Published in final edited form as:

J Cogn Dev. 2013 October 1; 14(4): 633–650. doi:10.1080/15248372.2012.698433.

Neonatal Intensive-Care Unit Graduates Show Persistent Difficulties in an Intra-Dimensional Shift Card Sort

Phyllis M. Kittler,

New York State Institute for Basic Research in Developmental Disabilities

Patricia J. Brooks,

College of Staten Island and the Graduate Center of City University of New York

Vanessa Rossi,

New York State Institute for Basic Research in Developmental Disabilities

Bernard Z. Karmel,

New York State Institute for Basic Research in Developmental Disabilities and Richmond University Medical Center

Judith M. Gardner, and

New York State Institute for Basic Research in Developmental Disabilities and Richmond University Medical Center

Michael J. Flory

New York State Institute for Basic Research in Developmental Disabilities and Richmond University Medical Center

Abstract

Neonatal intensive-care unit (NICU) graduates, a group at risk for attention problems and ADHD, performed an intra-dimensional shift card sort at 34, 42, 51, and 60 months to assess executive function and to examine effects of individual risk factors. In the ‘silly’ game, children sorted cards (airplanes and dogs) so they were *not* the same as targets. In the ‘same’ game they did the opposite. Performance on the ‘silly’ game was poor, especially when it was presented first. Success in following ‘silly’ game rules improved with age, and was significantly linked to maternal education and birth weight for gestational age, a measure of intrauterine stress. Degree of CNS injury differentiated children who completed the task from children who did not, and also affected the need to repeat instructions in the ‘same’ game. These results confirm an increased likelihood of impairments in executive function during preschool years in NICU graduates.

Advances in reproductive and neonatal medicine have produced a much higher proportion of low birth weight (BW) and preterm infants who survive, often as a result of medical care delivered in a neonatal intensive-care unit (NICU). These infants suffer high rates of complications, such as chronic *in utero* stress, respiratory distress, hypoxia and CNS injury, and have increased likelihood of developing problems related to attention, self-regulation, and executive function (EF) including Attention Deficit Hyperactivity Disorder (ADHD) (Bhutta, Cleves, Casey, Craddock, & Anand, 2002; McGrath et al., 2005). They also have been shown to have impairments in EF when they enter school, sometimes even after controlling for the effects of intelligence (e.g., Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009, 2004; Bayless & Stevenson, 2007; Böhm,

Smedler, & Forssberg, 2004). Deficiencies in EF and impulse control are predictive of behavioral and academic problems during the school years (e.g., Mazzocco & Kover, 2007; Pennington & Ozonoff, 1996).

Diagnosis of ADHD, the most common attention problem, frequently occurs only after academic difficulties are underway. Consequently it would be useful to identify EF deficits in at-risk children at younger ages to allow for the possibility of earlier intervention. Accelerated development of EF during the preschool years (Akshoomoff, 2002; Carlson, 2005; Rothbart & Posner, 2001) makes this period especially important. It is surprising, then, that few studies of EF in preschoolers target NICU graduates (Isquith, Crawford, Espy, & Gioia, 2005) and that a recent review of attention research in children born preterm (van de Weijer-Bergsma, Wijnroks, & Jongmans, 2008) found only 4 of 26 reports among preschoolers. In the current study, we examine EF processing in preschool NICU graduates using an intra-dimensional reversal-shift card sort task (IRCS) (Brooks, Hanauer, Padowska, & Rosman, 2003, Experiment 1; Kloo & Perner, 2003; Perner & Lang, 2002; Kloo, Perner, Kerschhuber, Dabernig, & Aichnorn, 2008).

Card sort tasks have in recent years been used to assess various components of EF in young children, particularly targeting cognitive flexibility. In the widely used dimensional change card sort (DCCS) (Zelazo, Müller, Frye, & Marcovitch, 2003; Zelazo, 2006), children sort the same set of cards (e.g., red rabbits, blue boats) first by one dimension (shape) and then by another (color) by placing each card-to-be-sorted next to a target card (a blue rabbit or a red boat). (Note that each correctly sorted card will differ from the target card in either color or shape, i.e., in the dimension not being used for sorting.) The DCCS thus requires children to classify cards first with respect to one attribute, and subsequently to re-classify them with respect to a different attribute. Most typically developing 3-year-olds fail at the DCCS by perseverating on the original sorting rule, thus exhibiting the cognitive inflexibility often observed in individuals with pre-frontal lobe damage (Zelazo, 2006). It is widely accepted that the DCCS task is not usually mastered until four to five years of age.

The IRCS contrasts with the DCCS in that it does not require children to re-classify cards based upon a different feature of the depicted object (e.g., to shift from the dimension of shape to color), but instead only requires them to reverse sort the cards with respect to whether the object matches the target card (to shift from matching to non-matching or vice versa). Children are instructed in one condition, the ‘same’ game, to place the cards-to-be-sorted so that they are the same as the targets, and in the subsequent condition, the ‘silly’ game, to sort the cards so that they are NOT the same. Kloo et al. (2008) directly compared children’s performance on DCCS and IRCS tasks and confirmed that for children with typical development making a reversal shift is simpler than switching between the dimensions of shape and color and is usually mastered by three years of age.

