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Children With Heavy Prenatal Alcohol Exposure Demonstrate Deficits on Multiple Measures of Concept Formation

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Abstract

Background—Children with heavy prenatal alcohol exposure have documented impairments in executive functioning (EF). One component of EF, concept formation, has not been well studied in this group.

Methods—Children (8 to 18 years) with histories of heavy prenatal alcohol exposure, with and without fetal alcohol syndrome (FAS), were compared to typically developing controls on 2 measures of concept formation and conceptual set shifting: the Wisconsin Card Sorting Test and the Card Sorting Test from the Delis–Kaplan Executive Functioning System. In addition to between-group comparisons, performance relative to overall intellectual functioning was examined.

Results—Children with histories of heavy prenatal alcohol exposure showed impairment on both tests of concept formation compared to non-exposed controls. These deficits included difficulty generating and verbalizing concepts, increased error rates and perseverative responses, and poorer response to feedback. However, in comparison to controls, alcohol-exposed children performed better on measures of concept formation than predicted by their overall IQ scores. Exploratory analyses suggest that this may be due to differences in how the measures relate at different IQ levels and may not be specific to prenatal alcohol exposure.

Conclusions—Deficits in concept formation and conceptual set shifting were observed in alcohol-exposed children with or without the diagnosis of FAS and in the absence of mental retardation. These deficits likely impact problem solving skills and adaptive functioning and have implications for therapeutic interventions in this population.

Keywords

Fetal Alcohol Syndrome; Prenatal Alcohol Exposure; Executive Functioning; Concept Formation

Fetal Alcohol Syndrome (FAS) is a developmental disorder caused by excessive maternal alcohol consumption during pregnancy, which has long lasting consequences on cognitive, behavioral, and psychosocial functioning in the offspring. It is characterized by a unique pattern of facial dysmorphism, growth retardation, and central nervous system (CNS) dysfunction (Hoyme et al., 2005; Jones and Smith, 1973; Jones et al., 1973). Children with histories of prenatal alcohol exposure, with or without a diagnosis of FAS, often exhibit qualitatively similar deficits on a variety of neuropsychological and behavioral measures

(e.g., Mattson et al., 1998). The cognitive and behavioral problems caused by prenatal alcohol exposure likely lead to more significant disability than do the minor facial anomalies required for the diagnosis of FAS. Although the range of behavioral impairments following gestational alcohol exposure is broad, identifying the core deficits and relative strengths and weaknesses associated with prenatal alcohol exposure may lead to improved differential diagnosis.

One neuropsychological domain that has received increased attention in this population is executive functioning, which is a complex construct that has been broadly defined as “the ability to maintain an appropriate problem solving set for attainment of a future goal” (Welsh and Pennington, 1988). A variety of cognitive functions are subsumed under this general definition including planning, concept formation, set shifting and set maintenance, inhibition, working memory, problem solving, and the ability to integrate information across time and space (Pennington and Ozonoff, 1996). Deficits have been reported in children with heavy prenatal alcohol exposure in areas of executive functioning including planning, flexibility, fluency, inhibition, concept formation, and reasoning (Kodituwakku et al., 1995; Kopera-Frye et al., 1996; Mattson et al., 1999; Schonfeld et al., 2001).

Concept formation is 1 component of executive function that has received limited attention in alcohol-exposed individuals. The ability to form mental categories for objects, events, and ideas is essential for abstract thought and problem solving in everyday life. Formally, concept formation relies on the ability to use prior knowledge to identify abstract concepts that capture common defining properties of a set of stimuli (Hartman and Stratton-Salib, 2007). In addition to the identification of concepts, the majority of tasks designed to assess concept formation are complex and require other cognitive abilities such as selective attention and working memory to focus and shift attention among stimuli features and keep track of concepts already generated. Previous studies have identified deficits on tasks tapping verbal and nonverbal concept formation in individuals with prenatal alcohol exposure. Specifically, alcohol-exposed individuals have more difficulty guessing the correct target word from sentences providing clues of context, structure, and meaning (Mattson et al., 1999) and providing reasonable responses on a numerical estimating task (Kopera-Frye et al., 1996). In the nonverbal domain, children with prenatal alcohol exposure show greater difficulty identifying conceptual rules on the Children’s Category Test (Mattson et al., 1998), and achieve fewer categories and are impaired in their ability to respond to feedback on the Wisconsin Card Sorting Test (WCST) (Carmichael Olson et al., 1998; Coles et al., 1997; Kodituwakku et al., 1995). The first goal of the current study was to evaluate concept formation in a sample of heavily exposed children using 2 well-validated tasks, the WCST and the Card Sorting Test (CST) from the Delis–Kaplan Executive Functioning System (DKEFS). While both of these tasks involve sorting, they place different constraints on concept formation and have different response requirements (as described below). Taken together, they provide information that may be useful in elucidating aspects of concept formation that are most problematic for children with heavy prenatal alcohol exposure.

The WCST is a classic test of executive functioning that requires the identification of 3 sorting principles and the flexible application of these rules in response to feedback (Heaton et al., 1993). On this task, individuals are asked to match cards to 4 key cards that have varying numbers of different colored shapes, and are given feedback regarding response accuracy. Once the category (color, shape, or number) is correctly completed, it is changed without notice, and individuals must use feedback to learn the new sorting rule. Overall, reports of WCST performance in children with prenatal alcohol exposure suggest impairments in concept formation and difficulty responding to feedback (i.e., shifting to a new category). Specifically, 3 studies of alcohol-exposed children have revealed deficits on

the WCST including increased errors and fewer categories achieved (Carmichael Olson et al., 1998; Coles et al., 1997; Kodituwakku et al., 1995). In contrast, a prospective study of children with lower levels of prenatal alcohol exposure found only a moderate correlation between WCST variables and prenatal alcohol exposure, suggesting that the relationship between prenatal alcohol exposure and concept formation may be dose-dependant (Streissguth et al., 1994).

