Effects of Fetal Tobacco Exposure on Focused Attention in Infancy

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Abstract

This study examined the association between fetal tobacco exposure (FTE) and focused attention at 9 months of child age, and the role of child sex and infant behavioral reactivity as potential moderators of this association. Data were obtained from 203 mothers and their infants (105 fetally exposed and 98 non-exposed) on infant focused attention and behavioral reactivity to a frustration task. FTE was ascertained via nicotine metabolites in infant meconium, reflecting primarily third trimester fetal exposure. Results demonstrated a main effect of FTE on focused attention, such that

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exposed infants exhibited lower levels of focused attention than non-exposed infants. Behavioral reactivity, but not infant sex, moderated the relationship between FTE and focused attention, such that exposed infants who were highly reactive to frustration had the lowest levels of focused attention. Results suggest that smoking interventions, even in the third trimester, may have a positive impact on attentional outcomes for infants.

Keywords

prenatal tobacco exposure; focused attention; behavioral reactivity; infants

Tobacco is one of the most commonly used drugs during pregnancy and is known to deliver significant amounts of chemical toxins to the fetus via the maternal bloodstream. Despite the known health consequences, 16.4% of American women continue to smoke while pregnant (Substance Abuse and Mental Health Services Administration, 2009), making prenatal tobacco exposure one of the largest preventable causes of poor fetal outcomes such as impaired fetal growth, respiratory problems, and infant mortality in the U.S. (Dietz et al., 2010). There is less consensus regarding other aspects of development, especially basic underlying processes of attention and arousal. One key aspect of attention in infancy that is predictive of both behavioral problems and cognitive abilities in early childhood is focused attention (Lawson & Ruff, 2004).

Focused attention in infancy is a state of attention during which the infant is selectively attending to an object to the exclusion of other things in the environment. Focused attention involves intense concentration, coupled with a quieting of vocalizations, social bids, and irrelevant body movements. In a state of focused attention, the infant is devoting their energy and resources to the exploration of the object, and may remain oriented to the object for longer periods of time than they would in a state of casual attention (Lawson & Ruff, 2001; Ruff, Capozzoli, & Saltarelli, 1996). As their primary source of information, measures of focused attention in infancy are an early index of memory and learning (Lamb, Bornstein, and Teti, 2002). This has been evidenced by the tendency of infants to use focused attention when presented with a novel object (Ruff, 1988; Ruff, Saltarelli, Capozzoli, & Dubiner, 1992; Oakes, Madole, & Cohen, 1991). Once information has been gathered, the infant may move on to more casual behaviors such as mouthing, banging, or shaking, which are characteristic of lower levels of attention. This type of active processing of objects during play is predominant from around 6 to 24 months (Lawson & Ruff, 2001). This study examined the association between FTE and focused attention at 9 months of child age.

Although there is a relatively large literature on the association between prenatal tobacco exposure and ADHD risk (Motlagh et al., 2011), few studies examined the attentional system, specifically. These small number of studies span different developmental periods. For instance, in infancy Espy et al. (2011) reported significant effects of prenatal tobacco exposure on attention/orientation at birth and 2 weeks, but not at 4 weeks. Authors attributed results to withdrawal effects (Espy et al., 2011). Willoughby et al. (2007) noted continued effects beyond the neonatal period, finding lower attention among prenatal tobacco exposed boys compared to control boys, but not girls, during developmental testing at 6-8 months of

age. In early childhood, trimester specific effects were noted, with second and third trimester prenatal tobacco exposure associated with greater inattention at 6 years of age (Leech, Richardson, Goldschmidt, & Day, 1999). Finally, in adolescence Jacobsen et al. (2007) found the lowest auditory and visual selective attention among prenatally exposed adolescent girls who were smokers compared to non-exposed girls or those who were non-smokers. Thus, studies examining the association between prenatal tobacco exposure and attentional processes are few in number and to our knowledge none examined the effects of prenatal tobacco exposure on focused attention specifically.

One explanation of the mixed results for attentional processes in general may be the presence of moderators. One such moderator may be behavioral reactivity or arousal, in light of the robust association between attention and arousal. The attention/arousal system is coordinated and attention is often used to regulate arousal (Lyon & Krasnegor, 1996). Attention, arousal, and the ability to maintain behavioral states reflect central nervous system functioning and work inter-dependently to regulate responses to internal and external stimulation (Karmel, Gardner, & Magnano, 1991). Indeed, this dynamic system of attention and arousal is the interface between the infant and their environment, and allows infants to shift and focus attention effectively to external stimuli (Richards, 2008). In this context, high arousal interferes with responses to external stimulation as attentional efforts may be allocated to facilitating emotion regulation and limiting potential distress, and may not be appropriately shifted to other external stimuli (Gardner, Karmel, & Magnano, 1992; Kopp, 2002). Thus, excessive arousal or reactivity may hamper infants' ability to focus attention effectively, especially among infants who are biologically vulnerable due to prenatal tobacco exposure. Individual differences in reactivity may be indicated by the latency and/or intensity of reactions to frustration. Indeed, Calkins and colleagues (2002) observed easily frustrated infants as less attentive than their less easily frustrated counterparts. Similarly, more intense reactivity to negative events were found previously in children with ADHD as compared to children without ADHD (Jensen & Rosén, 2004).

