference on DIS was not significant, but the 95% confidence interval spans small to large effects. On BS, unaffected males scored higher than unaffected females and the difference is moderate-to-large; there was not a significant difference between girls and women with CAH versus unaffected females on BS, but the 95% confidence interval spans small to moderate-to-large effects. On ES, boys and men with CAH scored lower than unaffected males and the difference is large. There were no other significant group differences on the sensation seeking subscales at Time 1.

Time 2. The correlations between age and the sensation seeking subscales TAS, $r(26) = -.26$, DIS, $r(26) = -.03$, BS, $r(26) = -.03$, and ES, $r(26) = -.31$, were not significant (all ps $> .05$). On DIS, there was a significant main effect of sex and of CAH status such that women scored higher than men and individuals with CAH scored lower than unaffected individuals, but there was not a significant interaction between sex and CAH status. There were no other significant main effects or interactions.

Exploratory *t* tests revealed that, on DIS, women with CAH scored lower than unaffected women and the difference is large (see Table 6). There were no other significant group differences on the sensation seeking subscales at Time 2. The 95% confidence intervals for the sex difference on TAS and BS span small to large effects, and the 95% confidence interval for the sex difference on DIS spans small to small-to-moderate effects.

Correlations. The correlation between ZSSS-V scores of the subset of participants who participated at both Time 1 and Time 2 was large, $r\ (11) = .73$, $p < .01$. ZSSS-V and BART

scores were significantly negatively correlated at Time 2 (moderate-to-large relationship), r (26) = -.37, $p < .05$.

Discussion

The aim of this study was to examine the effect of prenatal androgens on sensation seeking and risk-taking in adolescents and adults, using CAH as a natural experiment. Based on evidence from fraternal twin studies, natural experiments, and studies of typically-developing children, a sex difference and an effect of CAH among females were expected on sensation seeking and the BART. Exploratory analyses were also conducted to examine prenatal androgen effects on the four subscales of sensation seeking; a sex difference and an effect of CAH among females were expected on thrill and adventure seeking, disinhibition, and boredom susceptibility.

The results do not allow firm conclusions about prenatal androgen effects on sensation seeking or risk-taking, but the overall pattern is consistent with little or no effect of prenatal androgens. At Time 1, a sex difference was found on sensation seeking, but girls and women with CAH did not differ significantly from unaffected females (though the 95% confidence interval includes small to large effect sizes). At Time 2, failure to find a sex difference on sensation seeking and on the BART precluded testing of the effect of prenatal androgens.

Likewise, the results do not allow firm conclusions about prenatal androgen effects on the subscales of sensation seeking, but the overall pattern is consistent with little or no effect of prenatal androgens. However, there is some suggestion that prenatal androgens masculinize thrill and adventure seeking; at Time 1, there was a large sex difference on thrill and adventure seeking, and girls and women with CAH scored higher than unaffected girls and women (moderate-to-large difference). At Time 1, there was also a moderate-to-large sex difference on boredom susceptibility, but no significant difference between girls and women with CAH versus

unaffected women (though the 95% confidence interval includes both small and moderate-to-large effect sizes). There were no significant sex differences on any of the other subscales at Time 1 or Time 2, which precluded testing of prenatal androgen effects.

Exploratory correlations indicated that the test-retest reliability of the ZSSS-V was acceptable over the approximately 11-year interval between Time 1 and Time 2. The finding of a moderate-to-large negative correlation between Time 2 participants' ZSSS-V scores and BART scores was unexpected and likely due to limitations of the study, discussed later.

These results add to the mixed and limited literature concerning prenatal androgen effects on sensation seeking and risk-taking. For sensation seeking, only three studies have directly examined prenatal androgen effects, and all used a fraternal twin design. One study also found an effect of co-twin sex of the thrill and adventure seeking subscale of sensation seeking, but the effect was about one-eighth the size of the sex difference (Slutske et al., 2011), suggesting that prenatal androgen transfer from boy co-twins may be modest and more difficult to detect. Indeed, another study of fraternal twins did not find an effect of co-twin sex on thrill and adventure seeking, though it did find an effect on total sensation seeking (Resnick et al., 1993). The third study did not find a significant sex difference on sensation seeking (Cohen-Bendahan et al., 2005a), likely due to confounding effects of pubertal hormones. Since it is not clear if studies of fraternal twins provide a valid method for assessing effects of natural variation in prenatal androgen exposure, future work should first focus on assessing prenatal androgen effects on sensation seeking in natural experiments with larger samples.

For risk-taking, the evidence concerning prenatal androgen effects is limited, indirect, and only covers the social and alcohol-abuse domains (Ellingson et al., 2013; Loehlin & Martin, 1999; Meyers et al., 2014), likely because of their relevance to negative health outcomes, but

also in part because there has been no universally accepted measure of risk-taking (Lejuez et al., 2002). Therefore, future work examining prenatal androgen effects on risk-taking should continue to use measures that show large sex differences and that predict real-world risk-taking across multiple domains, such as the BART (Lejuez et al., 2003; Lejuez et al., 2002). Future studies of prenatal androgen effects on risk-taking should be conducted not only in natural experiments with larger samples, but also in other samples with natural variation in prenatal androgen exposure in order to build converging evidence across multiple methods.

The exploratory correlation results add to knowledge of the psychometric properties of the ZSSS-V, indicating that its test-retest reliability remains acceptable over about an 11-year interval. Previous work only examined test-retest reliability over a three-week interval (Zuckerman et al., 1980). The exploratory negative correlation of ZSSS-V and BART scores is contrary to expectation, but consistent with the conclusion of a recent meta-analysis of 22 studies that examined sensation seeking and BART scores: failure to find a small-to-moderate positive relationship between the measures (r = .14) is likely due to insufficient power from small samples (Lauriola et al., 2014). This points to methodological limitations of this study.

Several methodological limitations should be considered in interpreting the results. First, statistical power to detect group differences at both Time 1 and Time 2 was very limited due to small sample size. This is likely why some sex differences were not significant at both times. It may have also contributed to failure to find prenatal androgen effects when significant sex differences were found. When studying rare samples, such as natural experiments like CAH (Speiser et al., 2010), large samples are difficult to obtain, and power is further limited if expected differences are not large, as is the case for sensation seeking and risk-taking. Second, Type I error was increased as an effect of conducting multiple comparisons.

Third, several participants had particularly low scores on the ZSSS-V and the BART at Time 2. Two participants had particularly low scores on sensation seeking (both scored 1.10 on a scale ranging from 1 to 2). No individual reports of such low sensation seeking scores were found in the literature. These two participants are women with CAH, so it is possible that their low scores are related to some disease factor, such as overtreatment with cortisol (see below for further discussion). Similarly, three participants had particularly low scores on the BART at Time 2 (2.2, 7.9, and 11.3, whereas typical BART scores range from 24.6 to 44.1; Lauriola et al., 2014). These three participants are also women with CAH, so it is possible that their low scores are related to some disease factor, such as overtreatment with cortisol (see below for further discussion). These scores contributed to the especially large variance on BART scores among women with CAH (*SD* = 16.41). Notably, however, variance among all groups on the BART was larger than typical (all *SD*s > 9.1, whereas the typical standard deviation is around 6.93; Lauriola et al., 2014).

There are several conceptual issues that must be addressed. First, it is possible that circulating cortisol levels contributed to the sensation seeking and BART scores. There is evidence for an inverse relationship between cortisol and sensation seeking (Ballenger et al., 1983; Croissant, Demmel, Rist, & Olbrich, 2008; Freeman & Beer, 2010; Harl, Weisshuhn, & Kerschbaum, 2006; Netter, Hennig, & Roed, 1996; Rosenblitt, Soler, Johnson, & Quadagno, 2001; Shabani, Dehghani, Hedayati, & Rezaei, 2011), and individuals with CAH may have higher than normal levels of cortisol due to overtreatment (Helleday, Siwers, Ritzen, & Carlström, 1993b). In fact, the prescribed daily maintenance doses of cortisol for children and adolescents with CAH exceed daily physiological cortisol secretion (Speiser & White, 2003), as

the treatment goal of suppressing excessive androgens often requires supraphysiologic doses (Speiser et al., 2010).