The CST is another measure of concept formation that requires the flexible identification of multiple concepts within sets of stimuli (Delis et al., 1992, 2001). The task involves sorting 6 cards according to various unifying characteristics and requires the recognition of multiple sorting rules and the inhibition of perseverative responses. The CST requires both identification and verbalization of sorting principles following both spontaneous (by the participant) and structured (by the examiner) sorting. The principles differ in level of difficulty and include both verbal (semantic) and nonverbal (perceptual) concepts. In contrast to the WCST, individuals are not provided with feedback on their performance. In a factor analysis of the CST, the WCST loaded heavily on a CST factor related to accuracy of responding (i.e., errors), but was not related to 2 other independent CST factors: one for each of the verbal and nonverbal concept formation domains (Greve et al., 1995). This indicates that the CST provides unique information, and can provide additional information about verbal or nonverbal concept formation relative to the WCST. This may be particularly useful as the WCST may be heavily mediated by verbal skills (Goldstein et al., 1996; Rempfer et al., 2006). To date, no studies using the CST in a prenatally alcohol-exposed sample have been published.

The second goal of the current study was to examine the relationship between concept formation and general intellectual functioning in children with heavy prenatal alcohol exposure. Assessment of relative strengths and weaknesses in this population will assist in the definition of a cognitive profile or profiles, which is currently being sought (Riley et al., 2003). Little information exists regarding the relationship of concept formation or other executive function measures to general intellectual function. Although a small number of studies using the WCST exist, only one has attempted to determine the relationship of executive functioning to overall cognitive ability in an alcohol-exposed population (Connor et al., 2000). Performance on a computerized version of the WCST was examined in relation to estimates of IQ in an adult sample with heavy prenatal alcohol exposure. Nonlinear regression lines were computed from a large sample of adults ($n = 434$), the majority of which were recruited through the Seattle longitudinal prospective study on prenatal alcohol exposure (subjects falling in the highest 10% of exposure levels were excluded). Data from 29 clinically referred adult men with heavy prenatal alcohol exposure were then plotted and compared with the regression lines. For each of the 5 primary WCST variables, 6 to 7 of the heavily exposed subjects performed better than predicted based on regression estimates, whereas 22 to 23 alcohol-exposed subjects did worse than predicted. These results suggest that WCST performance, at least using the computerized version, may be a relative weakness for adults with heavy prenatal alcohol exposure. However, these results should be interpreted cautiously since the heavily exposed subjects with the lowest IQ scores do not appear to fall within the range of scores used to calculate the regression lines. Regression lines tend to be unreliable when based on few observations (i.e., at the extremes of a distribution) and extrapolation can lead to extraneous results (Cohen et al., 2003; Kuo, 2002). No studies using the CST exist with which to compare results to general intellectual functioning.

The current study incorporates tasks that require concept formation for successful performance. While previous studies have examined some areas of concept formation, the tests used in the current study represent a more comprehensive assessment, including both

verbal and nonverbal components and a level of detail not available in individual measures. In addition, concept formation was compared to general cognitive functioning to evaluate if concept formation is a relative strength or weakness in this population.

GENERAL METHOD

Two groups of children participated in this study: children with heavy prenatal alcohol exposure (ALC) and typically developing children with no known exposures to alcohol or other teratogenic agents (CON). The ALC group was composed of children with and without a diagnosis of FAS, based on the traditional diagnostic criteria described above. All alcohol-exposed children were evaluated by Kenneth Lyons Jones, M.D., a pediatric dysmorphologist at the University of California, San Diego and were referred by Dr. Jones, other professionals, or were self-referred by a caregiver. Non-exposed controls were informed of our project through community contacts and volunteered for participation. All children were screened for prenatal exposures through caregiver self-report. Additionally, for children in the ALC group, maternal self-report, or medical, social, and/or legal records were reviewed to confirm prenatal alcohol exposure. Although few specific details regarding alcohol exposure are available in this retrospective sample, records indicated that the mothers of all alcohol-exposed participants drank heavily in pregnancy and would likely meet criteria for alcohol abuse or dependence. Groups were matched on age, sex, race, and ethnicity. Children in the control group were not exposed to alcohol or other teratogenic agents. Socioeconomic status (SES) was measured by the Hollingshead Four Factor Index of Social Status (A. B. Hollingshead, unpublished data), with higher values reflecting higher SES homes. All children participating in this study were recruited from our ongoing investigation of neuropsychological functioning in children with prenatal alcohol exposure (cf. Mattson et al., 1997, 1998). As part of this program of study, IQ scores were available from the Wechsler Intelligence Scale for Children – Third Edition. Only children with an overall IQ score ≥ 68 were included to ensure that participants would be able to comprehend task requirements. This criterion is consistent with our previous studies in this area (cf. Mattson et al., 1997, 1998), and represented a natural cut-point in the data collected.

Two measures of concept formation, described in detail below, were administered according to standardized procedures. Experiment 1 involved the WCST, which was administered as part of a neuropsychological battery given to all participants in our neurobehavioral assessment of prenatal alcohol exposure. Experiment 2 involved the CST from the D-KEFS (Delis et al., 2001), which was administered separately to a subset of participants. Results from other portions of the D-KEFS are reported elsewhere (Mattson et al., 1999; Schonfeld et al., 2001). All children received a toy or monetary incentive for participation. Informed consent and assent were obtained from parents and children respectively, and the San Diego State University Institutional Review Board approved all procedures.