Infant sex may also have the potential to moderate the association between prenatal tobacco exposure and focused attention. Girls of all ages have fewer attentional problems than boys of the same age (Arnold, 1996). Boys typically receive higher ratings for symptoms of attentional problems than girls (DuPaul et al., 1998). In addition, the attentional abilities of girls often progress at different rates than boys, with sustained attention developing earlier in girls than in boys (Greenberg & Waldman, 1993). Furthermore, boys are more biologically vulnerable to prenatal insult than girls (Lewis & Kestler, 2012), indicating the possibility of the association between prenatal tobacco exposure and poor focused attention to be stronger for boys compared to girls.

The primary purpose of this study was to examine the relationship between prenatal tobacco exposure and focused attention in infancy in a diverse sample of low-income mothers and infants. Based on the literature presented above, we hypothesized that prenatal tobacco exposure would be associated with poorer focused attention, and that behavioral reactivity and infant sex would moderate this relationship. Specifically, we expected that the association between prenatal tobacco exposure and focused attention in infancy would be

stronger for infants with higher behavioral reactivity compared to infants with lower behavioral reactivity, and would also be stronger for boys than for girls.

Method

Participants

The sample included 258 mother/infant dyads, with 181 infants prenatally exposed to tobacco (99 boys and 82 girls), and 77 not exposed (35 boys and 42 girls). Pregnant women were recruited at their first prenatal appointment in a local area hospital and screened for eligibility. Women were eligible if they met the following criteria: greater than 20 weeks gestation, were not having a multiple birth, were at least 18 years old, were not using illicit drugs (other than cannabis), were not heavy alcohol users (defined as 4 or more drinks in one sitting or drinking an average of more than 1 drink/day), were not heavy marijuana users after pregnancy recognition (defined as smoking an average of more than 1 joint/day), and were English speakers. Women using other substances were excluded in order to disentangle the specific effects of tobacco exposure from those that might be caused by other drugs. At the conclusion of each recruitment month, participating smokers were matched on maternal age and highest educational attainment with the closest eligible nonsmoking woman, who was then invited to participate. The smoking group was oversampled such that one non-smoker was recruited for every two smokers. Oversampling was done to allow for a full range of light to heavy smokers, as well as to allow for the possibility of higher attrition in the smoking group over time. In total, 3,583 women were screened, 1,671 of which were eligible. Of those, 416 (25%) were interviewed prenatally, and 258 women completed at least one postnatal assessment. One mother-infant dyad was dropped from analyses because infant meconium was positive for methamphetamine, two infants were dropped because they had hydrocephaly, one was dropped because of a later diagnosis of autism, one because of binge drinking during pregnancy, four because of maternal diagnosis of bipolar disorder, one because of loss of custody, and one additional participant was excluded due to low maternal cognitive functioning, resulting in a sample size of 247 infants.

Maternal age ranged from 18 to 39 years at the time of their first appointment ($M = 24.01$, $SD = 4.96$). The women in the sample were 52% African-American, 30% Caucasian, 18% Hispanic, and 8% other or mixed race, with several identifying as more than one race. Forty-five percent of the expectant mothers were married or living with their partner, 33% were in a relationship, but not living with their partner, 21% were single, and 1% were divorced. Twenty-nine percent of women had less than a high school education, 29% completed high school, 29% completed some college, 9% had a vocational/technical or associates degree, and 4% had a bachelor's degree. Thus, the sample was largely comprised of single minority women with a high school diploma or less. Women were compensated $20 for each prenatal interview, and $40 for their 9 month appointment, along with a $20 gift card and a toy for the baby (worth an additional $20). Transportation to and from the lab was provided.

Procedures and Instruments

Informed written consent was obtained from all interested and eligible participants at their first laboratory visit, during the first trimester of pregnancy. Assessments were conducted