Although card sort tasks have become a popular method of assessing EF (Zelazo et al., 2003; Zelazo, 2006) and have contributed extensively to theoretical debates concerning EF development (cf. Garon, Bryson, & Smith, 2008 for a review), there is no consensus on the underlying processes making them difficult. A number of explanations have been proposed. According to Cognitive Complexity and Control Theory (e.g., Zelazo et al., 2003), the difficulty lies in young children’s inability to manage multi-level rules hierarchies, an ability related to working memory capacity. While 3-year-olds can easily follow a simple rule structure (if the card is red, place it with the red target, but if the card is blue place it with the blue target), they cannot follow an embedded structure that makes following a shape or color rule conditional on a higher-level rule. For instance, “if this is the color game, follow one set of rules, but if this is the shape game follow another set of rules”. Kirkham and Diamond (2003) alternatively propose “attentional inertia” as the basis for failure at card sorting. In

this view, insufficient inhibitory control leads to an inability to change the focus of attention to a new aspect of the stimulus. In their re-description hypothesis, Kloo and Perner (2003) counter that card sorting difficulty is based upon a requirement to describe the same cards first by one dimension then re-describe them by another. They find support for their view in the relative ease children have in performing the IRCS, a task not requiring re-description (Kloo et al., 2008). Lastly, Morton and Munakata (2002) propose a neural network model that explains 3-year-olds' perseveration during the post-switch card sort as based on the strength of the latent traces of the first rule relative to that of the active rule.

While the current study may indirectly contribute to this ongoing discussion, our primary goal was to use the IRCS as a tool to assess EF processing in NICU preschoolers. The relative ease of performing the IRCS compared to the DCCS made it an ideal choice for this purpose. That is, to examine EF development in NICU graduates from age 34 months, we used a task that typically developing children commonly master at three years of age (Kloo et al., 2008). We predicted improvement with age, but a delayed developmental trajectory compared to previously studied non-NICU graduates (Brooks et al., 2003, Experiment 1, Perner & Lang, 2002; Kloo et al., 2008) and thus administered the IRCS at multiple ages across the preschool years. In addition, we predicted individual differences in card sort performance based upon specific risk factors. The question of how individual differences affect EF development is an important one that has been relatively neglected in the card sort literature with the recent exception of cross-cultural and bilingual influences (Bialystok, Craik, Green & Gollan, 2009; Carlson & Meltzoff, 2008; Oh & Lewis, 2008; Sabbagh, Xu, Carlson, Moses, & Lee, 2006).

CNS injury, low BW for gestational age (GA), male gender, and maternal education were the sources of individual difference examined. Numerous studies have linked CNS injury to poor EF related outcomes (e.g., McGrath et al., 2005). Similarly, low BW for GA - an important indicator of chronic prenatal stress contributed to by decreased oxygen transport, poor placental functioning, compromised blood perfusion, placental infection, and multiple gestation, to name a few factors - has been linked specifically to characteristics of ADHD (Hultman et al., 2007; Strang-Karlsson et al., 2008). In relation to gender, boys are reported to be generally more susceptible to impairments in EF than girls (Wiebe, Espy, & Charak, 2008) and have a higher risk of attention regulation problems including ADHD (e.g., APA, 2000). Additionally, male infants seem to be more vulnerable to pre and perinatal insult (Kraemer, 2000; van de Weijer-Bergsma et al., 2008) and boys have performed more poorly on EF/attention tasks in several studies of preterm and medically at-risk children (Böhm et al., 2004; Kittler et al., 2011; McGrath et al., 2005). Higher maternal education, on the other hand, is associated with a number of beneficial environmental conditions such as higher socio-economic status, better home environment, and greater maturity of caregivers. Parents' level of education has specifically been shown to predict performance on the Wisconsin Card Sorting test in typically developing 5- to 6-year-olds (Ardila, Rosselli, Matute & Guajardo, 2005), and in a study of very preterm infants, maternal education, as well as GA, was predictive of EF outcomes at age six (Aarnoudse-Moens et al., 2009). Within this context of research findings, we predicted that the biologically related factors of CNS injury, low BW for GA, and male gender would have detrimental effect on IRCS performance, whereas, the environmental effect of higher maternal education would be associated with better performance.

Method

Participants

Participants were NICU graduates who were a subset of children enrolled at birth in a longitudinal study of attention and arousal in high perinatal risk infants (*ref removed*).

Selection criteria for the larger study included at least one of the following: low BW (< 1800 g); fetal distress with evidence of asphyxia at birth; assisted ventilation (> 48 hrs); persistent apnea or bradycardia; seizures, coma or signs of intracranial pressure; abnormal neurological signs; small for GA (< 10th percentile BW for GA), intrauterine growth restricted (IUGR), or dysmature (by clinical diagnosis); multiple gestation (at least one twin meeting one of the other criteria or with BW < 2000 g). Exclusion criteria for the current study were known prenatal exposure to neurotoxic substances such as cocaine or methadone, or diagnosis with a genetically-based developmental disability such as Down syndrome.

We obtained a measure of relative intrauterine growth (RIUG) for each participant as a proxy for prenatal stress by calculating a standard score of BW for GA based upon norms for infants 22 to 50 weeks (Fenton, 2003). RIUG is a continuous measure with a mean of 0 and SD of 1. More positive scores indicate higher BW for GA; more negative scores indicate lower BW for GA. RIUG contrasts with IUGR and small for GA which are dichotomous measures calculated based on a percentile cutoff (typically < 10th percentile).