If individuals with CAH have higher than normal levels of cortisol due to overtreatment, they would score lower than unaffected controls on sensation seeking, counteracting the hypothesized effect of prenatal androgens in girls and women with CAH. The control comparison of boys and men with CAH versus unaffected boys and men is informative here to dissociate effects of prenatal androgens versus other factors. Boys and men with CAH and unaffected boys and men both have high prenatal androgen exposure, so any differences between them can be attributed to other hormone abnormalities in CAH, such as cortisol, or the effects of living with a chronic disease.

At both Time 1 and Time 2, boys and men with CAH did score lower than unaffected boys and men on sensation seeking and the differences were large, but only the difference at Time 2 was significant. Furthermore, the exploratory analyses at Time 1 showed that boys and men with CAH scored lower than unaffected boys and men on the experience seeking subscale and the difference was large. They also scored lower than unaffected boys and men on the other three subscales at Time 1 and all but the boredom susceptibility subscale at Time 2, though these differences were not significant, perhaps due to low power. This pattern is consistent with an effect of cortisol or other chronic disease factors on sensation seeking.

Most importantly for the hypotheses, even if cortisol or chronic disease factors decreased sensation seeking in individuals with CAH, girls and women with CAH still scored higher than unaffected girls and women at Time 1. Perhaps the size of this difference was decreased due to counteracting cortisol or other chronic disease factors. In a similar fashion, the masculinizing effect of CAH on spatial ability has been shown to masked by neurological complications due to

early salt-wasting episodes or disease factors among some girls and women with CAH (Hampson & Rovet, 2015). It is clear that future studies, in addition to using larger samples to increase power, should measure circulating cortisol levels to rule out an activational effect on sensation seeking.

Similarly, it is possible that circulating cortisol levels contributed to the BART scores. There is evidence for an inverse relationship between basal levels of cortisol and risk-taking (Holi, Auvinen-Lintunen, Lindberg, Tani, & Virkkunen, 2006; Mehta, Welker, Zilioli, & Carre, 2015; Moss, Vanyukov, & Martin, 1995; Oosterlaan, Geurts, Knol, & Sergeant, 2005; Shirtcliff, Granger, Booth, & Johnson, 2005; van Honk, Schutter, Hermans, & Putman, 2003; Virkkunen, 1985). In this case, if individuals with CAH have higher basal cortisol levels, they would score lower on the BART than unaffected individuals. However, this is not borne out in the results. Men with CAH scored higher than unaffected men, though the difference was not significant. However, the very small sample (7 men total) does not allow any firm conclusions.

The second conceptual issue concerns the possibility of puberty being another organizational period for the development of sex differences in risky behavior (Berenbaum & Beltz, 2011; Steinberg, 2008). There is experimental evidence from rodents that the brain continues to be organized by sex hormones up through puberty (Sisk & Zehr, 2005), but with declining sensitivity following early development (Schulz et al., 2009). There is some suggestive evidence in human beings for an organizational effect of pubertal hormones on risky behavior. Individuals who go through puberty earlier show increased risky behavior beyond adolescence compared to those who go through puberty later (Copeland et al., 2010; Graber, Seeley, Brooks-Gunn, & Lewinsohn, 2004; Johansson & Ritzén, 2005; Kaltiala-Heino, Koivisto, Marttunen, & Fröjd, 2011; Richards & Oinonen, 2011). If there is indeed a timing-dependent, organizational

effect of pubertal hormones on risky behavior, then it is possible that this study's results are confounded by variation in pubertal timing among participants. However, the modest evidence for an organizational effect of pubertal hormones on risky behavior—in both rodents and human beings—greatly tempers the credence of this possibility.

The third conceptual issue concerns the size of the sex difference in risky behavior over time. There is evidence that the sex difference in the thrill and adventure seeking subscale of sensation seeking has declined by more than a third in the past four decades, owing to a reduction in men's scores (Cross et al., 2013). There is also evidence that the size of the sex difference in risk-taking declined by more than a third in the second half of the twentieth century (Byrnes et al., 1999), and this has been attributed to increases in women's agency (Wood & Eagly, 2012). It has been suggested that these narrowing sex differences might indicate a more influential role for socialization versus sex-related biology in the development of sex differences in risky behavior (Steinberg, 2008). However, this seems less likely to be the case for sensation seeking, given that the size of the sex differences in DIS, BS, and total sensation seeking have remained stable and that the changes in TAS could be the result of specific questions on the subscale becoming outdated (Cross et al., 2013). Furthermore, the relative strength of socialization effects does not rule out an effect of sex-related biology. Both sex-related biology and gendered socialization contribute to sex differences in risky behavior, and future work should investigate how they interact across development (Berenbaum, Blakemore, & Beltz, 2011).

In conclusion, the results of this study do not allow firm conclusions about prenatal androgen effects on sensation seeking or risk-taking, but they suggest that prenatal androgens affect the thrill and adventure seeking component of sensation seeking. Studies with larger

samples of individuals with CAH are needed to determine whether prenatal androgens affect the other sensation seeking subscales or risk-taking on the BART. Future studies of prenatal androgen effects on risk-taking should also employ multiple methods (e.g., natural experiments, direct assays of prenatal androgens in typically-developing individuals). Because CAH is not a perfect experiment, future studies should continue to compare boys and men with CAH to unaffected boys and men as a control. Measurement of cortisol levels can help to distinguish between other hormone abnormalities and chronic disease factors that may influence risky behavior in addition to prenatal androgens.

References

Abramovich, D. R. (1974). Human sexual differentiation—in utero influences. *BJOG: An International Journal of Obstetrics & Gynaecology, 81*(6), 448-453.

Abramovich, D. R., & Rowe, P. (1973). Foetal plasma testosterone levels at mid-pregnancy and at term: Relationship to foetal sex. *The Journal of Endocrinology, 56*(3), 621-622. doi:10.1677/joe.0.056062

Achermann, J. C. & Hughes, I. A. (2016). Pediatric Disorders of Sex Development. In S. Melmed, K. S. Polonsky, P. R. Larsen, & H. Kronenberg (Eds.), *Williams textbook of endocrinology, Thirteenth Edition* (pp. 893-963). Philadelphia, PA: Elsevier.

Auyeung, B., Baron-Cohen, S., Ashwin, E., Knickmeyer, R., Taylor, K., Hackett, G., & Hines, M. (2009). Fetal testosterone predicts sexually differentiated childhood behavior in girls and in boys. *Psychological Science, 20*(2), 144-148. doi:10.1111/j.1467-9280.2009.02279.x

Auyeung, B., Knickmeyer, R., Ashwin, E., Taylor, K., Hackett, G., & Baron-Cohen, S. (2012). Effects of fetal testosterone on visuospatial ability. *Archives of Sexual Behavior,41*(3), 571-581. doi:10.1007/s10508-011-9864-8

Aluja, A., García, Ó., & García, L. F. (2003). Relationships among extraversion, openness to experience, and sensation seeking. *Personality and Individual Differences, 35*(3), 671-680.

Arnold, A. P. (2009). The organizational-activational hypothesis as the foundation for a unified theory of sexual differentiation of all mammalian tissues. *Hormones and Behavior, 55*(5), 570-578.

Arnold, A. P., & Breedlove, S. M. (1985). Organizational and activational effects of sex steroids on brain and behavior: A reanalysis. *Hormones and Behavior, 19*(4), 469-498. doi:10.1016/0018-506X(85)90042-X

Ball, I. L., Farnill, D., & Wangeman, J. F. (1984). Sex and age differences in sensation seeking: Some national comparisons. *British Journal of Psychology, 75*(2), 257.

Ballenger, J. C., Post, R. M., Jimerson, D. C., Lake, C. R., Murphy, D., Zuckerman, M., & Cronin, C. (1983). Biochemical correlates of personality traits in normals: An exploratory study. *Personality and Individual Differences, 4*(6), 615-625.