once during each trimester of pregnancy, and at 2 (*M* = 2.51, *SD* = .41) and 9 (*M* = 8.81, *SD* = .87) months of infant age (corrected for prematurity). Data from prenatal interviews, infant meconium (the first neonatal feces), and the 9 month child assessment were the focus of the present study. Of the 258 mothers and infants who completed the 2 month assessment, 245 completed the 9-month assessment, and of those 245, 203 infants also had results from meconium testing. Meconium was not collected if either (a) milk stool appeared before collection could occur (n = 28), or (b) the participant changed her prenatal care such that she delivered at another hospital (n = 23). For an additional three infants, meconium was collected and sent to the laboratory, but the quantity was not sufficient for analysis. Finally, one infant was excluded because the infant's meconium was positive for prenatal methamphetamine exposure, leaving 203 infants with fetal exposure results. Mothers of infants missing meconium test results were not significantly different from those with meconium test results on maternal age, $t(254) = -1.16$ $p = .25$, education, $t(255) = 1.68$, $p = .10$, or prenatal use of cigarettes, $t(255) = -0.39$, $p = .70$, alcohol, $t(255) = 0.20$, $p = .84$, or marijuana, $t(255) = 0.53$, $p = .60$. The infants themselves were not significantly different with regard to birth weight, $t(255) = 0.44$, $p = .66$), head circumference, $t(232) = 1.85$, $p = .07$), birth length, $t(248) = 0.89$, $p = .37$, or gestational age, $t(255) = 0.24$, $p = .81$.

Substance use.—Maternal tobacco use in the prenatal period was assessed during each trimester of pregnancy via maternal report using the Timeline Followback Interview (TLFB; Sobell, Sobell, Klajmer, Pavan, & Basian, 1986). The TLFB (Sobell, et al., 1986) assessed self-reported maternal substance use during pregnancy. Participants were provided a calendar and asked to identify events of personal interest (e.g., holidays, birthdays, vacations, etc.) as anchor points to aid recall. This method was established as a reliable and valid method of obtaining longitudinal data on substance-use patterns, has good test-retest reliability, and is highly correlated with other intensive self-report measures (Brown et al., 1998). The TLFB yielded data on average number of cigarettes smoked per day during pregnancy, as well as number of joints per day, and number of standard drinks per day. These variables were used to examine potential dose/response effects.

In addition to maternal self-reports, infant meconium, the first neonatal feces, was collected after birth twice daily until the appearance of milk stools. Meconium was transferred to storage containers and frozen at −80°C until transport to the National Institute on Drug Abuse. Meconium was assayed with a validated quantitative LS-MSMS method (Gray, Shakleya, & Huestis, 2009) for nicotine, cotinine, and *trans*-3'–hydroxycotinine (OHCOT; see Gray et al. (2010) for further details). Limits of quantification were 2.5 ng/g for nicotine, 1 ng/g for cotinine, and 5 ng/g for OHCOT. As the gold standard for measuring fetal exposure, meconium is a reliable measure of fetal tobacco exposure in the third trimester specifically (Gray et al., 2010). The presence or absence of nicotine or any nicotine metabolites in meconium was used as an indicator of whether tobacco metabolites reached the fetus. Thus while these two measures of maternal tobacco use share some commonalities, each provided some unique information with regard to fetal exposure.

Birth outcomes.—Three measures of growth were examined as potential covariates in this study: birth weight (gm), birth length (cm), and head circumference (cm). All

measurements were taken by obstetrical nurses in the delivery room and recorded in the infant's medical chart. Research staff recorded this information directly from the charts after the birth of the infant. Gestational age was calculated by dates and extracted from medical records (see Table 1).

Focused attention.—Infants and their mothers came to the laboratory between 34 and 40 weeks of age corrected for prematurity. Infants participated in a brief warm up with the infant assessor, while the interviewer explained the procedures of the visit to the mother. Infants were placed in a high chair and presented with a series of 4 novel toys in a specific order.

Replacement toys were used ($n = 10$) if mothers indicated that the toys were not novel, as novelty has been related to increases in time spent examining objects (Ruff, 1988; Ruff, et al., 1992; Oakes et al., 1991). Mothers were seated in a chair next to the infant and asked not to interact with the infant during the focused attention procedure. The infant assessor presented each toy, one at a time, for 90 seconds. The procedure was terminated for one infant with repeated toy drops and modified for four infants who became upset during toy administration. For these four infants, the focused attention paradigm was administered at the end of the lab visit, with the child seated in mom's lap at a card table.

Toy 1 was a plastic block, with various colors and textures. Toy 2 was a blue ball within a yellow casing. When moved, the ball moved and made noise. Toy 3 was a cylinder with small beads inside. When moved, the beads would slide from one side to another. Toy 4 was the most complex; three handles moved in opposite directions of each other and made noise when they were cranked. Video tapes of the focused attention assessments were coded by research assistants who did not participate in the assessments and were blind to group status. The rating of focused attention was a global rating that was based on several dimensions, including duration of focused attention, latency to look at the toy, number of focused looks, vigor of movement, and number of times the toy was thrown or dropped. This global rating, outlined by Lawson and Ruff (2001), is comprised of a 5 point rating scale with a 1 indicating "no focused attention on the object" and a 5 indicating "long periods of focused attention". This global rating was rated separately for each of the 4 toys, with inter-rater reliabilities calculated on 12% of the tapes. Intra-class correlation were .83 for toy one, .94 for toy two, and .90 for toys three and four.