Experiment 1 – Wisconsin Card Sorting Test

Participants—One-hundred seven children took part in Experiment 1: 60 in the CON group and 47 in the ALC group (18 with FAS). Groups were matched on age, sex, race, and ethnicity. See Table 1 for group demographic information.

Procedure—The WCST is a standardized measure of concept formation and problem solving in which 4 stimulus cards, each with a specific number and pattern of colored shapes, are presented to the child. Children are asked to match response cards, also depicting colored shapes, to these stimulus cards. Children are told if their responses are right or wrong, but are not told the sorting rule. The 3 possible sorting principles are stimulus color, form (shape), and number. After 10 consecutive correct responses, the examiner switches the sorting principle without warning. Testing continues until 6 sorts (2 of each type) or 128

trials are completed. In order to complete the test successfully, the child must use examiner feedback to develop a sorting strategy and then change the strategy in response to changing task demands.

Demographic Variables—Chi-square analyses confirmed that the CON and ALC groups did not differ significantly in terms of sex, race, ethnicity, or handedness ($p > 0.05$). One-way analyses of variance (ANOVA) conducted on age, FSIQ, and SES revealed that the groups did not differ significantly in terms of age ($p > 0.05$). Not surprisingly, however, the CON group had significantly higher FSIQ scores than the ALC group [$F(1, 105) = 63.69, p < 0.001$]. Groups also differed in SES, with higher SES scores for the CON group [$F(1, 105) = 4.68, p = 0.03$].

Dependent Variables and Statistical Analyses—Raw scores on the WCST were converted to standard scores based on the most recent normative sample for the test (Heaton et al., 1993), with higher scores representing better performance (i.e., fewer errors). The following dependent variables were chosen for analysis in this study: percentage of conceptual level responses (CLR), percentage of perseverative responses (PR), percentage of total errors (ERR), percentage of perseverative errors (PE), and percentage of non-perseverative errors (NPE). All variables are defined in Table 2. Multivariate analyses of variance (MANOVA) were used to compare the groups (CON vs. ALC) on these 5 main WCST variables. Significant group main effects on the MANOVA were followed by univariate ANOVAs. Because we were interested in the relationship between IQ and concept formation, we conducted a repeated measures ANOVA with group as the between-subjects variable and IQ and the WCST composite score as the within-subject variables. The WCST composite variable was formed by averaging the standard scores of 3 primary standard scores: CLR, PR, and ERR. ERR includes both PE and NPE, and, therefore, these scales were not included to reduce redundancy in the composite score. Significant interactions were followed up by pairwise comparisons. To further explore the relationship between IQ and WCST performance, a difference variable was created by subtracting the WCST composite variable from FSIQ for each subject and group difference scores were compared using univariate ANOVA. This methodology was chosen over using IQ as a covariate because controlling for this variable would have removed variance of interest because of the extent that IQ is comprised in part of measures of concept formation. Identical analyses were used to compare alcohol-exposed children with and without FAS; results are presented following the primary analyses.

Results—Means, effect sizes, and univariate F -test results for WCST variables are presented in Table 3. As expected, the ALC group demonstrated impairments on the WCST in comparison to controls. The overall MANOVA revealed a significant effect of group [$F(5, 101) = 5.44, p < 0.001$], as did the 5 univariate ANOVAs ($p < 0.05$). For all comparisons, the ALC group performed more poorly than controls. The repeated measures analysis between the WCST composite and FSIQ scores revealed a significant group $\times$ test interaction [$F(1, 105) = 5.86, p = 0.02$]. Pairwise comparisons revealed that alcohol-exposed subjects had significantly higher WCST scores than IQ scores ($p = 0.001$), whereas scores did not differ for controls ($p = 0.74$). Difference scores further illustrate this interaction. ALC subjects performed an average of 8.42 points higher on the WCST than expected, whereas controls performed as expected. This group difference was statistically significant ($p = 0.02$). Effect size estimates for CLR, ERR, NPE, and WCST composite were in the large range ($d = 0.78$ to 0.98) according to Cohen's criteria (Cohen, 1988), whereas estimates for PR, PE, and the FSIQ-WCST difference score were in the small to medium range ($d = 0.45$ to 0.48).

Means, effect sizes, and univariate F -test results for the comparison between alcohol-exposed children with and without FAS are presented in Table 4. The overall MANOVA main effect for group was not significant [$F(5, 41) = 1.49, p = 0.21$]. However, univariate ANOVAs revealed that the alcohol-exposed children without FAS had significantly higher ERR ($p = 0.03$) and CLR ($p = 0.02$) scores, reflecting their tendency to make fewer total errors and more CLR than children with FAS. Group differences were marginally significant on the other 3 scales: PR ($p = 0.06$), PE ($p = 0.06$), and NPE ($p = 0.07$). The repeated measures analysis revealed a significant main effect of test [$F(1, 45) = 12.97, p = 0.001$] and group [$F(1, 45) = 6.43, p = 0.02$]. Specifically, both alcohol-exposed groups performed better on the WCST than was predicted by IQ, and the children without FAS performed better than children with FAS. The interaction was not significant [$F(1, 45) = 0.31, p = 0.58$], nor was the FSIQ-WCST difference score ($p = 0.58$). Effect size estimates for all 5 scales and the WCST composite were in the medium to large range ($d = 0.54$ to 0.74) according to Cohen's criteria (Cohen, 1988), whereas the FSIQ-WCST difference score was in the small range ($d = 0.16$).

Experiment 2 – California Card Sorting Test

Participants—Forty children from Experiment 1 took part in Experiment 2: 17 in the CON group and 23 in the ALC group (13 with FAS). Groups were matched on age, sex, race, and ethnicity. See Table 5 for group demographic information.