Children were also classified into 3 groups based on level of CNS involvement: 1) no detected abnormality on cranial ultrasound (CUS) or auditory brainstem evoked response (ABR) (50.3%); 2) neurofunctional abnormality on ABR (latencies and/or intervals for Waves I, III, and/or V delayed or prolonged on first NICU test based on laboratory norms) with no structural abnormality detected (35.4%); 3) neurostructural abnormality detected primarily by CUS (Papile, Burstein, Burstein, & Koffler, 1978) (14.3%). The neurostructural abnormality group comprised: *a) mild abnormality* (43.5%)—subependymal (SE) / intraventricular hemorrhage (IVH) (Papile Grades I/II) alone or with tiny SE or choroid cysts, lobular or prominent choroids, ventriculomegaly (vmeg) ≤ 5 mm; *b) moderate abnormality* (43.5%)—IVH (Papile Grades II/III), periventricular leukomalacia, hyperechoic echogenicity, cyst ≤ 3 mm or multiple cysts, vmeg > 5 mm and < 10 mm; *c) severe abnormality* (13.0%)—IVH (Papile Grade IV), dilatation or hemorrhage of IIIrd or IVth ventricle, large or multiple sites of porencephaly, parenchymal hemorrhage or infarct, vmeg ≥ 10 mm, seizures requiring treatment.

The sample was ethnically/racially diverse with 47.2% non-Hispanic white, 28.6% Hispanic (including e.g., Hispanic black and Hispanic white), 12.4% non-Hispanic black, 5.6% non-Hispanic Asian, and 6.2% non-Hispanic mixed ethnicity. As part of the larger study, participants were administered the Griffiths Mental Development Scale (GMDS; Griffiths, 1984), a standardized measure of mental development for the period from birth to eight years.¹ See Table 1 for additional participant characteristics.

To the extent possible, the IRCS task was administered to every child in our longitudinal study who came for an evaluation at 34, 42, 51 or 60 months of age (adjusted for gestation). However, because the study was ongoing, some children had already exceeded the younger test ages when the IRCS was introduced, while others never reached the older ages by the time the study ended. Additionally, the IRCS task was sometimes skipped because, e.g. parents had to leave early or children were having a bad day, and some families moved away or discontinued participation. Within this context, there were 276 tests on 161 children administered from January 2007 through July 2009 for an average of 1.7 tests per child, with 83 children tested once, 47 children tested twice, 25 children tested three times, and 6

¹The Griffiths scores reported in Table 1 may seem high for a NICU group. A major factor accounting for this is that the 1984 version of the (0 to 8 years) Griffiths we administered was normed in the 1960s. (A newly normed 0–8 Griffiths was released only in 2006, too late for use in our ongoing study.) Thus our scores were susceptible to the rise in IQ known as the Flynn effect (Flynn, 1999; Wolke, Ratschinski, Ohrt, & Riegel, 1994). In addition, they reflect correction for gestational age and selection based on ability to complete all card sorts. Because they were included to factor out general cognitive ability rather than to draw broad conclusions about cognitive outcome, the absolute numbers are not critical.

children tested all four times. See Table A1 for the exact breakdown. In addition, 16 children started the IRCS task but did not complete it on at least one visit.

Materials and Procedure

Cards were modeled after Brooks et al. (2003). They were 8.7 cm by 2.2 cm laminated cards with 6 identical black and white line drawings of airplanes and 6 of dogs, with one image per card. One additional dog and one airplane card, held in clear plastic 9 cm by 12.5 cm photo frames were targets.

The IRCS task had two phases, six trials of the ‘same’ game and six of the ‘silly’ game. Game order was counterbalanced with approximately equal numbers of children at each test age assigned to ‘same’ first and ‘silly’ first game orders. The task began by asking the child to name the target pictures. For the ‘same’ game, the experimenter then said, “We are going to play a game called the ‘same’ game. In the ‘same’ game, we place the cards so that they are the same. If the card has an airplane on it, we place it next to the airplane because it is the same [E holds up airplane card in front of airplane target], and if the card has a dog on it, we place it next to the dog because it is the same [E holds up the dog card in front of dog target]. Here is an airplane/dog. Can you point and show me where the airplanes/dogs go in the ‘same’ game?” The ‘silly’ game started the same way except the experimenter said, “In the ‘silly’ game, we place the cards so that they are NOT the same, so that’s silly, right?” and the cards were placed with the target that was different. For both games, if the child pointed correctly, the experimenter praised the child and placed the card in front of the appropriate target. If the child did not point correctly, the experimenter showed the child where the card should go and repeated the practice. The practice could be repeated up to three times.

Each game used three cards depicting a dog, and three with an airplane. The card order was different for ‘same’ and ‘silly’ games (with identical cards never presented more than twice in a row), but did not vary among participants. On each trial, the experimenter asked the child “Where does this card go in the ‘same’/‘silly’ game?” while emphasizing the word ‘same’ or ‘silly’. The child was asked to point to the appropriate target. After the child’s response, the experimenter placed the card face down in front of the target indicated. No feedback was given except on trial 1 where if the child pointed to the wrong target, the experimenter said: “Remember, we are playing the ‘same’/‘silly’ game, and you have to put the card where it is the same/not the same”. Otherwise, the experimenter said “okay” and proceeded to the next trial.

Phase 2 was exactly like Phase 1, except that the game switched from ‘same’ to ‘silly’ or vice versa. To introduce Phase 2, the experimenter placed the picture frames face down, exchanged their positions, and said, “Now we are going to play a new game, the ‘silly’ (or ‘same’) game. We’re not going to play the ‘same’ (or ‘silly’) game anymore. We’re now going to play the ‘silly’ (or ‘same’) game”. Then the experimenter explained the rules of the new game.