Beltz, A. M., Swanson, J. L., & Berenbaum, S. A. (2011). Gendered occupational interests: Prenatal androgen effects on psychological orientation to things versus people. *Hormones and Behavior, 60*(4), 313-317. doi:10.1016/j.yhbeh.2011.06.002

Berenbaum, S. A. (1999). Effects of early androgens on sex-typed activities and interests in adolescents with congenital adrenal hyperplasia. *Hormones and Behavior, 35*(1), 102-110. doi:10.1006/hbeh.1998.1503

Berenbaum, S. A., & Bailey, J. M. (2003). Effects on gender identity of prenatal androgens and genital appearance: Evidence from girls with congenital adrenal hyperplasia. *The Journal of Clinical Endocrinology & Metabolism, 88*(3), 1102-1106. doi:10.1210/jc.2002-020782

Berenbaum, S. A. & Beltz, A. M. (2016). How early hormones shape gender development. *Current Opinion in Behavioral Sciences, 7,* 53-60.

Berenbaum, S. A. & Beltz, A. M. (2011). Sexual differentiation of human behavior: Effects of prenatal and pubertal organizational hormones. *Frontiers in Neuroendocrinology, 32*(2), 183-200. doi:10.1016/j.yfrne.2011.03.001

Berenbaum, S. A., Blakemore, J. E. O., & Beltz, A. M. (2011). A role for biology in gender-related behavior. *Sex Roles, 64*(11), 804-825. doi:10.1007/s11199-011-9990-8

Berenbaum, S. A., Bryk, K. L. K., & Beltz, A. M. (2012). Early androgen effects on spatial and mechanical abilities: Evidence from congenital adrenal hyperplasia. *Behavioral Neuroscience, 126*(1), 86-96. doi:10.1037/a0026652

Berenbaum, S. A., Bryk, K., Duck, S. C., & Resnick, S. M. (2004). Psychological adjustment in children and adults with congenital adrenal hyperplasia. *The Journal of Pediatrics, 144*(6), 741-746. doi:10.1016/j.jpeds.2004.03.037

Berenbaum, S. A., Bryk, K. K., Nowak, N., Quigley, C. A., & Moffat, S. (2009). Fingers as a marker of prenatal androgen exposure. *Endocrinology, 150*(11), 5119-5124. doi:10.1210/en.2009-0774

Berenbaum, S. A., Duck, S. C., & Bryk, K. K. (2000). Behavioral effects of prenatal versus postnatal androgen excess in children with 21-hydroxylase-deficient congenital adrenal hyperplasia. *Journal of Clinical Endocrinology & Metabolism, 85*(2), 727-733.

Berenbaum, S. A., & Hines, M. (1992). Early androgens are related to childhood sex-typed toy preferences. *Psychological Science, 3*(3), 203-206. doi:10.1111/j.1467-9280.1992.tb00028.x

Berenbaum, S. A. & Resnick, S. M. (1997). Early androgen effects on aggression in children and adults with congenital adrenal hyperplasia. *Psychoneuroendocrinology, 22*(7), 505-515. doi:10.1016/S0306-4530(97)00049-8

Berenbaum, S. A. & Snyder, E. (1995). Early hormonal influences on childhood sex-typed activity and playmate preferences: Implications for the development of sexual orientation. *Developmental Psychology, 31*(1), 31-42. doi:10.1037/0012-1649.31.1.31

Blakemore, J. E. O., Berenbaum, S. A., & Liben, L. S. (2009). *Gender development*. New York, NY: Psychology Press, Taylor & Francis Group.

Block, J. (2010). The five-factor framing of personality and beyond: Some ruminations. *Psychological Inquiry, 21*(1), 2-25. doi:10.1080/10478401003596626

Bussey, K., & Bandura, A. (1984). Influence of gender constancy and social power on sex-linked modeling. *Journal of Personality and Social Psychology, 47*(6), 1292-1302.

Byrnes, J. P., Miller, D. C., & Schafer, W. D. (1999). Gender differences in risk taking: A meta-analysis. *Psychological Bulletin, 125*(3), 367-383. doi:10.1037/0033-2909.125.3.367

Chapman, E., Baron-Cohen, S., Auyeung, B., Knickmeyer, R., Taylor, K., & Hackett, G. (2006). Fetal testosterone and empathy: Evidence from the Empathy Quotient (EQ) and the "Reading the Mind in the Eyes" test. *Social Neuroscience, 1*(2), 135-148. doi:10.1080/17470910600992239

Charness, G. & Gneezy, U. (2012). Strong evidence for gender differences in risk taking. *Journal of Economic Behavior & Organization, 83*(1), 50. doi:10.1016/j.jebo.2011.06.007

Clark, M. M., & Galef, B. G. (1998). Effects of intrauterine position on the behavior and genital morphology of litter-bearing rodents. *Developmental Neuropsychology, 14*(2-3), 197. doi:10.1080/87565649809540709

Coates, J. M. & Herbert, J. (2008). Endogenous steroids and financial risk taking on a London trading floor. *Proceedings of the national academy of sciences,* 105(16), 6167-72. doi: 10.1073/pnas.0704025105

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: L. Erlbaum Associates.

Cohen-Bendahan, C. C. C., Buitelaar, J. K., van Goozen, S. H. M., Orlebeke, J. F., & Cohen-Kettenis, P. T. (2005a). Is there an effect of prenatal testosterone on aggression and other behavioral traits? A study comparing same-sex and opposite-sex twin girls. *Hormones and Behavior, 47*(2), 230-237. doi: 10.1016/j.yhbeh.2004.10.006

Cohen-Bendahan, C. C. C., van de Beek, C., & Berenbaum, S. A. (2005b). Prenatal sex hormone effects on child and adult sex-typed behavior: Methods and findings. *Neuroscience and Biobehavioral Reviews, 29*(2), 353-384. doi:10.1016/j.neubiorev.2004.11.004

Cohen-Bendahan, C. C. C., Van Goozen, S. H. M., Buitelaar, J. K., & Cohen-Kettenis, P. T. (2005c). Maternal serum steroid levels are unrelated to fetal sex: A study in twin pregnancies. *Twin Research and Human Genetics, 8*(2), 173-177. doi:10.1375/1832427053738764

Collaer, M. L., & Hines, M. (1995). Human behavioral sex differences: A role for gonadal hormones during early development? *Psychological Bulletin, 118*(1), 55-107. doi:10.1037/0033-2909.118.1.55

Constantinescu, M., & Hines, M. (2012). Relating prenatal testosterone exposure to postnatal behavior in typically developing children: Methods and findings. *Child Development Perspectives, 6*(4), 407-413. doi:10.1111/j.1750-8606.2012.00257.x

Copeland, W., Shanahan, L., Miller, S., Costello, E. J., Angold, A., & Maughan, B. (2010). Outcomes of early pubertal timing in young women: A prospective population-based study. *American Journal of Psychiatry, 167*(10), 1218-1225. doi:10.1176/appi.ajp.2010.09081190

Croissant, B., Demmel, R., Rist, F., & Olbrich, R. (2008). Exploring the link between gender, sensation seeking, and family history of alcoholism in cortisol stress-response dampening. *Biological Psychology, 79*(2), 268-274. doi:10.1016/j.biopsycho.2008.07.001

Cross, C. P., Cyrenne, D. M., & Brown, G. R. (2013). Sex differences in sensation-seeking: A meta-analysis. *Scientific Reports, 3*, 2486. doi:10.1038/srep02486

Dahl, R. E. (2004). Adolescent brain development: A period of vulnerabilities and opportunities, Keynote address. *Annals of the New York Academy of Sciences, 1021*(1), 1-22. doi:10.1196/annals.1308.001

Dahlen, E. R., & White, R. P. (2006). The Big Five factors, sensation seeking, and driving anger in the prediction of unsafe driving. *Personality and Individual Differences, 41*(5), 903-915.

Dattani, M. T. & Gevers, E. F. (2016). Endocrinology of Fetal Development. In S. Melmed, K. S. Polonsky, P. R. Larsen, & H. Kronenberg (Eds.), *Williams textbook of endocrinology, Thirteenth Edition* (pp. 849-892). Philadelphia, PA: Elsevier.