Behavioral reactivity.—Behavioral reactivity was our index of infant arousal. To assess behavioral reactivity, we used a gentle arm restraint procedure that is well-validated and widely employed as a measure of infant anger and frustration (Goldsmith & Rothbart, 1999; Stifter & Braungart, 1995). This procedure occurred while the infant was still seated at the high chair, immediately after watching a 3 minute neutral video (Spot). Infants were presented with a novel and attractive toy for 30 seconds. The infant assessor facilitated engagement with the toy by saying "Look (baby's name)", and demonstrating the movement of the toy at the start of each engagement period. After the 30 second engagement, the infant assessor stood behind the child, moved the toy to the corner of the high chair tray, and placed her hands gently on the child's forearms, holding them by the child's side for 30 seconds (trial 1). Infant assessors maintained a neutral expression and did not engage the

infant at all during this time. The toy was then moved back in front of the infant, who was again encouraged to play with it for 30 seconds, followed by another 30 seconds of gentle arm restraint (trial 2). These trials were stopped at the request of the caregiver, or if the child reached maximum distress, which was defined as a full cry. This occurred for six infants. Coders blind to group status coded the tapes on how intensely the infant struggled against the restraint, with scores ranging from 0, indicating no struggle, to 4, indicating high intensity struggle. Reliabilities were calculated for 12% of the tapes, and inter-rater reliability for the episode was .93. The maximum intensity of struggle score from the two trials was used.

There were three additional codes for the arm restraint episodes. First, the effectiveness of the experimenter was coded, with codes ranging from 0 (ineffective: not restraining child) to 2 (effective: restrains even when child struggles). Note that there were no cases for which there was a 0 rating on the measure of experimenter effectiveness. Second, child engagement with the toy prior to the episode was coded, with codes ranging from 0 (indifferent) to 2 (fully engaged). Finally, the infant's baseline state was recorded on a scale ranging from 0 (drowsy) to 5 (crying).

Data Analytic Strategy—We first examined associations between the different prenatal substance exposure variables and our variables of interest using Pearson correlations or ANOVAs as appropriate. These included the fetal exposure variable of meconium positive for tobacco, and the dose response variable of the average number of cigarettes per day across the entire pregnancy. Analyses to guide selection of potential covariates were conducted next using correlations or ANOVAs as appropriate. Demographic or perinatal risk variables that were associated with the independent variables or the dependent variable at p < .10 were treated as covariates in subsequent analyses.

As with any longitudinal study, there were incomplete data for some of the participants on one or more of the variables included in this study. Of these, 28 had missing data for focused attention, 31 had missing data for behavioral reactivity, and four had missing data for head circumference. There were no significant differences between families with complete vs. missing data on maternal education, or on their use of prenatal substances (alcohol, marijuana, and cigarettes), with *p* values ranging from .08 to .98. Missing cases were deleted listwise from the analysis, leaving an analytic sample of 171[1].

To test the primary hypotheses, a four step hierarchical multiple regression was employed with SPSS statistical software (Version 24, IBM Corp., 2016). Variables were entered into the regression models, along with their corresponding interaction terms to test moderation. These included centered scores for baseline state, effectiveness of experimenter, engagement with toy, and behavioral reactivity, as well as the dummy coded fetal exposure variable. The outcome variable was the global rating of focused attention for Toy 1 as described in the instruments section. Simple slopes were tested following the guidelines set forth by Aiken

[1]Analyses were also run utilizing multiple imputation with the full 203 participants, using SAS PROC MI (SAS, 1999). These results were identical.

and West (1991). Specifically, covariates were entered in Step 1, followed by fetal tobacco exposure in Step 2, moderator in Step 3, and the interaction term in Step 4.

Results

Correlational analyses were conducted with the two indicators of prenatal tobacco exposure (maternal self-report and infant meconium) and focused attention. Results indicated that maternal self-report of cigarettes per day across the entire pregnancy was not related to infant focused attention on any of the 4 toys presented. However, there was a significant association between presence or absence of nicotine metabolites in meconium and infant focused attention for Toy 1 (see Table 1). Thus, all remaining analyses were conducted with infant meconium as the primary independent variable, hereby referred to as FTE, and focused attention during the presentation of Toy 1 as the primary dependent variable.

Demographics

Descriptive statistics for both demographic and substance use variables for mothers and infants in the FTE and non-FTE groups are presented in Table 2. In this predominantly low-income sample, mothers in the FTE group were significantly less educated and less likely to be married or living with their partner. As would be expected, mothers of infants in the FTE group also consumed significantly more alcohol and smoked significantly more cigarettes and marijuana both prenatally and postnatally than mothers of non-exposed infants (see Table 2).

Examination of Potential Covariates

Infants in the FTE group were not significantly different from infants in the non-FTE group in terms of sex, percent premature, or the three variables from the gentle arm restraint procedure (intensity of struggle, baseline state, and engagement with toy). Infants in the FTE group were, however, significantly smaller on all birth outcomes (birth weight, length, and head circumference), had a significantly lower gestational age, and had significantly lower levels of focused attention on Toy 1 than those in the non-FTE group (see Table 1).