Data Analysis

Because all children were not available for testing at each age, we performed statistical analyses using Generalized Estimating Equations (GEE; Liang and Zeger 1986; Zeger and Liang 1986). GEEs are essentially regression models with correction for the distortion of variance estimates that results from autocorrelation in longitudinal analyses. Separate GEE models were run for the ‘silly’ and ‘same’ games. The number of correct responses (0 – 6) was the dependent variable and test age, game order (i.e. pre or post switch), maternal education, RIUG, GA, gender, and CNS injury group were entered as predictors. GMDS

score was included to account for effects of general cognitive ability. RIUG may reflect prenatal stress but does not completely capture maturity, as it is possible to be full term and still be growth restricted or small for GA. Therefore, GA, a direct measure of maturity, was included as a predictor. Interactions between significant predictors and test age were also entered into the models and those that significantly affected card sort scores were maintained.

We additionally analyzed card sort tasks that children did not complete. Rather than supply zeroes for scores on incomplete tests, we excluded incomplete tests from the GEE analyses and instead compared participants who were untestable on at least one test to those who were never untestable. GEE analyses were done in StataSE8; all other analyses were done in SYSTAT 11.

Results

Participants

Table 1 presents participant information as a function of age at test in months. The total column summarizes data for the 161 children tested at least once. None of the variables used as predictors differed significantly based upon test age except GMDS ($Z = -2.07, p = .039$), which was higher at the youngest age. CNS injury groups did not differ on GMDS scores.

Comparisons between children who failed to complete at least one card sort after starting (untestable) and those who were always testable, revealed that untestable children had more CNS injury ($\chi^2(2) = 9.16, p = .010$). As presented in Table 2, a higher percentage of untestable children were in the CUS structural injury group and a lower percentage were in the no injury detected group. These children also had lower GMDS scores ($F(1,175) = 24.71, p < .001$). The distribution across test ages also differed between groups ($\chi^2(3) = 13.30, p = .004$), with untestable children clustered at the 34-month test and absent at the 51- and 60-month tests, reflecting age-related improvement in their ability to finish the task. This difference in distribution across age groups, combined with the lower GMDS of the untestable group, may explain why the GMDS of children completing the task was significantly higher at the 34-month test than at other ages. The youngest children with the lowest GMDS scores may not have been able to complete the task at 34 months, and the absence of their low scores may have raised the mean.

'Same' Game

Table 3 presents standardized coefficients, their standard errors, *Z-scores* and *p-values* of these coefficients, and 95% confidence intervals for each predictor from the GEE analysis of the 'same game'. The overall model was significant ($Wald \chi^2(9) = 29.71, p < .001$), as were GMDS, game order, and the game order by test age interaction. Higher GMDS scores were associated with better performance. The order effect was consistent with the card sort literature in that children were poorer at applying the 'same' rule when the 'same' game was played second (see Figure 1, left panel). However, they improved rapidly with increased age and the order effect disappeared after 42 months, thus accounting for the game order by test age interaction. The absence of an overall effect of test age reflected the high level of proficiency at applying the 'same' rule even at 34 months. Gender, maternal education, CNS injury group, RIUG and GA did not significantly affect scores, which may have been relatively insensitive to these predictors given the near ceiling performance.

'Silly' Game

The overall GEE model was significant ($Wald \chi^2(9) = 75.01, p < .001$), with test age and maternal education significantly affecting 'silly' game scores (see Table 4). Older test ages

(Figure 1, right panel) and higher maternal education were both associated with better scores. In addition, lower *Z-scores* for RIUG (i.e., scores at the lower end of the normalized distribution for relative growth in utero) were associated with poorer performance (Figure 2). The effect of RIUG was modified by a marginally significant ($p = .058$) RIUG by test-age interaction, indicating RIUG had more of an effect at younger ages.

Game order also affected performance; however, the order effect contradicted the pattern predicted by the literature on the DCCS, i.e., that children would tend to perseverate on the pre-switch rule. Rather than having difficulty switching from the 'same' to the 'silly' rule (i.e., performing more poorly on post-switch trials), children exhibited strong order effects in the opposite direction. They had higher scores on the 'silly' game when it was played second, rather than first (Figure 1, right panel). Unlike the 'same' game, there was no interaction of game order with test age. Although children became better at applying the 'silly' rule with age, there was no evidence that the negative effect of playing the 'silly' game first declined at the older ages. Gender, CNS injury group, GA, and GMDS did not affect 'silly' game scores.

Post Hoc Analyses of Instructions

The effect of CNS injury was unexpectedly not reflected in 'same' or 'silly' game scores, but indirectly in comparisons between children who always completed the task and those who did not complete the task at least once. Thus, it seemed possible that the number of times the instructions had to be repeated (0–3) might also be influenced by CNS injury. 'Same' and 'silly' instruction repetition scores were analyzed using the same GEE models used for game scores. Overall models were significant for both the 'same' ($Wald \chi^2(8) = 29.59, p < .001$) and 'silly' games ($Wald \chi^2(8) = 72.13, p < .001$). In the 'same' game (Table 5), test age, game order, GMDS scores, and CNS injury group affected the number of repetitions of instructions. In the 'silly' game (Table 6), only test age and GMDS scores had effects. For both games, higher GMDS scores and older test ages were associated with fewer repetitions. In the 'same' game, the group with CNS injury on CUS needed more repetitions of instructions, and instructions had to be repeated more times when the 'same' game was played second, which was further confirmation that the 'same' game was more difficult to play after a rule switch.