Davis, B. A., Clinton, S. M., Akil, H., & Becker, J. B. (2008). The effects of novelty-seeking phenotypes and sex differences on acquisition of cocaine self-administration in selectively bred high-responder and low-responder rats. *Pharmacology, Biochemistry and Behavior, 90*(3), 331-338. doi:10.1016/j.pbb.2008.03.008

Deditius-Island, H. K. & Caruso, J. C. (2002). An examination of the reliability of scores from Zuckerman's Sensation Seeking Scales, Form V. *Educational and Psychological Measurement, 62*(4), 728-734. doi:10.1177/001316402128774996

De Moor, M. H. M., Beem, A. L., Stubbe, J. H., Boomsma, D. I., & De Geus, E. J. C. (2006). Regular exercise, anxiety, depression and personality: A population-based study. *Preventive Medicine, 42*(4), 273-279. doi:10.1016/j.ypmed.2005.12.002

de Vries, G. J., Fields, C. T., Peters, N. V., Whylings, J., & Paul, M. J. (2014). Sensitive periods for hormonal programming of the brain. In S. L. Andersen & D. S. Pine (Eds.), *The neurobiology of childhood* (pp. 79-108). Heidelberg, Berlin: Springer.

Ellingson, J. M., Slutske, W. S., Richmond-Rakerd, L. S., & Martin, N. G. (2013). Investigating the influence of prenatal androgen exposure and sibling effects on alcohol use and alcohol use disorder in females from opposite-sex twin pairs. *Alcoholism: Clinical and Experimental Research, 37*(5), 868-876. doi:10.1111/acer.12035

Even, M. D., Dhar, M. G., & F. S. vom Saal. (1992). Transport of steroids between fetuses via amniotic fluid in relation to the intrauterine position phenomenon in rats. *Journal of Reproduction and Fertility, 96*(2), 709-716. doi:10.1530/jrf.0.0960709

Figner, B., & Weber, E. U. (2011). Who takes risks when and why? Determinants of risk taking. *Current Directions in Psychological Science, 20*(4), 211-216. doi:10.1177/0963721411415790

Freeman, H. D., & Beer, J. S. (2010). Frontal lobe activation mediates the relation between sensation seeking and cortisol increases. *Journal of Personality, 78*(5), 1497-1528. doi:10.1111/j.1467-6494.2010.00659.x

Gitau, R., Adams, D., Fisk, N. M., & Glover, V. (2005). Fetal plasma testosterone correlates positively with cortisol. *Archives of Disease in Childhood. Fetal and Neonatal Edition, 90*(2), F166-F169. doi:10.1136/adc.2004.049320

Glasgow, M. R., Cartier, A. M., & Wilson, G. D. (1985). Conservatism, sensation-seeking and music preferences. *Personality and Individual Differences, 6*(3), 395-396. doi:10.1016/0191-8869(85)90065-0

Graber, J., Seeley, J., Brooks-Gunn, J., & Lewinsohn, P. (2004). Is pubertal timing associated with psychopathology in young adulthood? *Journal of the American Academy of Child and Adolescent Psychiatry, 43*(6), 718-726. doi:10.1097/01.chi.0000120022.14101.11

Grimshaw, G. M., Sitarenios, G., & Finegan, J. A. K. (1995). Mental rotation at 7 years - relations with prenatal testosterone levels and spatial play experiences. *Brain and Cognition, 29*(1), 85-100. doi:10.1006/brcg.1995.1269

Hall, C. M., Jones, J. A., Meyer-Bahlburg, H. F. L., Dolezal, C., Coleman, M., Foster, P., . . . Clayton, P. E. (2004). Behavioral and physical masculinization are related to genotype in girls with congenital adrenal hyperplasia. *The Journal of Clinical Endocrinology & Metabolism, 89*(1), 419-424. doi:10.1210/jc.2003-030696

Hamann, S., Stevens, J., Vick, J. H., Bryk, K., Quigley, C. A., Berenbaum, S. A., & Wallen, K. (2014). Brain responses to sexual images in 46,XY women with complete androgen insensitivity syndrome are female-typical. *Hormones and Behavior, 66*(5), 724-730. doi:10.1016/j.yhbeh.2014.09.013

Hampson, E., & Rovet, J. F. (2015). Spatial function in adolescents and young adults with congenital adrenal hyperplasia: Clinical phenotype and implications for the androgen hypothesis. *Psychoneuroendocrinology, 54*, 60-70. doi:10.1016/j.psyneuen.2015.01.022

Harl, B., Weisshuhn, S., & Kerschbaum, H. (2006). Cortisol titre increases with novelty of academic oral examinations. *Neuroendocrinology Letters, 27*(5), 669-674.

Heil, M., Kavšek, M., Rolke, B., Beste, C., & Jansen, P. (2011). Mental rotation in female fraternal twins: Evidence for intra-uterine hormone transfer? *Biological Psychology, 86*(1), 90-93. doi:10.1016/j.biopsycho.2010.11.002

Helleday, J., Edman, G., Ritzén, E. M., & Siwers, B. (1993a). Personality characteristics and platelet MAO activity in women with congenital adrenal hyperplasia (CAH). *Psychoneuroendocrinology, 18*(5), 343-354. doi:10.1016/0306-4530(93)90010-I

Helleday, J., Siwers, B., Ritzen, E. M., & Carlström, K. (1993b). Subnormal androgen and elevated progesterone levels in women treated for congenital virilizing 21-hydroxylase deficiency. *The Journal of Clinical Endocrinology & Metabolism, 76*(4), 933-936.

Het, S., Ramlow, G., & Wolf, O. T. (2005). A meta-analytic review of the effects of acute cortisol administration on human memory. *Psychoneuroendocrinology, 30*(8), 771-784. doi:10.1016/j.psyneuen.2005.03.005

Hines, M. (2011). Gender development and the human brain. *Annual Review of Neuroscience, 34*(1), 69-88. doi:doi:10.1146/annurev-neuro-061010-113654

Hines, M. (2010). Sex-related variation in human behavior and the brain. *Trends in Cognitive Sciences, 14*(10), 448-456. doi:10.1016/j.tics.2010.07.005

Hines, M., Ahmed, S. F., & Hughes, I. A. (2003). Psychological outcomes and gender-related development in complete androgen insensitivity syndrome. *Archives of Sexual Behavior, 32*(2), 93-101. doi:10.1023/A:1022492106974

Hines, M., Constantinescu, M., & Spencer, D. (2015). Early androgen exposure and human gender development. *Biology of Sex Differences, 6*(1), 3. doi:10.1186/s13293-015-0022-1

Hines, M., Golombok, S., Rust, J., Johnston, K. J., Golding, J., & Parents and Children Study Team. (2002). Testosterone during pregnancy and gender role behavior of preschool children: a longitudinal, population study. *Child Development, 73*(6), 1678-1687.

Holi, M., Auvinen-Lintunen, L., Lindberg, N., Tani, P., & Virkkunen, M. (2006). Inverse correlation between severity of psychopathic traits and serum cortisol levels in young adult violent male offenders. *Psychopathology, 39*(2), 102-104.

Horvath, P., & Zuckerman, M. (1993). Sensation seeking, risk appraisal and risky behavior. *Personality and Individual Differences*, 14, 41-52.

Hughes, R. N. (1968). Behaviour of male and female rats with free choice of two environments differing in novelty. *Animal Behaviour, 16*(1), 92-96. doi:10.1016/0003-3472(68)90116-4

Imperato-McGinley, J., Pichardo, M., Gautier, T., Voyer, D., & Bryden, M. P. (1991). Cognitive abilities in androgen-insensitive subjects: Comparison with control males and females from the same kindred. *Clinical Endocrinology, 34*(5), 341-347. doi:10.1111/j.1365-2265.1991.tb00303.x

Johansson, T. & Ritzén, E.M. (2005). Very long-term follow-up of girls with early and late menarche. *Endocrine Development, 8*, 126–136.

Kaltiala-Heino, R., Koivisto, A., Marttunen, M., & Fröjd, S. (2011). Pubertal timing and substance use in middle adolescence: A 2-year follow-up study. *Journal of Youth and Adolescence, 40*(10), 1288-1301. doi:10.1007/s10964-011-9667-1

Kandasamy, N., Hardy, B., Page, L., Schaffner, M., Graggaber, J., Powlson, A. S., . . . Coates, J. (2014). Cortisol shifts financial risk preferences. *PNAS, 111*(9), 3608-3613.