We examined the relation of maternal variables (age, education, parity, partner status, prenatal alcohol and marijuana use), and infant variables (birth weight, head circumference at birth, gestational age, and sex) with infant focused attention at 9 months of age. None of the variables that were associated with FTE, including maternal education and measures of fetal growth such as head circumference, birth weight, and gestational age, were associated with focused attention, nor was prenatal alcohol ($r = -.07$, $p = .35$) or marijuana ($r = -.10$, $p = .20$) use. Consequently, these variables were not considered further as covariates.

Association Between FTE and Focused Attention Controlling for Covariates

ANOVA's with FTE group status as the independent variable and each of the four focused attention scores (one for each toy) as the dependent variables yielded a significant group difference on Toy 1 only, $F(1,173) = 3.08$, $p = .02$, $d = -3.28$, while Toy 2, $F(1,173) = 0.02$, $p = .85$, $d = -.26$, Toy 3 $F(1,173) = 0.82$, $p = .37$, $d = -1.28$, and Toy 4 $F(1,173) = 0.05$, $p = .82$, $d = -.33$, were not significant (see Table 2). Thus, we utilized the global rating for Toy 1

as the dependent variable in the next set of analyses examining moderation. Bivariate correlations for all variables included in the final regression model are presented in Table 2.

Behavioral Reactivity

We conducted multiple regression analyses to examine whether the association between fetal tobacco exposure and focused attention was moderated by behavioral reactivity. The effectiveness of the experimenter, infant baseline state, and infant engagement with the toy during the arm restraint task were included as covariates in order to account for possible differences in the infant's experience of the reactivity task. The covariates were entered in the first step, followed by fetal exposure in the second step, behavioral reactivity in the third step, and the interaction term in the final step.

Overall, the model was significant, accounting for 11% of the variability in focused attention, $F(6,164) = 3.37$, $p > .01$. Examination of the residuals indicated that the assumptions of normality and homoscedasticity were tenable. Results are presented in Table 3. As noted earlier, there was a main effect of FTE status, such that exposed infants had lower levels of focused attention than non-exposed infants. There were no main effects for the covariates or behavioral reactivity. There was, however, a significant interaction between FTE status and behavioral reactivity (see Table 3). As depicted in Figure 1, there was a significant association, $b = -0.57$, $p < .001$, between fetal exposure and focused attention at high levels of reactivity (+1 SD above the mean), but not at low levels of reactivity (−1 SD below the mean), where infants had similar focused attention ratings, $b = 0.02$, $p = .90$, regardless of prenatal exposure.

Sex as a Moderator

We then conducted multiple regression analyses to examine whether the association between fetal tobacco exposure and focused attention was moderated by child sex. The effectiveness of the experimenter, infant baseline state, and infant engagement with the toy during the arm restraint task were again included as covariates. The covariates were entered in the first step, followed fetal exposure in the second step, child sex in the third step, and the interaction term in the final step. Overall, the model was not significant, accounting for only 6.2% of the variability in focused attention, $F(6,164) = 1.82$, $p = .10$. As before, there was a significant main effect of FTE status, but there was no main effect of sex, nor was there a significant interaction between FTE status and child sex (see Table 4).

Discussion

The main goal of this study was to examine the association between fetal tobacco exposure and focused attention, and to see whether this association was moderated by behavioral reactivity and infant sex. Our results indicated that one index of prenatal tobacco exposure that reflects fetal exposure primarily in the third trimester (Gray et al., 2010) was associated with higher risk for poor focused attention in infancy. Results also highlighted the role of infant behavioral reactivity as a significant moderator of this association.

Previous studies found relationships between infants at high risk and focused attention. Lawson and Ruff (2001) found that high risk infants (in their case very low birthweight

preterm infants) had low mean global focused attention ratings at 7 ($M = 1.71$, $SD = .63$), and 12 months ($M = 2.33$, $SD = .86$). In the current study, the mean global focused attention ratings were higher than the Lawson and Ruff (2001) scores for both the FTE ($M = 2.64$, $SD = .68$) and non-FTE infants ($M = 2.92$, $SD = .83$). This may be due to differences in the toys, but also may be due to differences in how high risk was determined. Although our sample consisted of infants who were prenatally exposed to tobacco, only a small number were preterm and none qualified as very low birthweight (< 1500 grams). Consequently, our global ratings were higher overall. Despite this, FTE infants in this study exhibited significantly lower focused attention compared to non-FTE infants. Future studies with prospective data may examine how differences in focused attention in infancy may be associated with different developmental trajectories for FTE and non-FTE children.