Discussion

In the current study the 'same'/'silly' IRCS (Brooks et al., 2003, Experiment 1) was administered to preschool NICU graduates to assess EF and to examine how CNS injury, prenatal stress, gender and maternal education impact EF development in an at-risk sample. The IRCS targets cognitive flexibility as well as other components of EF and was chosen based on reported ease of performance by typically developing 3-year-olds (Brooks et al., 2003; Kloo & Perner, 2003; Perner & Lang, 2002; Kloo, et al., 2008). As predicted, NICU graduates were delayed in mastering the IRCS but did improve with age. In addition, maternal education was positively related, whereas in-utero stress was negatively related, to IRCS performance. Contrary to predictions, there were only indirect indications of a detrimental effect of CNS injury and no gender effects. Moreover, we observed a striking and unexpected 'silly' game order effect, suggesting EF vulnerabilities beyond those normally tapped by card sort tasks.

Individual differences in IRCS performance were linked to maternal education and low BW for GA, but only the 'silly' game was sensitive to these predictors, most likely due to near ceiling level performance on the 'same' game. Finding that higher maternal education predicted higher 'silly' game scores fits into a large literature reporting positive connections between maternal education and outcome measures such as IQ, language abilities, and

academic achievement both in low medical risk term (e.g., Bornstein & Bradley, 2003; Hoff, 2003) and in preterm children (Aarnoudse et al., 2009; Gardner, Karmel, Lennon, Kittler, & Flory, 2008; Lawrence & Blair, 2003; Ment et al., 2003; Wocadio & Rieger, 2007). Maternal education and intrauterine growth effects were significant even with GMDS scores included in the analyses, showing that these effects were likely to be specific to EF and not simply a by-product of overall cognitive ability. Lower intrauterine growth scores (smaller for GA) predicted poorer 'silly' game performance at the two younger ages only. This developmental trajectory is consistent with our prior report indicating that biological effects on cognitive development tend to become less pronounced with increasing age as environmental factors such as maternal education exert more influence (*ref withheld*).

Observing that indicators of growth-related problems in utero (IUGR/ RIUG) affected card sorting adds to an emerging literature that links prenatal stress to adverse cognitive outcomes specifically in the areas of attention and EF. For example, term infants born small for GA were reported to have more attention deficit symptoms as adolescents than appropriate for GA controls (Indredavik, Vik, Heyerdahl, Kulseng, & Brubakk, 2005), and small for GA male twins were more likely to have a DSM-IV diagnosis of inattention (Rooney, Hay, & Levy, 2003). Recently, Geva et al. (2009) reported higher rates of impulsivity and lower problem solving skills in the Tower of London test, which taps EF planning processes, in a group of 6-year-olds with extreme deficits in growth in utero relative to controls. Similarly, Robson and Cline (1998) found effects of growth restriction on 5-year-olds' ability to sustain attention and inhibit impulsive responses.

The neuroanatomical basis underlying the relationship between IUGR and poor cognitive outcome is under investigation. One possibility is that IUGR infants have higher levels of CNS injury. Padilla-Gomes et al. (2007) explored this by comparing premature infants with and without IUGR (24 to 34 weeks gestational age) on the prevalence of hemorrhagic brain lesions, periventricular leukomalacia, and transient periventricular echodensities at 3 time points between birth and term gestational age. Infants with IUGR had more of the latter two categories of CNS injury as visualized with cranial ultrasound. Two fMRI studies compared brain neuroanatomy in 12-month-olds who were pre-term small for GA, pre-term appropriate for GA, or full-term appropriate for GA. One study used standard fMRI techniques to assess white and gray matter density and distribution (Padilla et al. 2011); the other analyzed the structural complexity of gray and white matter using the fractal dimension, a measurement of topological complexity (Esteban et al., 2010). Both studies reported neuroanatomical gray and white matter anomalies in the IUGR 12-month-olds and found connections between structural or complexity differences and neurodevelopmental parameters as assessed by the Bayley III.

Although, deficits in intrauterine growth negatively affected IRCS performance, contrary to our predictions, gender and level of CNS injury did not. One reason that we may not have observed a direct effect of CNS injury is that the numbers of children in the most severe CNS injury category at each age were relatively small. However, we did observe indirect signs of a negative effect. Children with greater CNS injury were less likely to complete the task than children without injury. Additionally, children with structural CNS injury required more repetitions of the 'same' game instructions than children in the other CNS injury groups, although they were undifferentiated on 'same' game performance. Finding direct effects of poor growth but only indirect ones for CNS injury suggests that despite overlap between children with deficits in intrauterine growth and those with CNS injury, as shown by Padilla-Gomes et al. (2007), these groups are not identical. Undetected CNS injury is not likely to provide the complete explanation for negative outcomes in children who are growth restricted.

Overall, as we predicted, NICU graduates in our study were delayed in mastering the IRCS, but did improve with age. Contrary to reports of typically developing children (Brooks et al., 2003, Perner & Lang, 2002; Kloo et al., 2008), our sample failed to master the IRCS at 3 years of age and, in fact, did not completely master it at the oldest ages tested. Kloo et al.'s (2008) 3-year-olds achieved 95% correct for non-match second, while Brooks et al.'s (2003, Experiment 1) achieved 100% for non-match second and 98% for non-match first. At 4 years of age, our at-risk pre-schoolers scored only 84% for non-match second and 69% for non-match first. Even at 5 years of age they scored only 92% for non-match second and 76% for non-match first (see Table A2).