Kann, L., McManus, T., Harris, W., Shanklin, S., Flint, K., Hawkins, J., . . . Zaza, S. (2016). Youth risk behavior surveillance - United States, 2015. *Morbidity and Mortality Weekly Report: Surveillance Summaries, 65*(6), 1-174.

Kinsley, C., Madonia, L., Gifford, G., Tureski, K., Griffin, G., Lowry, C., . . . Lambert, K. (1999). Motherhood improves learning and memory - Neural activity in rats is enhanced by pregnancy and the demands of rearing offspring. *Nature, 402*(6758), 137-138.

Kish, G. B., Netterberg, E. E., & Leahy, L. (1973). Stimulus-seeking and conservatism. *Journal of Clinical Psychology, 29*(1), 17-20. doi:10.1002/1097-4679(197301)29:1<17::AID-JCLP2270290106>3.0.CO;2-H

Knickmeyer, R., Baron-Cohen, S., Raggatt, P., Taylor, K., & Hackett, G. (2006). Fetal testosterone and empathy. *Hormones and Behavior, 49*(3), 282-292. doi:10.1016/j.yhbeh.2005.08.010

Knickmeyer, R. C., Wheelwright, S., Taylor, K., Raggatt, P., Hackett, G., & Baron-Cohen, S. (2005). Gender-typed play and amniotic testosterone. *Developmental Psychology, 41*(3), 517-528. doi:10.1037/0012-1649.41.3.517

Lauriola, M., Panno, A., Levin, I. P., & Lejuez, C. W. (2014). Individual differences in risky decision making: A meta-analysis of sensation seeking and impulsivity with the Balloon

Analogue Risk Task. *Journal of Behavioral Decision Making*, *27*(1), 20-36. doi:10.1002/bdm.1784

Laviola, G., Macrì, S., Morley-Fletcher, S., & Adriani, W. (2003). Risk-taking behavior in adolescent mice: Psychobiological determinants and early epigenetic influence. *Neuroscience and Biobehavioral Reviews, 27*(1), 19-31. doi:10.1016/S0149-7634(03)00006-X

Lejuez, C. W., Aklin, W. M., Zvolensky, M. J., & Pedulla, C. M. (2003). Evaluation of the Balloon Analogue Risk Task (BART) as a predictor of adolescent real-world risk-taking behaviours. *Journal of Adolescence, 26*(4), 475-479. doi:10.1016/S0140-1971(03)00036-8

Lejuez, C., Read, J., Kahler, C., Richards, J., Ramsey, S., Stuart, G., & Brown, R. (2002). Evaluation of a behavioral measure of risk taking: The Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied, 8*(2), 75-84. doi:10.1037//1076-898X.8.2.75

Leveroni, C. L., & Berenbaum, S. A. (1998). Early androgen effects on interest in infants: Evidence from children with congenital adrenal hyperplasia. *Developmental Neuropsychology, 14*(2-3), 321. doi:10.1080/87565649809540714

Loehlin, J. C., & Martin, N. G. (1999). Dimensions of psychological masculinity-femininity in adult twins from opposite-sex and same-sex pairs. *Behavior Genetics, 30*(1), 19-28. doi:10.1023/A:1002082325784

Mathews, G. A., Fane, B. A., Conway, G. S., Brook, C. G. D., & Hines, M. (2009). Personality and congenital adrenal hyperplasia: Possible effects of prenatal androgen exposure. *Hormones and Behavior, 55*(2), 285-291. doi:10.1016/j.yhbeh.2008.11.007

Martin, C. L., & Halverson, C. F. (1981). A schematic processing model of sex typing and stereotyping in children. *Child Development, 52*(4), 1119-1134.

Martin, C., Kelly, T., Rayens, M., Brogli, B., Brenzel, A., Smith, W., & Omar, H. (2002). Sensation seeking, puberty, and nicotine, alcohol, and marijuana use in adolescence. *Journal of the American Academy of Child and Adolescent Psychiatry, 41*(12), 1495-1502. doi:10.1097/01.CHI.0000024864.60748.9D

Mazur, T. (2005). Gender dysphoria and gender change in androgen insensitivity or micropenis. *Archives of Sexual Behavior, 34*(4), 411-421. doi:10.1007/s10508-005-4341-x

McCarthy, M. M. (2011). A lumpers versus splitters approach to sexual differentiation of the brain. *Frontiers in Neuroendocrinology, 32*(2), 114-123. doi:10.1016/j.yfrne.2011.01.004

Mehta, P., Welker, K., Zilioli, S., & Carre, J. (2015). Testosterone and cortisol jointly modulate risk-taking. *Psychoneuroendocrinology, 56*, 88-99. doi:10.1016/j.psyneuen.2015.02.023

Meulenberg, P. M. M., & Hofman, J. A. (1991). Maternal testosterone and fetal sex. *Journal of Steroid Biochemistry and Molecular Biology, 39*(1), 51-54. doi:10.1016/0960-0760(91)90012-T

Meyers, J. L., Salvatore, J. E., Vuoksimaa, E., Korhonen, T., Pulkkinen, L., Rose, . . . Dick, D. M. (2014). Genetic influences on alcohol use behaviors have diverging developmental trajectories: A prospective study among male and female twins. *Alcoholism: Clinical and Experimental Research, 38*(11), 2869-2877. doi:10.1111/acer.12560

Miller, E. M. (1994). Prenatal sex hormone transfer: A reason to study opposite-sex twins. *Personality and Individual Differences, 17*(4), 511-529. doi:10.1016/0191-8869(94)90088-4

Miller, E. M., & Martin, N. (1994). Analysis of the effect of hormones on opposite-sex twin attitudes. *Acta Geneticae Medicae Et Gemellologiae, 44*(1), 41-52. doi:10.1017/S0001566000001884

Morrongiello, B. A., & Matheis, S. (2007). Understanding children's injury-risk behaviors: The independent contributions of cognitions and emotions. *Journal of Pediatric Psychology, 32*(8), 926-937.

Moss, H. B., Vanyukov, M. M., & Martin, C. S. (1995). Salivary cortisol responses and the risk for substance abuse in prepubertal boys. *Biological Psychiatry, 38*(8), 547-555. doi:10.1016/0006-3223(94)00382-D

Netter, P., Hennig, J., & Roed, I. (1996). Serotonin and dopamine as mediators of sensation seeking behavior. *Neuropsychobiology, 34*(3), 155-165.

Nordenström, A., Servin, A., Bohlin, G., Larsson, A., & Wedell, A. (2002). Sex-typed toy play behavior correlates with the degree of prenatal androgen exposure assessed by CYP21 genotype in girls with congenital adrenal hyperplasia. *The Journal of Clinical Endocrinology & Metabolism, 87*(11), 5119-5124. doi:10.1210/jc.2001-011531

Oosterlaan, J., Geurts, H. M., Knol, D. L., & Sergeant, J. A. (2005). Low basal salivary cortisol is associated with teacher-reported symptoms of conduct disorder. *Psychiatry Research, 134*(1), 1-10. doi:10.1016/j.psychres.2004.12.005

Palanza, P., Morley-Fletcher, S., & Laviola, G. (2001). Novelty seeking in periadolescent mice: Sex differences and influence of intrauterine position. *Physiology & Behavior, 72*(1), 255-262. doi:10.1016/S0031-9384(00)00406-6

Pasterski, V., Acerini, C. L., Dunger, D. B., Ong, K. K., Hughes, I. A., Thankamony, A., & Hines, M. (2015). Postnatal penile growth concurrent with mini-puberty predicts later sex-typed play behavior: Evidence for neurobehavioral effects of the postnatal androgen surge in typically developing boys. *Hormones and Behavior, 69*, 98-105. doi:10.1016/j.yhbeh.2015.01.002

Pasterski, V. L., Geffner, M. E., Brain, C., Hindmarsh, P., Brook, C., & Hines, M. (2005). Prenatal hormones and postnatal socialization by parents as determinants of male-typical toy play in girls with congenital adrenal hyperplasia. *Child Development, 76*(1), 264-278. doi:10.1111/j.1467-8624.2005.00843.x