As hypothesized, behavioral reactivity or reactive arousal was an important moderator of the relationship between FTE and focused attention. Highly reactive children who were fetally exposed to tobacco had the poorest outcomes with regard to focused attention. In other words, the association between fetal tobacco exposure and focused attention was stronger in the context of high behavioral reactivity. The results are generally supportive of studies indicating the coordination between attention and arousal system (Lyon & Krasnegor, 1996; Karmel, Gardner, & Magnano, 1991). Future studies may examine if this is one developmental process linking fetal tobacco exposure to higher risk for disruptive behaviors in later childhood.

Contrary to our hypothesis, the sex of the child was not related to focused attention, nor did sex moderate the association between FTE and focused attention. As noted in a recent review of the literature on sex differences in tobacco exposure (Coles, Kable, & Lynch, 2012), most studies of FTE did not examine the potential for sex differences. However, within this limited literature, our results are supportive of a few studies reporting no sex differences (Pridham, Becker, & Brown, 2000), even when using other measures of focused attention, such as the duration of fixation on an object (Miceli, Whitman, Borkowski, Braungart-Rieker, & Mitchell, 1998).

Implications

A large number of women quit or reduce smoking spontaneously upon pregnancy recognition (Homish, Eiden, Leonard, & Kozlowski, 2012). However, while the majority of women reduce smoking after pregnancy recognition, about 10% of women continue smoking into their third trimester (CDC, 2011). Our results indicated that while infant focused attention was not associated with maternal self-report of tobacco use across the entire pregnancy, it was associated with the presence or absence of nicotine biomarkers in infant meconium. This suggests that fetal tobacco exposure has a significant teratogenic effect on focused attention as evidenced by fetal exposure in the third trimester, and that maternal self-report alone, even when collected prospectively, may not be an adequate index of fetal risk. Given that tobacco metabolites in meconium identifies third trimester tobacco exposure (Gray et al., 2010), results suggest that persistent smoking throughout pregnancy is a stronger risk factor for infant focused attention than smoking only in the early stages of

pregnancy. Thus smoking cessation interventions, even in the third trimester, may have a positive impact on infant attentional outcomes.

Also of interest to researchers working to improve observational measures of attention was our finding of group differences on only one of the four toys we presented. Toys two, three, and four were not related to any of our questions of interest. Given that toy one was a simple block and was the only toy that did not have moving parts and did not make any noise, it is possible that the other toys invited the use of more casual attention like shaking and banging as this produced different sounds. It is also possible that the infants may have found the other toys to be too engaging, thus little variability was seen between the groups. Finally, it could be that differences between the FTE and non-FTE infants are only apparent initially, and that they become more similar once the novelty of the task wears off. This perspective is supported by our data, which show a decline in the average focused attention ratings across the four toys. While the focused attention ratings were not significantly different between toys 1 and 2, they were significantly different between toy 1 and toys 3 and 4, indicating significantly lower mean levels of focused attention overall for the last two toys presented. Future studies may want to examine how features of the objects presented, as well as habituation to the task itself, may contribute to, or detract from, infant's attentional efforts.

Strengths, Limitations, and Conclusion

Our use of meconium to determine fetal tobacco exposure is a strength of the current study. Meconium is the gold standard for assessing fetal substance exposure, and is not prone to the problems of self-reported or retrospective data, making our results more reliable. In addition, while some studies included duration of focused attention as the outcome (Thomas, Whitfield, Oberlander, Synnes, & Grunau, 2012; Lawson & Ruff, 2004; Choudhury & Gorman, 2000), our global attention rating combined several important elements of focused attention, including duration, quieting of motor movements and vocalizations, and object orientation. Finally, Calkins et. al. (2002) discussed the need for studies of frustration and attention in diverse samples. Our study contributes to the literature by exploring this relationship in a sample of primarily single, minority, low-income mothers and their infants.

One limitation of this study may be the lack of repeated assessments of focused attention. There may be changes in focused attention as higher order attentional abilities mature across the second year of life. Future studies exploring focused attention across infancy with multiple assessments points may be better able to answer questions regarding these changes. In addition, the sample was restricted to pregnant smokers with low levels of alcohol use, low to moderate marijuana use after pregnancy recognition, and no other illicit substance use during pregnancy. Thus, the results are generalizable to low-income smokers who met these criteria. It is possible that infants of heavier smokers (who were also more likely to engage in heavier use of other substances) might have different patterns of focused attention than those noted in this more restricted sample, but inclusion of heavy poly-drug users would make it difficult to disentangle the effects of tobacco exposure from those of other drugs. Future studies with less stringent recruitment criteria and including heavy poly-drug users may yield different results.

Despite these limitations, the present findings provide additional support for the deleterious effects of fetal substance exposure on infant focused attention, particularly in the third trimester of pregnancy. Results indicated that this association was stronger in the context of high behavioral reactivity, suggesting greater vulnerability of infants who were more intensely aroused or frustrated. More generally, the results may reflect the fundamental role of emotion regulation for focused attention to occur, although the direction of this association can only be tested with prospective designs. Our findings highlight the potential for positive effects for infants of interventions targeted at persistent pregnancy smokers. Results also suggest the need for prospective data to examine if differences in focused attention in infancy are one developmental mechanism explaining associations between tobacco exposure and poor behavioral outcomes in later childhood.