When playing match first, children's bias to match cards to targets produced ceiling performance even at the youngest ages, but scores were lower when it was played second (Figure 1, left panel). This order effect is consistent with the post-switch decline in card sorting reported in the DCCS literature. Given that non-match first performance was at chance levels at the youngest age when the order effect was strongest, the poorer performance on match second appears to result from a generic task-switching effect rather than perseveration on a specific pre-switch 'silly' rule. Informal inspection of individual performance at 34 months supports this in that the few participants with the highest scores on 'silly' first also had the highest, rather than the lowest, scores after switching to the 'same' rule.

Children had the greatest difficulty performing the 'silly'/non-match game, regardless of game order. Most unexpectedly, however, performance was better when it was played after a rule switch. This is opposite the DCCS pattern (Zelazo et al., 2003; Zelazo, 2006) in which children play worse after a rule switch because they continue sorting based on the pre-switch rule. 'Silly' game performance improved overall from around 54% correct at 34 months to 84% at 60 months, but there was no diminution of this atypical post-switch effect (Figure 1, right panel). Performance remained significantly better for non-match second at all ages.

Our atypical order effect contradicts an explanation of poor 'silly' game performance in terms of inadequate inhibition of a prepotent bias to match, an explanation consistent with Kirkham and Diamond's (2003) interpretation of preschoolers' difficulty in the post-switch phase of DCCS. Completing 6 trials of matching, rather than generating perseveration on the 'same' rule, seemed to facilitate children grasping non-matching. That is, the 'silly' game made more sense to children in the context of a switch from matching to not matching the cards. A vast literature addressing 'same'/'different' (match/non-match) processing indicates that 'different' is the harder concept to master (e.g., Baker, Friedman & Leslie, 2010; Diamond, Towle, & Boyer, 1994; Katz, Wright, & Bodily, 2007; Levin & Maurer, 1969). Poor IRCS performance overall and the observed order effect might be explained by an incomplete mastery of the concept of 'different' by our NICU sample.

Without total mastery of 'different', playing 'silly'/non-match first may make greater demands on working memory processes than playing it second. Children may first have to activate and maintain the match process in working memory before attempting its reversal. For example, they may reason, "this is an airplane and it is the same as the airplane target, but this is the non-match/'silly' game, so it doesn't go with the airplane, it goes with the one that is not the same". However, if the child has just matched six airplanes, he may be able to proceed directly to non-matching. Thus the first step in the reversal process, viz., maintaining the match rule, may take less effort after the 'same' game has been played. Once the concept of 'different' is firmly established developmentally, allowing automatic application of a non-match process, and/or working memory has become more efficient, doing 'same' processing first is no longer necessary or facilitative, but instead results in the typically observed order effect. This interpretation suggests working memory vulnerability

in our sample, which is consistent with previous reports in NICU graduates and children born pre-term (Aarnoudse-Moens, 2009; Anderson et al., 2004; Böhm et al., 2004; Curtis, Lindeke, Georgieff, & Nelson, 2002). More generally, it suggests that the child's conceptual understanding is a critical factor affecting whether a post-switch rule will be more or less difficult than a pre-switch rule. Of course, this post hoc account is speculative and requires further research.

These speculations draw attention to the near ceiling-level performance on pre-switch rules that is typical of most card sort studies. Such tight control of performance levels is useful for focusing attention on the components of EF required for switching between rules or tasks, however it might inadvertently suggest that EF operates independently of facility with the rules or task contents. As the current study highlights, individual differences and task or rule specifics may interact, to a greater extent than previously considered, with the ability to be cognitively flexible or to carry out EF control processes. Consistent with this view, Qu and Zelazo (2007) demonstrated superior 3-year-old DCCS rule switching ability when cards depicted emotional faces instead of standard red/blue rabbits/boats. The authors suggest that the opposite pattern might occur (i.e., worse performance with emotional faces) in children with Autism Spectrum Disorder, a group with abnormalities in face processing, emotion recognition, and social cognition (e.g. Chawarska, Volkmar, & Klin, 2010). Conceptualizing EF processes as independent of task contents is problematic, similar to attempting to conceptualize dual task processing without considering the difficulty of the component tasks and the participants' expertise.

In conclusion, the IRCS proved successful in highlighting EF difficulties and sources of individual differences in performance in NICU graduates. 'Same' game play produced an order effect showing a developmental delay in rule switching ability for a well-mastered rule. Poor success at 'silly' game play, in combination with an unexpected order effect in which prior matching facilitated non-matching, pointed to a delay in mastery of the concept of 'different' and a possible weakness in working memory, topics that should be explored in future research. Successful performance of the 'silly' game was linked to prenatal stress, and to maternal education. Future studies should compare the performance of children at risk on the intra-dimensional and extra-dimensional card sort tasks to evaluate which executive skills are differentially impacted by specific medical/neurological and environmental risk factors.