Pasterski, V., Hindmarsh, P., Geffner, M., Brook, C., Brain, C., & Hines, M. (2007). Increased aggression and activity level in 3- to 11-year-old girls with congenital adrenal hyperplasia (CAH). *Hormones and Behavior, 52*(3), 368-374. doi:10.1016/j.yhbeh.2007.05.015

Pearson, P. R., & Sheffield, B. F. (1975). Social attitude correlates of sensation-seeking in psychiatric patients. *Perceptual and Motor Skills, 40*(2), 482-482. doi:10.2466/pms.1975.40.2.482

Ray, J. & Hansen, S. (2004). Temperament in the rat: Sex differences and hormonal influences on harm avoidance and novelty seeking. *Behavioral Neuroscience, 118*(3), 488-497. doi:10.1037/0735-7044.118.3.488

Reinisch, J. (1981). Prenatal exposure to synthetic progestins increases potential for aggression in humans. *Science, 211*(4487), 1171-1173. doi:10.1126/science.7466388

Resnick, S. M., Berenbaum, S. A., Gottesman, I. I., & Bouchard, T. J. (1986). Early hormonal influences on cognitive functioning in congenital adrenal hyperplasia. *Developmental Psychology, 22*(2), 191-198. doi:10.1037//0012-1649.22.2.191

Resnick, S. M., Gottesman, I. I., & McGue, M. (1993). Sensation seeking in opposite-sex twins: An effect of prenatal hormones? *Behavior Genetics, 23*(4), 323-329. doi: 10.1007/BF01067432

Reyes, F. I., Boroditsky, R. S., Winter, J. S., & Faiman, C. (1974). Studies on human sexual development. II. Fetal and maternal serum gonadotropin and sex steroid concentrations. *The Journal of Clinical Endocrinology and Metabolism, 38*(4), 612.

Richards, M. A., & Oinonen, K. A. (2011). Age at menarche is associated with divergent alcohol use patterns in early adolescence and early adulthood. *Journal of Adolescence, 34*(5), 1065-1076. doi:10.1016/j.adolescence.2010.11.001

Rodeck, C. H., Gill, D., Rosenberg, D. A., & Collins, W. P. (1985). Testosterone levels in midtrimester maternal and fetal plasma and amniotic fluid. *Prenatal Diagnosis, 5*(3), 175-181. doi:10.1002/pd.1970050303

Rohde Parfet, K. A., Ganjam, V. K., Lamberson, W. R., Rieke, A. R., vom Saal, F. S., & Day, B. N. (1990). Intrauterine position effects in female swine: Subsequent reproductive performance, and social and sexual behavior. *Applied Animal Behaviour Science, 26*(4), 349-362. doi:10.1016/0168-1591(90)90034-B

Rosenblitt, J. C., Soler, H., Johnson, S. E., & Quadagno, D. M. (2001). Sensation seeking and hormones in men and women: Exploring the link. *Hormones and Behavior, 40*(3), 396-402. doi:10.1006/hbeh.2001.1704

Ross, M. G. & Beall, M. H. (2013). Amniotic Fluid Dynamics. In R. K. Creasy, R. Resnik, J. D. Iams, C. J. Lockwood, T. Moore, & M. F. Greene (Eds.), *Creasy and Resnik's maternal-fetal medicine: Principles and practice* (pp. 47-52). Philadelphia, PA: Elsevier.

Roth, M., Schumacher, J., & Brähler, E. (2005). Sensation seeking in the community: Sex, age and sociodemographic comparisons on a representative German population sample. *Personality and Individual Differences, 39*(7), 1261-1271. doi:10.1016/j.paid.2005.05.003

Russell, P. A. (1977). Sex differences in rats' stationary exploration as a function of stimulus and environmental novelty. *Animal Learning & Behavior, 5*(3), 297-302. doi:10.3758/BF03209243

Russo, M. F., Stokes, G. S., Lahey, B. B., Christ, M. A. G., McBurnett, K., Loeber, R., . . . Green, S. M. (1993). A sensation seeking scale for children: Further refinement and psychometric development. *Journal of Psychopathology and Behavioral Assessment, 15*(2), 69-86. doi:10.1007/BF00960609

Ryan, B. C., & Vandenbergh, J. G. (2002). Intrauterine position effects. *Neuroscience & Biobehavioral Reviews, 26*(6), 665-678. doi: 10.1016/S0149-7634(02)00038-6

Schulz, K. M., Molenda-Figueira, H. A., & Sisk, C. L. (2009). Back to the future: The organizational–activational hypothesis adapted to puberty and adolescence. *Hormones and Behavior, 55*(5), 597-604. doi:10.1016/j.yhbeh.2009.03.010

Servin, A., Nordenström, A., Larsson, A., & Bohlin, G. (2003). Prenatal androgens and gender-typed behavior: A study of girls with mild and severe forms of congenital adrenal hyperplasia. *Developmental Psychology, 39*(3), 440-450. doi:10.1037/0012-1649.39.3.440

Shabani, S., Dehghani, M., Hedayati, M., & Rezaei, O. (2011). Relationship of serum serotonin and salivary cortisol with sensation seeking. *International Journal of Psychophysiology, 81*(3), 225-229. doi:10.1016/j.ijpsycho.2011.06.015

Shirtcliff, E. A., Granger, D. A., Booth, A., & Johnson, D. (2005). Low salivary cortisol levels and externalizing behavior problems in youth. *Development and Psychopathology, 17*(1), 167-184. doi:10.1017/S0954579405050091

Shulman, E. P., Harden, K. P., Chein, J. M., & Steinberg, L. (2015). Sex differences in the developmental trajectories of impulse control and sensation-seeking from early adolescence to early adulthood. *Journal of Youth and Adolescence, 44*(1), 1-17. doi:10.1007/s10964-014-0116-9

Sisk, C. L., & Zehr, J. L. (2005). Pubertal hormones organize the adolescent brain and behavior. *Frontiers in Neuroendocrinology, 26*(3), 163-174. doi:10.1016/j.yfrne.2005.10.003

Slutske, W. S., Bascom, E. N., Meier, M. H., Medland, S. E., & Martin, N. G. (2011). Sensation seeking in females from opposite- versus same-sex twin pairs: Hormone transfer or sibling imitation? *Behavior Genetics, 41,* 533-542. doi: 10.1007/s10519-010-9416

Speiser, P. W., Azziz, R., Baskin, L. S., Ghizzoni, L., Hensle, T. W., Merke, D. P., Meyer-Bahlburg, H. F. L., Miller, W. L., Montori, V. M., Oberfield, S. E., Ritzen, M., & White, P. C. Endocrine Society. (2010). Congenital adrenal hyperplasia due to steroid 21-hydroxylase deficiency: An endocrine society clinical practice guideline. *The Journal of Clinical Endocrinology & Metabolism, 95*(9), 4133-4160. doi:10.1210/jc.2009-2631

Speiser, P. W., & White, P. C. (2003). Congenital adrenal hyperplasia. *The New England Journal of Medicine, 349*(8), 776-788. doi:10.1056/NEJMra021561

Steinberg, L. (2010). A dual systems model of adolescent risk-taking. *Developmental Psychobiology, 52*(3), 216-224. doi:10.1002/dev.20445

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review, 28*(1), 78-106. doi:10.1016/j.dr.2007.08.002

Steinberg, L., Albert, D., Cauffman, E., Banich, M., Graham, S., & Woolard, J. (2008). Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: Evidence for a dual systems model. *Developmental Psychology, 44*(6), 1764-1778. doi:10.1037/a0012955

Thornton, J., Zehr, J. L., & Loose, M. D. (2009). Effects of prenatal androgens on rhesus monkeys: A model system to explore the organizational hypothesis in primates. *Hormones and Behavior, 55*(5), 633-644. doi:10.1016/j.yhbeh.2009.03.015

Toledo-Rodriguez, M., & Sandi, C. (2011). Stress during adolescence increases novelty seeking and risk-taking behavior in male and female rats. *Frontiers in Behavioral Neuroscience, 5*, 17. doi:10.3389/fnbeh.2011.00017