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Highlights

- Examined focused attention in infants with fetal tobacco exposure.

- Lower focused attention in infants with fetal tobacco exposure.

- Gender did not moderate, but behavioral reactivity did.

- Infants more highly reactive to frustration had lowest levels of focused attention.
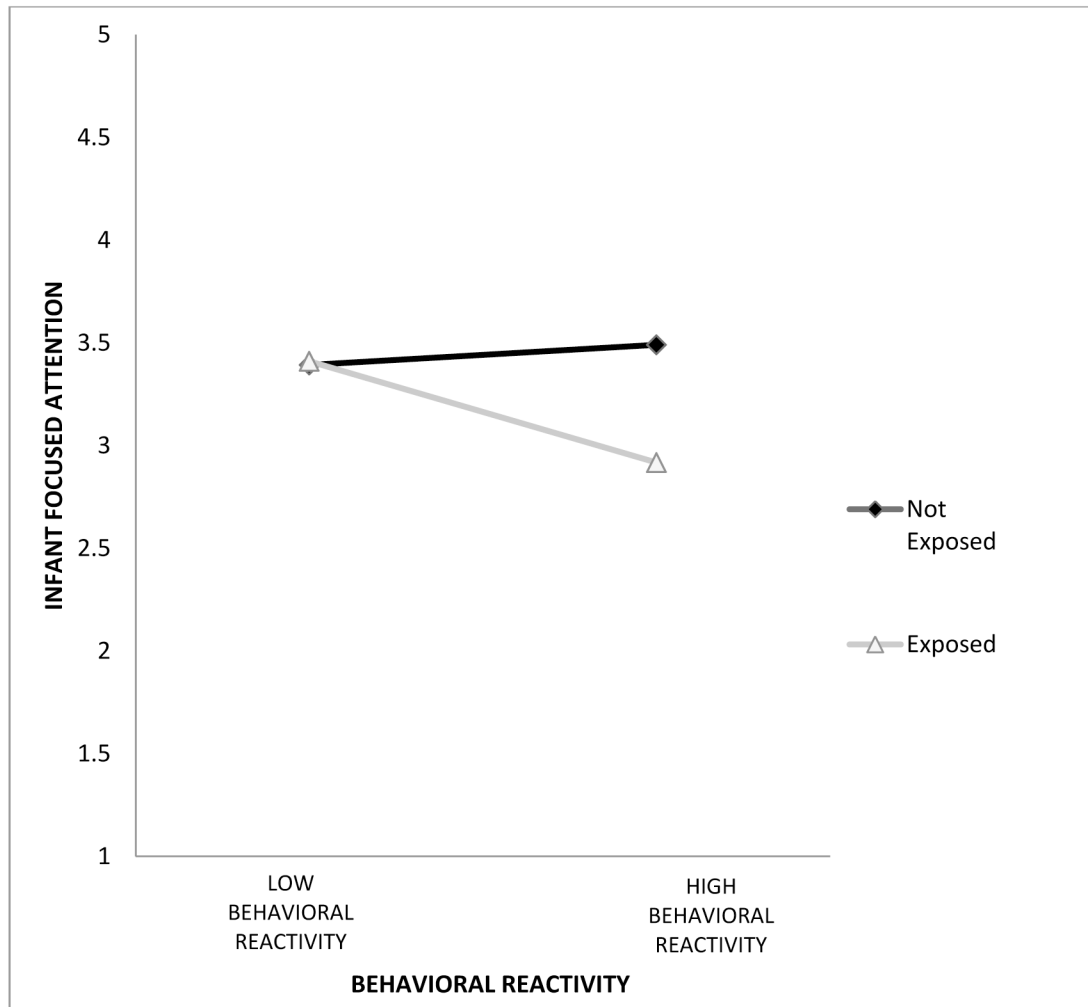
Figure 1.
Interaction of Fetal Exposure & Behavioral Reactivity. This figure indicates that there is no association between behavioral reactivity and focused attention among non-exposed infants, but there is a significant association between behavioral reactivity and focused attention among fetally exposed infants. Infants with fetal tobacco exposure and high behavioral reactivity have lower focused attention compared to non-exposed infants with high behavioral reactivity.