References

- Aarnoudse-Moens CSH, Smidts DP, Oosterlaan J, Duivenvoorden HJ, Weisglas-Kuperus N. Executive function in very preterm children at early school age. *Journal of Abnormal Child Psychology*. 2009; 37:981–993. [PubMed: 19488851]
- Akshoomoff N. Selective attention and active engagement in young children. *Developmental Neuropsychology*. 2002; 22:625–642. [PubMed: 12661973]
- American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 4. Washington, DC: Author; 2000. text rev
- Anderson PJ, Doyle LW. the Victorian Infant Collaborative Study Group. Executive functioning in school-aged children who were born very preterm or with extremely low birth weight in the 1990s. *Pediatrics*. 2004; 114:50–57. [PubMed: 15231907]
- Ardila A, Rosselli M, Matute E, Guajardo S. The influence of the parents' educational level on the development of executive functions. *Developmental Neuropsychology*. 2005; 28(1):539–560. [PubMed: 15992255]
- Baker ST, Friedman O, Leslie AM. The opposites task: Using general rules to test cognitive flexibility in preschoolers. *Journal of Cognition and Development*. 2010; 11(2):240–254.

- Bayless S, Stevenson J. Executive functions in school-age children born very prematurely. *Early Human Development*. 2007; 83:247–254. [PubMed: 16837146]
- Bhutta AT, Cleves MA, Casey PH, Cradock MM, Anand KJS. Cognitive and behavioral outcomes of school-aged children who were born preterm A Meta-analysis. *Journal of the American Medical Association*. 2002; 288:728–737. [PubMed: 12169077]
- Bialystok E, Craik FIM, Green DW, Gollan TH. Bilingual minds. *Psychological Science in the Public Interest*. 2009; 10(3):89–129.
- Böhm B, Smedler AC, Forssberg H. Impulse control, working memory and other executive functions in preterm children when starting school. *Acta Paediatrica*. 2004; 93:1363–1371. [PubMed: 15499959]
- Bornstein, MH.; Bradley, RH., editors. Socioeconomic status, parenting and child development. Mahwah, NJ: Lawrence Erlbaum Associates; 2003.
- Brooks PJ, Hanauer JB, Padowska B, Rosman H. The role of selective attention in preschoolers' rule use in a novel dimensional card sort. *Cognitive Development*. 2003; 18:195–215.
- Carlson SM. Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*. 2005; 28:595–616. [PubMed: 16144429]
- Carlson SM, Meltzoff AN. Bilingual experience and executive function in young children. *Developmental Science*. 2008; 11:282–292. [PubMed: 18333982]
- Chawarska K, Volkmar F, Klin A. Limited attentional bias for faces in toddlers with autism spectrum disorders. *Archives of General Psychiatry*. 2010; 67:178–185. [PubMed: 20124117]
- Curtis WJ, Lindeke LL, Georgieff MK, Nelson CA. Neurobehavioral functioning in neonatal intensive care unit graduates in late childhood and early adolescence. *Brain*. 2002; 125:1646–1659. [PubMed: 12077013]
- Diamond A, Towle C, Boyer K. Young children's performance on a task sensitive to the memory functions of the medial temporal lobe in adults—the Delayed Nonmatching-to-Sample task—reveals problems that are due to non-memory-related task demands. *Behavioral Neuroscience*. 1994; 4:659–680. [PubMed: 7986361]
- Esteban FJ, Padilla N, Sanz-Cortés M, Ruiz de Miras J, Bargalló N, Villoslada P, Gratacós E. Fractal-dimension analysis detects cerebral changes in preterm infants with and without intrauterine growth restriction. *Neuroimage*. 2010; 53:1225–1232. [PubMed: 20633658]
- Fenton TR. A new growth chart for preterm babies: Babson and Brenda's chart updated with recent data and a new format. *BMC Pediatrics*. 2003; 3:13. <http://www.biomedcentral.com/1471-2431/3/13>. [PubMed: 14678563]
- Flynn JR. Searching for justice: The discovery of IQ gains over time. *American Psychologist*. 1999; 54:5–20.
- Gardner, JM.; Karmel, BZ.; Flory, MJ. Arousal modulation of neonatal visual attention: Implications for development. In: Soraci, S., editor. *Perspectives on fundamental processes in intellectual functioning*, Vol. 2, Visual information processing and individual differences. Stamford, CT: JAI Press; 2003. p. 125-153.
- Gardner, JM.; Karmel, BZ.; Lennon, EM.; Kittler, PM.; Flory, MJ. Shifts in the Relative Influence of Biological and Environmental Risk Factors on Developmental Outcome of High-Risk Infants. Pediatric Academic Societies' & Asian Society for Pediatric Research Joint Meeting; Honolulu, HI. May. 2008
- Garon N, Bryson SE, Smith IM. Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*. 2008; 134(1):31–60. [PubMed: 18193994]
- Geva R, Yosipof R, Eshel R, Leitner Y, Fattal A, Harel S. Readiness and adjustments to school for children with Intrauterine Growth Restriction (IUGR): An extreme test case paradigm. *Exceptional Children*. 2009; 75(2):211–230.
- Griffiths, R. A comprehensive system of mental measurement for the first eight years of life. Bucks: The Test Agency Ltd; 1984. The abilities of young children.
- Hoff E. The specificity of environmental influence: Socioeconomic status affects early development via maternal speech. *Child Development*. 2003; 74:1368–1378. [PubMed: 14552403]
- Hultman CM, Torráng A, Tuvblad C, Cnattingius S, Larsson JO, Lichtenstein P. Birth weight and attention-deficit/hyperactivity symptoms in childhood and early adolescence: A prospective