Demographic Variables—As expected, chi-square analyses revealed that the ALC group did not differ significantly from the CON group in terms of sex, race, ethnicity, or handedness ($ps > 0.05$). One-way ANOVAs were conducted on age, SES, and FSIQ. The groups did not differ significantly in terms of age [$F(1, 38) = 2.15, p = 0.15$]. However, significant differences were revealed between groups for SES [$F(1, 38) = 16.98, p < 0.001$] and FSIQ [$F(1, 38) = 44.14, p < 0.001$], with the CON group demonstrating higher SES and FSIQ.

Procedure—The CST is a measure of problem solving and concept formation and consists of free and structured sorting conditions. Both conditions use the same 2 card sets, each consisting of 6 cards. Within each card set, various properties are shared (e.g., color, shape, word characteristics). In the free sorting condition, the examinee sorts the card set into 2 groups of 3 cards based on a shared characteristic (e.g., animals in 1 group and modes of transportation in the other). The children must then verbally define how they sorted the cards, explaining how the cards in each group are similar. An item can be sorted correctly in the absence of a correct definition. There are 8 possible correct sorts for each card set: 3 based on verbal characteristics (i.e., semantic similarities) and 5 based on perceptual characteristics (i.e., physical characteristics such as card color). Children are given a total of 10 trials to sort the cards in as many unique ways as possible. The procedure is repeated with the second card set. Testing is discontinued when children complete all 10 trials, cumulative sorting time is 4 minutes, or until they cannot produce additional sorts. The structured sorting condition uses the same 2 card sets. In this condition, however, the examiner sorts the cards according to the previously described verbal or perceptual characteristics, and the child must verbally define the sorting strategy. Eight trials for each card set are presented in structured sorting.

Dependent Variables and Statistical Analyses—Raw scores on the CST were converted to scaled scores based on the normative sample for the test (Delis et al., 2001). Twelve CST variables were selected for analysis (see Table 2) to answer the following 5 specific research questions utilizing standard ANOVA or MANOVA techniques. Significant interactions were followed up using simple main effects. First, we were interested in correct

concept formation for verbal versus perceptual sorts. To answer this question, a repeated measures ANOVA was run on confirmed correct verbal and perceptual scores. Second, we were interested in overall correct sorting (verbal plus perceptual) and correct verbal descriptions of the sort. Two separate one-way ANOVAs were run on percent accuracy sorting and percent accuracy description to address this question. Third, we wanted to know if groups differed in the number of errors made during the free sorting condition, and conducted a MANOVA on the following raw error scores: repeated sorts, set loss errors, nontarget even sorts, repeated descriptions, and incorrect descriptions. Fourth, on the structured sorting condition, we were interested if alcohol-exposed subjects differed from controls in their ability to describe sorts performed by the examiner. To compare performance on the structured condition, a one-way ANOVA was run on description scores. Fifth, we wanted to know if groups differed in the number of errors they made during the structured sorting condition. To answer this question, raw incorrect and repeated description errors were analyzed by MANOVA. In addition, similar to the WCST analysis, a composite score was created utilizing the following scores: confirmed correct verbal, confirmed correct perceptual, percent accuracy sorting, percent accuracy description, and recognition description. Scores were converted from scaled scores to standard scores before averaging to be consistent with FSIQ. A repeated measure ANOVA was then conducted to evaluate the relationship between IQ and concept formation with group as the between-subjects variable and IQ and the CST composite score as the within-subject variables. Significant interactions were followed up by pairwise comparisons. As above, to further explore the relationship between IQ and CST performance, a difference variable was created by subtracting the CST composite variable from FSIQ for each subject and group difference scores were compared using univariate ANOVA. Identical analyses were used to compare alcohol-exposed children with and without FAS; results are presented following primary analyses.

Results—Means, effect sizes, and univariate *F*-test results for CST variables are found in Table 6. In the first analysis, examining the ability to identify target sorts, a significant interaction between group membership and type of sort (i.e., verbal vs. perceptual) was present [$F(1, 38) = 5.77, p = 0.02$]. Alcohol-exposed subjects differed significantly from controls in the number of correctly identified perceptual sorts ($p < 0.001$), but did not differ on verbal sorts ($p = 0.64$). In the second analysis, examining sorting and description accuracy, the ALC group made significantly fewer correct sorts per total number of attempts ($p = 0.01$) and poorer descriptions per number of attempts ($p = 0.008$). The third analysis, addressing errors during free sorting, revealed that alcohol-exposed subjects did not generally make more errors than controls [$F(5, 34) = 2.21, p = 0.08$]. Given the marginal significance and that our a priori hypotheses predicted group differences on error measures, univariate analyses were performed on the individual error scores. Univariate analyses revealed that the ALC group gave more incorrect descriptions ($p = 0.003$) and tended to repeat more sorts ($p = 0.05$) and descriptions ($p = 0.04$) than their non-exposed peers. Results of the fourth and fifth analyses, addressing structured sorting, indicated that alcohol-exposed subjects gave significantly poorer descriptions ($p < 0.001$) and made more errors [$F(2, 37) = 5.28, p = 0.01$], including repeated descriptions ($p = 0.003$) and incorrect descriptions ($p = 0.003$), than controls. In examining the relationship between IQ and CST performance, the repeated measures analysis revealed a significant group $\times$ test interaction [$F(1, 38) = 8.77, p = 0.005$]. Pairwise comparisons revealed that CST and IQ scores did not differ for alcohol-exposed subjects ($p = 0.49$), whereas controls had significantly lower CST scores than IQ ($p < 0.001$). Difference scores further illustrate this interaction. Control subjects performed an average of 13.59 points lower on the CST than expected, whereas the average difference score for the alcohol-exposed subjects was only 1.83. This group difference was statistically significant ($p = 0.005$). Effect size estimates for variables with significant differences between groups were in the large ($d > 0.8$) range according to

Cohen's criteria (Cohen, 1988). The remaining variables had effect sizes in the small to medium range.