Trimpop, R. M., Kerr, J. H., & Kirkcaldy, B. (1999). Comparing personality constructs of risk-taking behavior. *Personality and Individual Differences, 26*(2), 237-254. doi:10.1016/S0191-8869(98)00048-8

van de Beek, C., Goozen, S. H. M., Buitelaar, J. K., & Cohen-Kettenis, P. T. (2009). Prenatal sex hormones (maternal and amniotic fluid) and gender-related play behavior in 13-month-old infants. *Archives of Sexual Behavior, 38*(1), 6-15. doi:10.1007/s10508-007-9291-z

van Hemmen, J., Veltman, D. J., Hoekzema, E., Cohen-Kettenis, P. T., Dessens, A. B., & Bakker, J. (2016). Neural activation during mental rotation in complete androgen insensitivity syndrome: The influence of sex hormones and sex chromosomes. *Cerebral Cortex, 26*(3), 1036-45. doi:10.1093/cercor/bhu280

van Honk, J., Schutter, D., Hermans, E., & Putman, P. (2003). Low cortisol levels and the balance between punishment sensitivity and reward dependency. *Neuroreport, 14*(15), 1993-1996. doi:10.1097/01.wnr.0000091690.72892.ec

Virkkunen, M. (1985). Urinary free cortisol secretion in habitually violent offenders. *Acta Psychiatrica Scandinavica, 72*(1), 40-44.

vom Saal, F. S. (1989). Sexual differentiation in litter-bearing mammals: Influence of sex of adjacent fetuses in utero. *Journal of Animal Science, 67*(7), 1824. doi:10.2527/jas1989.6771824x

Vuoksimaa, E., Kaprio, J., Kremen, W. S., Hokkanen, L., Viken, R. J., Tuulio-Henriksson, A., & Rose, R. J. (2010). Having a male co-twin masculinizes mental rotation performance in females. *Psychological Science, 21*(8), 1069-1071. doi:10.1177/0956797610376075

Wallen, K. (2005). Hormonal influences on sexually differentiated behavior in nonhuman primates. *Frontiers in Neuroendocrinology, 26*, 7-26.

Wallen, K. (2009). The organizational hypothesis: Reflections on the 50th anniversary of the publication of Phoenix, Goy, Gerall, and Young (1959). *Hormones and Behavior, 55*(5), 561-565. doi:10.1016/j.yhbeh.2009.03.009

Welte, J. W., Barnes, G. M., Tidwell, M. O., & Hoffman, J. H. (2008). The prevalence of problem gambling among U.S. adolescents and young adults: Results from a national survey. *Journal of Gambling Studies, 24*(2), 119-133. doi:10.1007/s10899-007-9086-0

Wisniewski, A. B., Migeon, C. J., Meyer-Bahlburg, H. F., Gearhart, J. P., Berkovitz, G. D., Brown, T. R., & Money, J. (2000). Complete androgen insensitivity syndrome: Long-term medical, surgical, and psychosexual outcome. *The Journal of Clinical Endocrinology and Metabolism, 85*(8), 2664-2669. doi:10.1210/jc.85.8.2664

Wong, W. I., Pasterski, V., Hindmarsh, P. C., Geffner, M. E., & Hines, M. (2013). Are there parental socialization effects on the sex-typed behavior of individuals with congenital adrenal hyperplasia? *Archives of Sexual Behavior, 42*(3), 381-391. doi:10.1007/s10508-012-9997-4

Wood, W. & Eagly, A. H. (2012). Biosocial construction of sex differences and similarities in behavior. *Adv. Exp. Soc. Psychol. 46*, 55–123. doi:10.1016/B978-0-12-394281-4.00002-7

Zuckerman, M. (1994). *Behavioral expressions and biosocial bases of sensation seeking*. New York: Cambridge University Press.

Zuckerman, M. (1979). Sensation seeking and risk-taking. In C. E. Izard (Ed.), *Emotions in personality and psychopathology* (pp. 163-197). New York: Plenum.

Zuckerman, M. (2007). *Sensation seeking and risky behavior*. Washington, DC: American Psychological Association.

Zuckerman, M., Buchsbaum, M. S., & Murphy, D. L. (1980). Sensation seeking and its biological correlates. *Psychological Bulletin, 88*(1), 187-214. doi:10.1037/0033-2909.88.1.187

Zuckerman, M., Eysenck, S. B., & Eysenck, H. J. (1978). Sensation seeking in England and America: Cross-cultural, age, and sex comparisons. *Journal of Consulting and Clinical Psychology, 46*(1), 139-149. doi:10.1037/0022-006X.46.1.139

Zuckerman, M., & Kuhlman, D. M. (2000). Personality and risk-taking: Common biosocial factors. *Journal of Personality, 68*(6), 999.

Zuckerman, M., Kuhlman, D. M., Joireman, J., Teta, P., & Kraft, M. (1993). A comparison of three structural models for personality: The Big Three, the Big Five, and the Alternative Five. *Journal of Personality and Social Psychology, 65*(4), 757-768.

Tables

Table 1

Participant *N*s and Age

	Females		Males	
	CAH	**Control**	**CAH**	**Control**
Time 1				
N	22	14	11	14
Age:				
M	20.96	19.96	19.50	19.00
SD	2.23	2.86	3.02	2.33
Range	16.2 – 24.2	16.6 – 26.5	16.4 – 25.7	16.3 – 24.4
Time 2				
N	13	8	3	4
Age:				
M	28.12	26.56	25.86	28.01
SD	5.06	5.78	2.71	4.70
Range	20.9 – 37.0	18.4 – 34.4	23.5 – 28.8	25.4 – 31.4

Table 2

Descriptive statistics and effect sizes for group differences on sensation seeking and the BART

	Females				Males					
	CAH	**Control**	***d***	**95% CI for *d***	**CAH**	**Control**	***d***	**95% CI for *d***	**Sex differences Controls *d***	**95% CI for *d***
Time 1: Sensation seeking										
N	22	14			11	14				
M	1.47	1.41	.36	[-.32, 1.03]	1.48	1.60	-.72	[-1.5, .12]	1.12**	[.29, 1.88]
SD	.17	.16			.15	.18				
Time 2: Sensation seeking										
N	13	8			3	4				
M	1.45	1.53	-.42	[-1.29, .49]	1.35	1.54	-2.04^{+}	[-3.46, .03]	.08	[-1.13, 1.27]
SD	.21	.15			.11	.08				
Time 2: BART										
N	13	8			3	4				
M	32.5	31.80	.05	[-.83, .93]	40.18	31.35	.92	[-.78, 2.32]	-.05	[-1.24, 1.16]
SD	16.41	9.13			9.47	9.73				

Note: Group differences significant by *t* test.
$^{+}p < .05$ (two-tailed); $^{**}p < .01$ (one-tailed)

Table 3

Statistical tests of group differences on sensation seeking and the BART

	Sex Effect	Status Effect	Sex * Status
Time 1: Sensation seeking	$F(1, 57) = 5.14$*	$F(1, 57) = .35$	$F(1, 57) = 4.27$*
Time 2: Sensation seeking	$F(1, 24) = .34$	$F(1, 24) = 3.04$	$F(1, 24) = .50$
Time 2: BART	$F(1, 24) = .37$	$F(1, 24) = .65$	$F(1, 24) = .47$

Note: Effects significant with *F* test (ANOVA).