Table 1

Bivariate Correlations

	1	2	3	4	5	6	7	8	9	10	11	12
1. Focused Attention												
2. Fetal Exposure	−.17[*]											
3. Behavioral Reactivity	−.12	−.01										
4. Maternal Edu. (yrs)	−.04	−.15[*]	.05									
5. Birth HC	.14	−.28[**]	.09	.15[*]								
6. Engagement w/ Toy	.02	−.02	.04	−.03	.08							
7. Exp. Effectiveness	.00	−.05	.01	−.06	.06	−.04						
8. Baseline State	−.15	−.11	.06	−.01	−.07	−.34[**]	.04					
9. Sex	.02	−.05	.05	.03	−.14	−.07	.01	.11				
10. GA	.03	−.19[**]	−.09	.15[*]	.51[**]	.09	.08	−.10	−.10			
11. Birthweight	−.01	−.20[**]	.05	.19[**]	.67[**]	.02	.03	−.03	−.11	.54		
12. Prenatal Cigarettes: Maternal Self-Report	−.09	.57[**]	−.07	−.05	−.14	.05	−.05	.01	.04	−.07	−.12	

Note. n = 203. Edu = Education; HC = Head Circumference; Exp = Experimenter; GA = Gestational Age. The pattern of associations for maternal reports of cigarette use per day in each trimester was similar to that of the maternal report of average cigarettes per day across the entire pregnancy. As such the average cigarettes per day across the entire pregnancy was retained as it was more parsimonious.

[*] $p < 0.05$.

[**] $p < 0.01$.

Table 2

Group Differences for Maternal and Infant Characteristics

Variables	Fetal Exposure (n =105)		No Fetal Exposure (n =98)		df	t
	M	SD	M	SD		
<u>Maternal Characteristics</u>						
Demographics						
Maternal Age	24.7	5.4	23.6	5.5	200	−1.38
Education (In Years)	11.7	0.2	12.2	0.2	201	2.12[*]
Parity	2.4	1.8	2.1	1.4	199	−1.41
Married/Living with Partner	37.1% (n=39)		54.1% (n=53)			χ^2 =5.87[*]
Prenatal Substance Use (TLFB)						
Cigs/Day	6.2	5.3	.69	2.5	173	−8.80[**]
Joints/Day	0.4	0.7	.00	0.1	173	−4.59[**]
Standard Drinks/Day	0.1	0.2	.00	0.1	173	−2.48[*]
Postnatal Substance Use						
Cigs/Day	7.3	5.4	1.2	3.4	173	−8.80[**]
Joints/Day	1.2	2.1	0.1	0.4	173	−4.59[**]
Standard Drinks/Day	2.9	3.1	1.6	2.1	173	−3.25[**]
<u>Infant Characteristics</u>						
Perinatal Growth/Risk						
% Premature	9.5% (n = 10)		4.1% (n = 4)			χ^2 = 2.34
Birthweight (g)	3120	563.3	3340	521.0	201	2.89[**]
Birth Length (cm)	49.7	3.0	50.4	2.0	201	2.04[*]
Birth Head Circumference (cm)	33.4	1.9	34.4	1.6	197	4.15[**]
Gestational Age (weeks)	38.6	1.8	39.2	1.4	201	2.67[**]
Sex (% male)	55.2% (n = 58)		50% (n = 49)			χ^2= .56
Focused Attention	2.6	0.7	2.9	0.8	173	2.39[*]
Behavioral Reactivity	−.05	1.0	.00	1.0	170	.33
Baseline State	2.9	0.7	3.0	0.7	170	1.18
Engagement with Toy	1.9	0.4	1.9	0.3	170	.62

Note. TLFB = Timeline Follow Back

[*]
p < 0.05

[**]
p < 0.01

Table 3

Regression Analysis: DV Focused Attention

Predictor	R^2	R^2	β	SE	t	95% CI LL	95% CI UL
Step 1	.022	.022					
Engagement w/ Toy			−0.06	0.21	−0.02	−0.48	0.36
Baseline State			−0.17	0.09	−1.92	−0.35	0.01
Experimenter Effectiveness			0.01	0.18	0.03	−0.35	0.36
Step 2	.061	.039					
Fetal Exposure			−0.15*	0.06	−2.65	−0.26	−0.04
Step 3	.073	.013					
Behavioral Reactivity			0.05	0.08	0.69	−0.10	0.21
Step 4	.110	.036					
Interaction of Arousal and Exposure			−0.30*	0.11	−2.59	−0.52	−0.07

Note. DV = dependent variable.

*
$p < .05.$

Table 4

Regression Analysis: DV Focused Attention

Predictor	R^2	R^2	β	SE	t	95% CI LL	95% CI UL
Step 1	.022	.022					
Engagement w/ Toy			−0.11	0.22	−0.51	−0.54	0.32
Baseline State			−0.20*	0.09	−2.19	−0.38	−0.02
Experimenter Effectiveness			0.00	0.19	−0.01	−0.37	0.37
Step 2	.061	.039					
Fetal Exposure			−0.35*	0.17	−2.08	−0.67	−0.02
Step 3	.062	.001					
Child Sex			−0.09	0.17	−0.54	−0.42	0.24
Step 4	.062	.001					
Interaction of Sex and Exposure			−0.09	0.24	0.36	−0.38	0.55

Note. DV = dependent variable.

*
$p < .05$.