Means, effect sizes, and univariate F -test results for the comparison between alcohol-exposed children with and without FAS are presented in Table 7. The repeated measures ANOVA revealed no significant main effect of group [$F(1, 21) = 0.01, p = 0.91$], type of sort [$F(1, 21) = 3.32, p = 0.08$], or interaction between these variables [$F(1, 21) = 0.06, p = 0.82$]. In addition, groups did not differ in percent accuracy of sorting ($p = 0.71$) or description ($p = 0.64$). The MANOVA of free sorting errors revealed no significant overall main effect [$F(5, 17) = 0.74, p = 0.60$] or univariate effects of any of the error types ($ps > 0.05$). The 2 subgroups did not significantly differ on the recognition condition ($p = 0.74$) and did not make significantly more errors on this condition ($ps > 0.05$). In the repeated measures analysis examining the relationship between IQ and CST performance, no interaction or significant main effects were present: Group $\times$ Test [$F(1, 21) = 0.22, p = 0.65$], Test [$F(1, 21) = 0.44, p = 0.51$], Group [$F(1, 21) = 0.01, p = 0.93$]. In addition, groups did not differ on the FSIQ-CST difference score ($p = 0.65$). Effect size estimates were in the very small to medium ($d = 0.03$ to 0.47) range according to Cohen's criteria (Cohen, 1988) for all variables except repeated descriptions during the structured sorting condition, which was in the medium to large range ($d = 0.67$).

Additional Exploratory Analyses

Additional analyses were conducted to clarify the relationship between concept formation and IQ, as different patterns emerged on the 2 measures examined. On the WCST it originally appeared that the ALC group had a relative strength in concept formation whereas the CON group had WCST scores consistent with IQ estimates. However, on the CST, the ALC group had scores consistent with IQ, whereas the CON group appeared to have a relative weakness on the CST. To try to understand this pattern we looked at discrepancy scores by IQ level to see if a consistent pattern would emerge. First, we categorized the participants by FSIQ within each group; thus, the lowest 25% of subjects in each group were assigned to category 1, the next 25% were assigned to category 2, and so on. Within-group categorization was used because of the group differences in IQ scores. WCST difference scores were analyzed by ANOVA with group and IQ category as between-subjects variables. Results of this analysis indicated significant main effects of group [$F(1, 99) = 6.73, p = 0.011$], and IQ category [$F(3, 99) = 15.68, p < 0.001$], but no interaction between these variables [$F(3, 99) = 0.51, p = 0.68$]. Difference scores for both groups increased with increasing IQ and were greater for the CON group than for the ALC group. For both groups, lower IQ categories were associated with negative difference scores (i.e., WCST > IQ) and higher IQ categories were associated with positive difference scores (i.e., WCST < IQ). See Table 8.

The same analyses were conducted for the CST difference scores. Because of the smaller sample size, only 3 IQ categories, each including approximately 33% of the group, were used. Results indicated significant main effects of group [$F(1, 34) = 11.28, p = 0.002$], and IQ category [$F(2, 34) = 8.68, p = 0.001$], and a marginally significant interaction between these variables [$F(2, 34) = 3.27, p = 0.05$]. Difference scores increased with increasing IQ for the CON group but not the ALC group. In addition, although difference scores were positive (i.e., FSIQ > CST) for more children in the control group (88%) than in the ALC group (52%), the average difference scores were lower for the ALC group than the CON group at all IQ intervals. These group differences were significant for the 2 higher IQ categories. See Table 9.

DISCUSSION

In the present study, children with histories of heavy prenatal alcohol exposure were evaluated on their ability to form concepts on 2 sorting measures. The 2 measures share some similarities but emphasize unique aspects of concept formation. The WCST provides information on how well individuals incorporate feedback in their critical thinking strategies, whereas the CST assesses both verbal and nonverbal abilities as well as verbalization of principles, and has participant-driven versus examiner-driven sorts. In comparison with controls, alcohol-exposed children displayed deficits in both experiments. Specifically, current findings from the WCST are consistent with reports that alcohol-exposed children achieve fewer categories (Coles et al., 1997) and show increased perseverations (Kodituwakku et al., 1995) and errors (Carmichael Olson et al., 1998) on this task, suggesting difficulties with flexibility and the evaluation of outcomes. The current findings also document difficulties with concept attainment in alcohol-exposed children as indicated by fewer conceptual level responses. On the CST, children in the alcohol-exposed group had fewer confirmed perceptual sorts than controls on the free sorting condition, but did not differ in the number of confirmed verbal sorts made. Both groups likely had similar performance on confirmed verbal sorts because of the smaller number of possible verbal sorts (i.e., 3 possible target verbal sorts vs. 5 perceptual sorts) and relative difficulty of generating all 3. Additionally, alcohol-exposed children were less able than controls to correctly sort the cards and received fewer points for their descriptions of the sorts. These sorting results are consistent with findings from the WCST demonstrating poorer cognitive flexibility, and suggest concurrent validity. Moreover, the child's verbal descriptions on the CST allow us to make stronger inferences about the child's sorting strategies and suggest that alcohol-exposed children have difficulty inferring the similarities among the cards and drawing higher order inferences. On the structured (examiner-driven) sorting condition, alcohol-exposed children gave poorer descriptions and gave more incorrect and repeated responses than controls, suggesting poorer attention to relevant cues. Thus, children with heavy prenatal alcohol exposure had difficulty in not only arriving at a concept on their own, but were less able to recognize and verbally identify a concept when categories were provided. Taken together, results from these measures suggest that children with heavy prenatal alcohol exposure have difficulty in identifying and generating concepts, which impairs their ability to solve problems. This is true for verbal and nonverbal information, with and without feedback, and on structured and unstructured tasks.