*$p < .05$ (one-tailed)

Table 4

Descriptive statistics and effect sizes for group differences on sensation seeking subscales at Time 1

	Females				Males					
	CAH ($N = 22$)	**Control ($N = 14$)**	***d***	**95% CI for *d***	**CAH ($N = 11$)**	**Control ($N = 14$)**	***d***	**95% CI for *d***	**Sex differences Controls *d***	**95% CI for *d***
TAS										
M	1.70	1.50	.64*	[-.06, 1.31]	1.70	1.80	-.45	[-1.23, .37]	1.04**	[.22, 1.80]
SD	.30	.33			.20	.24				
DIS										
M	1.33	1.36	-.11	[-.78, .56]	1.43	1.52	-.31	[-1.09, .50]	.58	[-.19, 1.32]
SD	.27	.25			.28	.30				
BS										
M	1.29	1.30	-.06	[-.73, .61]	1.35	1.41	-.35	[-1.14, .45]	.69*	[-.09, 1.43]
SD	.17	.15			.17	.17				
ES										
M	1.56	1.49	.29	[-.39, .96]	1.41	1.65	-.87^{+}	[-1.67, -.02]	.58	[-.19, 1.32]
SD	.24	.24			.22	.31				

Note: Group differences significant by *t* test.
*$p < .05$ (one-tailed); $^{+}p < .05$ (two-tailed); **$p < .01$ (one-tailed)

Table 5

Statistical tests of group differences on sensation seeking subscales at Time 1

	Sex Effect	Status Effect	Sex * Status
TAS	$F(1, 57) = 3.87$	$F(1, 57) = .55$	$F(1, 57) = 3.87$
DIS	$F(1, 56) = 3.09$	$F(1, 56) = .54$	$F(1, 56) = .17$
BS	$F(1, 57) = 4.52$*	$F(1, 57) = .52$	$F(1, 57) = .55$
ES	$F(1, 57) = .02$	$F(1, 57) = 1.73$	$F(1, 57) = 5.25$*

Note: Effects significant with *F* test (ANOVA).

*$p < .05$ (one-tailed)

Table 6

Descriptive statistics and effect sizes for group differences on sensation seeking subscales at Time 2

	Females				Males					
	CAH ($N = 13$)	**Control ($N = 8$)**	***d***	**95% CI for *d***	**CAH ($N = 3$)**	**Control ($N = 4$)**	***d***	**95% CI for *d***	**Sex differences Controls *d***	**95% CI for *d***
TAS										
M	1.61	1.65	-.12	[-1.00, .76]	1.53	1.85	-1.12	[-2.52, .63]	.85	[-.46, 2.02]
SD	.36	.26			.40	.17				
DIS										
M	1.35	1.55	-.93*	[-1.81, .03]	1.13	1.33	-1.45	[-2.84, .41]	-1.03	[-2.21, .31]
SD	.20	.24			.15	.13				
BS										
M	1.29	1.36	-.28	[-1.15, .62]	1.40	1.33	.44	[-1.14, 1.88]	-.12	[-1.31, 1.09]
SD	.23	.29			.17	.15				
ES										
M	1.55	1.55	0.00	[-.88, .88]	1.33	1.65	-1.69	[-3.09, .25]	.60	[-.66, 1.78]
SD	.23	.12			.06	.24				

Note: Group differences significant by *t* test.
*$p < .05$ (one-tailed)

Table 7
Statistical tests of group differences on sensation seeking subscales at Time 2

	Sex Effect	Status Effect	Sex * Status
TAS	$F(1, 24) = .20$	$F(1, 24) = 1.64$	$F(1, 24) = .96$
DIS	$F(1, 24) = 6.02$*	$F(1, 24) = 4.83$*	$F(1, 24) = .00$
BS	$F(1, 24) = .11$	$F(1, 24) = .00$	$F(1, 24) = .46$
ES	$F(1, 24) = .44$	$F(1, 24) = 3.40$	$F(1, 24) = 3.31$

Note: Effects significant with *F* test (ANOVA).
*$p < .05$ (one-tailed)

Academic Vita
Timothy L. Groh

tgroh55@gmail.com

Education

Bachelor of Science in Psychology
The Presidential Leadership Academy
College of the Liberal Arts, Schreyer Honors College
The Pennsylvania State University, University Park, PA

Research Experience

Sept. 2013 – May 2017 **Berenbaum Laboratory, Research Assistant**
Department of Psychology, The Pennsylvania State University
Data collection, scoring, and analysis for studies of sex hormone influences on human behavior
Supervisor: Sheri Berenbaum, Professor of Psychology and Pediatrics

May – Dec. 2016 **Grozinger Laboratory, Research Assistant**
Department of Entomology, The Pennsylvania State University
Tissue processing, RNA extraction, cDNA synthesis, and qRT-PCR for study of viral evolution in honey bees
Supervisor: David Galbraith, post-doctoral scholar

Sept. 2015 – July 2016 **Rural Fathers Study, Research Assistant**
Department of Psychology, The Pennsylvania State University
Home visits for data collection for doctoral thesis on rural fatherhood
Supervisor: Elizabeth Miller, PhD student

May – July 2014 **Bilingualism and Language Development Laboratory, Research Assistant**
Department of Psychology, The Pennsylvania State University
Stimulus development for study of language processing in bilinguals
Supervisor: Sarah Grey, post-doctoral scholar

Leadership & Policy Experience

Aug. 2015 – May 2017 **Berenbaum Laboratory, Undergraduate Lab Manager**
- Interviewed and selected new research assistants, coordinated weekly tasks, and communicated between Dr. Berenbaum and the research assistants

April 2016 – Jan. 2017 **Penn State Alternative Breaks, Co-Site Director**
- Designed, organized, and led a group of ten students on a week-long service learning experience about refugee resettlement in Atlanta, GA

Aug. 2015 – May 2016 **Schreyer Honors College-Radboud University Health Policy Think Tank**

- Collaborated with peers from the Schreyer Honors College and Radboud University in the Netherlands to conduct a literature review and survey nursing home administrators in order to report to the Dutch Ministry of Health, Welfare, and Sport on factors that support or impede the early integration of palliative care in nursing homes
- "Timely Palliative Care in Nursing Homes: A Comparison of the Dutch and American Health Care Systems" (May 2016) https://www.dropbox.com/s/ibu9dxisv1luxbd/Timely%20Palliative%20Care%20in%20Nursing%20Homes.pdf?dl=0

Aug. 2013 – May 2016 **Penn State Presidential Leadership Academy**

- Took courses with Penn State's President and the Dean of the Schreyer Honors College on leadership and critical thinking
- Presented a policy proposal for reforming general education at Penn State
- "General Education at Penn State: A Policy for Reforming Structure, Communication, and Assessment" (April 2014) https://academy.psu.edu/documents/current/policy-proposals/2014/general_education.pdf
- Leadership Portfolio (April 2016) https://sites.psu.edu/timgrohplaportfolio/

Posters

Groh, T. L., Bryk, K. L., Beltz, A. M., & Berenbaum, S. A. (2017, April). *Prenatal androgen effects on risky behavior*. Poster presented at the annual Penn State Undergraduate Research Exhibition, State College, PA.

Reitz, E. L., **Groh, T. L.**, Beltz, A. M., Bryk, K. L., McHale, S. M., & Berenbaum, S. A. (2017, April). *Gendered peer preferences in girls with prenatal androgen exposure: Effects of gender identity, cognitions, and activities*. Poster presented at the biennial meeting of the Society for Research in Child Development, Austin, TX.

Fernando, N., Gortman, L., **Groh, T.**, McDermott, E., Mertens, V., Rouweler, S., Solanki, P., Tjepkema, E., Verhagen, N., Wilkie, S., ZhuParris, A., Engels, Y., van Gurp, J., & Sceigaj, M. (2016, March). *Timely palliative care in nursing homes: A comparison of the American and Dutch Health Care Systems*. Poster presented at the annual ASA Aging in America Conference, Washington, D.C.

Groh, T. L., Marshall, E., Bryk, K. L., & Berenbaum, S. A. (2015, April). *Prenatal androgens and personality*. Poster presented at the annual Penn State Psi Chi Research Conference, State College, PA.

Beltz, A. M., **Groh, T. L.**, Nuri, D., & Berenbaum, S. A. (2014, April). *Sex hormone effects on brain activation for spatial ability*. Poster presented at the annual Penn State Psi Chi Research Conference, State College, PA.

***2nd Place Award for Conceptual Posters**

Honors & Awards

2012 – 2016	Schreyer Honors College Academic Excellence Scholarship
2016	Apes Valentes Undergraduate Research Award
2016	Costello Family Scholarship in Psychology
2015	Phi Beta Kappa
2015	Penn State Evan Pugh Scholar Award
2014	Penn State President Sparks Award
2014	Schreyer Honors College Summer Research Grant
2013	Penn State President's Freshman Award
2010	Eagle Scout Award