Follow-up analyses comparing children with heavy prenatal alcohol exposure with and without FAS identified some differences in performance on measures of concept formation. On the WCST, the alcohol-exposed children without FAS made fewer total errors and more conceptual level responses than the subgroup with FAS. In addition, differences on the other 3 scales approached significance, suggesting that children with FAS generally perform more poorly on the WCST than alcohol-exposed children without FAS. In contrast, groups did not significantly differ on any scale of the CST. It should be noted that the sample size for the CST was smaller and the lack of significant differences could be due to reduced power. While this explanation is plausible, a comparison of effect size estimates suggests that group differences on the WCST are larger in magnitude than on the CST. To detect the medium to large effect sizes for the primary scales of the WCST, power analyses suggest that 30 to 55 subjects per group are required. In contrast, on the CST, 394 subjects per group or more are needed to detect a small effect ($d = 0.2$), 54 per group to detect a medium effect ($d = 0.5$) and 36 per group would be needed to detect the largest effect observed ($d = 0.67$).

Current research in the field of prenatal alcohol exposure has focused on determining a profile of strengths and weaknesses in order to improve diagnostic specificity (Riley et al., 2003). Lower intellectual functioning is a common outcome in children with prenatal

alcohol exposure and it is important to determine whether deficits in other cognitive domains are specific to prenatal alcohol exposure or are secondary to global reductions in IQ. In an attempt to address this research question in the area of concept formation we examined the relationship between performance on each measure of concept formation and general intellectual functioning. Initial analyses identified significant group differences on both the WCST and the CST with alcohol-exposed subjects performing better on measures of concept formation relative to IQ estimates than controls, suggesting that concept formation may be a relative strength in this population. However, follow-up exploratory analyses revealed that within each group, children with lower IQ scores (relative to their group) tend to have negative difference scores ($IQ < WCST, CST$), and children with higher IQ scores tend to have positive difference scores ($IQ > WCST, CST$). This relationship is also seen in the large normative sample of the D-KEFS ($n = 470$ children) and is present for all primary measures, including the CST (Delis, DC 2007, pers. comm., 12 April). This relationship is likely a result of regression to the mean (i.e., difficulty to get equally low or high scores at the extremes) and the nonlinearity of scaled scores. Thus, in comparison to controls, children with prenatal alcohol exposure performed better than predicted by IQ on average because they tend to have lower IQ scores and were less likely to get equally low scores on measures of concept formation. Future work comparing alcohol-exposed individuals to controls matched on IQ scores may help address this issue.

The only other study to examine the relationship between IQ and concept formation with individuals with prenatal alcohol exposure utilized a different methodology and it is difficult to compare results (Connor et al., 2000). While they found that the majority of subjects with heavy prenatal alcohol exposure performed worse than expected based on nonlinear regression estimates of WCST and IQ scores derived from a large comparison group, data from some heavily exposed subjects appear outside the range of IQ scores obtained in the comparison group. In regression, extrapolation outside of the range of scores used to derive the line can result in erroneous or unreliable conclusions (Cohen et al., 2003; Kuo, 2002).

One possible limitation to our findings is the relatively smaller sample utilized in the second experiment. While large effect sizes and significant group differences were obtained for comparisons between children with prenatal alcohol exposure and controls, the possibility for bias and chance differences is larger for the CST than the WCST. This is especially pertinent for the exploratory analyses examining the relationship between concept formation and IQ as fewer IQ categories could be formed for the CST. Having fewer IQ categories reduces the resolution of the effect and could lead to inaccurate conclusions. However, results from the CST were similar to those of the larger sample in the WCST, allowing for more confidence in these preliminary findings.

Although both the WCST and CST rely heavily on concept formation, both are complex tests and require other cognitive abilities for adequate performance. Thus, concept formation is necessary but not sufficient for adequate performance on the WCST and CST and it is conceivable that an individual could have intact concept formation abilities but perform poorly on these measures because of deficits in other areas. While this is true, the areas of impairment on both measures in the current study are congruous and provide validity to our conclusions of deficits in concept formation. However, at this point, there may not be sufficient information yet to specify the exact nature of an executive function deficit in this population.

Impairments on measures of concept formation suggest that an individual is likely to have difficulty with abstract thinking and problem solving in daily life. Tests such as the measures included herein assess skills that are necessary for carrying out daily functions that require individuals to problem solve in an efficient manner (e.g., dressing oneself, following

rules and procedures, working out interpersonal conflicts). Additional research should be undertaken to corroborate deficits functionally. Results from the current study suggest that interventions aimed at overcoming deficits in problem solving may be warranted for children with prenatal alcohol exposure. For example, classroom intervention based on social cognitive theory improved problem solving in typically developing sixth graders (Sharma et al., 1999) and problem solving skills training has been shown to be efficacious in clinical studies of children with externalizing behavior problems (Kazdin et al., 1992), which are also present in alcohol-exposed children (e.g., Mattson and Riley, 2000). Although these findings need testing in more diverse samples, they indicate the promise of problem solving interventions in school-age children and could be effective in children affected by prenatal alcohol exposure.

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Table 1

Demographic Information for Non-Exposed Control (CON) and Alcohol-Exposed (ALC) Groups in Experiment 1

Demographics	CON	ALC
N	60	47
Sex (% female)	56.7	51.1
Age [mean (SD)]	11.31 (2.03)	11.24 (2.21)
Range	8.167–15.583	8.083–15.833
Race (% White)	80.0	66.0
Ethnicity (% Hispanic)	11.7	10.6
Full Scale IQ [mean (SD)] *	107.27 (11.58)	88.83 (12.21)
Range	73–131	68–128
Handedness (% right)	93.3	80.9
SES [mean (SD)] *	49.03 (11.75)	43.88 (12.77)
Range	11–66	14–66

* CON group differed significantly from the ALC group ($p < 0.05$).

Table 2

Dependent Variables Analyzed for the Wisconsin Card Sorting Test (WCST) and the Card Sorting Test (CST)

Measure	Description
Experiment 1: WCST	
% Conceptual level responses (CLR)	Percentage of responses indicating a conceptual understanding of the task (e.g., at least 3 correct category responses in a row)
% Errors (ERR)	Percentage of error responding regardless of type
% Perseverative responses (PR)	Percentage of responses, correct or incorrect, that indicate a perseverative response style or failure to change strategies when appropriate
% Perseverative errors (PE)	Percentage of perseverative errors
% Nonperseverative errors (NPE)	Percentage of nonperseverative errors
Experiment 2: CST	
Confirmed correct verbal	Number of correctly sorted and identified verbal sorts
Confirmed correct perceptual	Number of correctly sorted and identified perceptual sorts
Percent accuracy sorting	Percent of total sorts attempted that were correct
Percent accuracy description	Percent of total descriptions attempted that were correct
Repeated sorts	Number of repeated sorts made during the free sorting condition
Set loss errors	Number of times the subject fails to observe the basic task instructions (e.g., 4 cards in 1 group, stacking cards)
Nontarget even sort	Number sorts that follow task instructions but do not match 1 of the 8 identified sorts
Repeated descriptions / free	Number of repeated descriptions made during the free sorting condition
Incorrect description / free	Number of incorrect descriptions made during the free sorting condition
Structured description score	Description score for the structured sorting condition
Incorrect description / structured	Number of incorrect descriptions on the structured condition
Repeated description / structured	Number of repeated descriptions on the structured condition

Table 3

Means, Effect Sizes, and Univariate *F*-Test Results for Variables From Experiment 1 for Non-Exposed Control (CON) and Alcohol-Exposed (ALC) Groups

Variable	CON M (SD)	ALC M (SD)	ES ^a	F	p
CLR	108.95 (16.32)	96.02 (12.60)	0.89	20.10	<0.001
PR	106.10 (14.39)	99.89 (12.80)	0.46	5.40	0.02
ERR	108.85 (16.43)	95.83 (13.06)	0.88	19.74	<0.001
PE	106.23 (14.31)	99.57 (13.39)	0.48	6.04	0.02
NPE	106.93 (15.31)	93.38 (12.17)	0.98	24.61	<0.001
WCST composite ^b	107.97 (15.25)	97.25 (12.13)	0.78	15.51	<0.001
FSIQ-WCST	-0.70 (17.41)	-8.42 (14.93)	0.48	5.86	0.02

All scores are standard scores with a mean of 100 and a standard deviation of 15 and higher scores reflect better performance.

^aEffect sizes are Cohen's *d* with small effects > 0.2, medium effects > 0.5, and large effects > 0.8.

^bWCST composite is an average of CLR, PR, and ERR.

Table 4

Means, Effect Sizes, and Univariate *F*-Test Results for Variables From Experiment 1 for Alcohol-Exposed Children With Fetal Alcohol Syndrome (FAS) and Without (PEA)

Variable	FAS M (SD)	PEA M (SD)	ES ^a	F	p
CLR	90.44 (13.17)	99.48 (11.09)	0.74	6.39	0.02
PR	95.44 (12.80)	102.66 (12.21)	0.58	3.73	0.06
ERR	90.72 (14.75)	99.00 (11.00)	0.64	4.83	0.03
PE	94.89 (13.83)	102.48 (12.46)	0.58	3.79	0.06
NPE	89.28 (14.08)	95.93 (10.28)	0.54	3.50	0.07
WCST composite ^b	92.20 (12.76)	100.38 (10.79)	0.69	5.54	0.02
FSIQ-WCST	-6.87 (19.08)	-9.38 (11.94)	0.16	0.31	0.58

All scores are standard scores with a mean of 100 and a standard deviation of 15 and higher scores reflect better performance.

^aEffect sizes are Cohen's *d* with small effects > 0.2, medium effects > 0.5, and large effects > 0.8.

^bWCST composite is an average of CLR, PR, and ERR.

Table 5

Demographic Information for Non-Exposed Control (CON) and Alcohol-Exposed (ALC) Groups in Experiment 2

Demographics	CON	ALC
<i>N</i>	17	23
Sex (% female)	52.9	56.5
Age [mean (SD)]	12.89 (2.89)	11.67 (2.37)
Range	9.167–18.162	8.083–16.250
Race (% White)	47.1	69.6
Ethnicity (% Hispanic)	5.9	8.7
Full Scale IQ [mean (SD)] *	110.76 (12.88)	85.22 (11.36)
Range	90–131	69–105
Handedness (% right)	94.1	82.6
SES [mean (SD)] *	53.82 (6.55)	39.35 (13.31)
Range	40–66	14–63

* CON group differed significantly from the ALC group ($p < 0.05$).

Table 6

Means and Effect Sizes for Selected Variables From Experiment 2 for Non-Exposed Control (CON) and Alcohol-Exposed (ALC) Groups

Variable	CON M (SD)	ALC M (SD)	ES ^a	F	p
Confirmed correct verbal	9.41 (2.50)	8.91 (3.72)	0.16	0.23	0.64
Confirmed correct perceptual	10.82 (1.74)	7.04 (3.47)	1.38	16.93	<0.001
Percent accuracy sorting	8.88 (2.42)	6.04 (3.84)	0.88	7.15	0.01
Percent accuracy description	9.06 (2.41)	6.17 (3.74)	0.92	7.72	0.008
Repeated sorts	2.76 (1.75)	4.61 (3.43)	0.68	4.09	0.05
Set loss errors	0.00 (0.00)	0.22 (0.67)	0.46	1.77	0.19
Nontarget even sort	0.53 (0.94)	0.96 (1.11)	0.42	1.65	0.21
Repeated descriptions / free	1.06 (1.56)	3.48 (4.56)	0.71	4.38	0.04
Incorrect description / free	1.76 (1.89)	6.00 (5.28)	1.07	9.93	0.003
Structured description score	9.00 (2.45)	5.22 (3.49)	1.25	14.60	<0.001
Incorrect description / structured	3.18 (3.66)	7.74 (5.11)	1.03	9.80	0.003
Repeated description / structured	1.29 (1.76)	5.00 (4.48)	1.09	10.38	0.003
CST composite ^b	97.18 (6.06)	83.39 (14.92)	1.21	12.86	0.001
FSIQ–CST	13.59 (13.24)	1.83 (11.78)	0.94	8.77	0.005

All scores except the FSIQ–CST difference score and error scores are scaled scores with a mean of 10 and a standard deviation of 3. Scaled scores were converted to standard scores to calculate the CST composite. Error scores are presented as raw scores.

^aEffect sizes are Cohen's *d* with small effects > 0.2, medium effects > 0.5, and large effects > 0.8.

^bCST composite is an average of the following scores: confirmed correct verbal, confirmed correct perceptual, percent accuracy sorting, percent accuracy description, and recognition description. Before averaging, scores were converted from scaled scores to standard scores to be consistent with FSIQ.

Table 7

Means and Effect Sizes for Selected Variables From Experiment 2 for Alcohol-Exposed Children With Fetal Alcohol Syndrome (FAS) and Without (PEA)

Variable	FAS M (SD)	PEA M (SD)	ES ^a	F	p
Confirmed correct verbal	9.08 (4.17)	8.70 (3.23)	0.10	0.06	0.82
Confirmed correct perceptual	7.00 (3.63)	7.10 (3.45)	0.03	0.004	0.95
Percent accuracy sorting	5.77 (3.94)	6.40 (3.89)	0.16	0.15	0.71
Percent accuracy description	5.85 (3.91)	6.60 (3.66)	0.20	0.22	0.64
Repeated sorts	5.31 (3.57)	3.70 (3.20)	0.47	1.25	0.28
Set Loss errors	0.31 (0.86)	0.10 (0.32)	0.32	0.53	0.48
Nontarget even sort	1.15 (1.28)	0.70 (0.82)	0.42	0.95	0.34
Repeated descriptions / free	4.38 (5.09)	2.30 (3.68)	0.47	1.19	0.29
Incorrect description / free	6.62 (6.28)	5.20 (3.80)	0.27	0.40	0.54
Structured description score	5.00 (3.61)	5.50 (3.50)	0.14	0.11	0.74
Incorrect description / structured	8.23 (5.57)	7.10 (4.65)	0.22	0.27	0.61
Repeated description / structured	6.23 (4.97)	3.40 (3.34)	0.67	2.40	0.14
CST composite ^b	82.69 (16.18)	84.30 (13.91)	0.11	0.06	0.81
FSIQ-CST	2.85 (11.49)	0.50 (12.64)	0.19	0.22	0.65

All scores except the FSIQ-CST difference score and error scores are scaled scores with a mean of 10 and a standard deviation of 3. Scaled scores were converted to standard scores to calculate the CST composite. Error scores are presented as raw scores.

^aEffect sizes are Cohen's *d* with small effects > 0.2, medium effects > 0.5, and large effects > 0.8.

^bCST composite is an average of the following scores: confirmed correct verbal, confirmed correct perceptual, percent accuracy sorting, percent accuracy description, and recognition description. Before averaging, scores were converted from scaled scores to standard scores to be consistent with FSIQ.

Table 8
Average Difference Scores on the Wisconsin Card Sorting Test (WCST) by FSIQ Category

Group	FSIQ category	FSIQ range	N	WCST difference score	Children with difference scores < 0 [N (%)]
CON	1	73–99	15	–9.38	10 (67)
	2	100–107	13	–11.59	12 (92)
	3	108–115	17	2.94	8 (47)
	4	116–131	15	13.29	2 (13)
ALC	1	68–80	12	–19.06	12 (100)
	2	83–87	12	–12.75	12 (100)
	3	89–95	12	–5.47	7 (58)
	4	97–128	11	4.70	4 (36)

FSIQ categories represent approximately 25% of participants per group. Negative difference scores indicate WCST scores higher than IQ scores and positive difference scores reflect IQ scores higher than WCST scores.

Table 9
Average Difference Scores on the California Card Sorting Test (CST) by FSIQ Category

Group	FSIQ category	FSIQ range	N	CST difference score	Children with difference scores <0 [N (%)]
CON	1	90–100	5	0.00	2 (12)
	2	106–113	6	11.33	0 (0)
	3	117–131	6	27.17	0 (0)
ALC	1	69–75	7	0.43	4 (17)
	2	77–90	8	0.13	5 (22)
	3	91–105	8	5.75	2 (9)

FSIQ categories represent approximately 25% of participants per group. Negative difference scores indicate CST scores higher than IQ scores and positive difference scores reflect IQ scores higher than CST scores.