- Swedish twin study. *Journal of the American Academy of Child and Adolescent Psychiatry*. 2007; 46:370–377. [PubMed: 17314723]
- Indredavik MS, Vik T, Heyerdahl S, Kulseng S, Brubakk AM. Psychiatric symptoms in low birth weight adolescents, assessed by screening questionnaires. *European Child & Adolescent Psychiatry*. 2005; 14:226–236. [PubMed: 15981134]
- Isquith PK, Crawford JS, Espy KA, Gioia GA. Assessment of executive function in preschool-aged children. *Mental Retardation and Developmental Disabilities Research Reviews*. 2005; 11:209–215. [PubMed: 16161093]
- Katz JS, Wright AA, Bodily KD. Issues in the comparative cognition of abstract-concept learning. *Comparative Cognition & Behavior Reviews*. 2007; 2:79–92. [PubMed: 20228966]
- Kirkham NZ, Cruess L, Diamond A. Helping children apply their knowledge to their behavior on a dimension-switching task. *Developmental Science*. 2003; 6(5):449–467.
- Kirkham NZ, Diamond A. Sorting between theories of perseveration: Performance in conflict tasks requires memory, attention, and inhibition. *Developmental Science*. 2003; 6(5):474–476.
- Kittler PM, Gardner JM, Lennon EM, Flory MJ, Mayes LC, Karmel BZ. The development of selective attention and inhibition in NICU graduates during the preschool years. *Developmental Neuropsychology*. 2011; 36:1003–1017. [PubMed: 22004021]
- Kloo D, Perner J. Training transfer between card sorting and false belief understanding: Helping children apply conflicting descriptions. *Child Development*. 2003; 74(6):1823–1839. [PubMed: 14669898]
- Kloo D, Perner J, Kerschhuber A, Dabernig S, Aichhorn M. Sorting between dimensions: Conditions of cognitive flexibility in preschoolers. *Journal of Experimental Child Psychology*. 2008; 100:115–134. [PubMed: 18241879]
- Kraemer S. The fragile male. *British Medical Journal*. 2000; 321(7276):1609–1612. [PubMed: 11124200]
- Lawrence FR, Blair C. Factorial invariance in preventative intervention: Modeling the development of intelligence in low birth weight, preterm infants. *Prevention Science*. 2003; 4(4):249–261. [PubMed: 14598997]
- Levin GR, Maurer D. The solution process in children's matching-to-sample. *Developmental Psychology*. 1969; 1:679–690.
- Liang K-Y, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika*. 1986; 78(1):13–22.
- Mazzocco MMM, Kover ST. A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology*. 2007; 13(1):18–45. [PubMed: 17364562]
- McGrath MM, Sullivan M, Devin J, Fontes-Murphy M, Barcelos S, DePalma JL, Faraone S. Early precursors of low attention and hyperactivity in a preterm sample at age four. *Issues in Comprehensive Pediatric Nursing*. 2005; 28:1–15. [PubMed: 15824026]
- Ment LR, Vohr B, Allan W, Katz KH, Schneider KC, Westerveld M, Duncan CC, Makuch RW. Changes in cognitive function over time in very low-birth-weight infants. *JAMA: Journal of the American Medical Association*. 2003; 286(5):705–711.
- Morton JB, Munakata Y. Active versus latent representations: A neural network model of perseveration, dissociation, and decalage. *Developmental Psychobiology*. 2002; 40:255–265. [PubMed: 11891637]
- Müller U, Dick AS, Gela K, Overton WF, Zelazo PD. The role of negative priming in preschoolers' flexible rule use on the dimensional change card sort task. *Child Development*. 2006; 77:395–412. [PubMed: 16611180]
- Oh S, Lewis C. Korean preschoolers' advanced inhibitory control and its relation to other executive skills and mental state understanding. *Child Development*. 2008; 79:80–99. [PubMed: 18269510]
- Padilla-Gomes NF, Enriquez G, Acosta-Rojas R, Perapoch J, Hernandez-Andrade E, Gratacos E. Prevalence of neonatal ultrasound brain lesions in premature infants with and without intrauterine growth restriction. *Acta Paediatr*. 2007; 96:1582–1587. [PubMed: 17888056]
- Padilla N, Falcón C, Sanz-Cortés M, Figueras F, Bargallo N, Crispi F, Eixarch E, Arranz A, Botet F, Gratacós E. Differential effects of intrauterine growth restriction on brain structure and

- development in preterm infants: A magnetic resonance imaging study. *Brain Research*. 2011 Jan. 1910.1016/j.brainres.2011.01.032
- Papile LA, Burstein J, Burstein R, Koffler H. Incidence and evaluation of subependymal and intraventricular hemorrhage: a study of infants with birth weights less than 1500 gm. *Journal of Pediatrics*. 1978; 92(4):529–534. [PubMed: 305471]
- Pennington B, Ozonoff S. Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry*. 1996; 37(1):51–87. [PubMed: 8655658]
- Perner J, Lang B. What causes 3-year-olds' difficulty on the dimensional change card sorting task? *Infant and Child Development*. 2002; 11(2):93–105.
- Qu L, Zelazo D. The facilitative effect of positive stimuli on 3-year-olds' flexible rule use. *Cognitive Development*. 2007; 22:456–473.
- Robson A, Cline B. Developmental consequences of intrauterine growth retardation. *Infant Behavior and Development*. 1998; 21(2):331–344.
- Rooney R, Hay D, Levy F. Small for gestational age as a predictor of behavioral and learning problems in twins. *Twin Research*. 2003; 6:46–54. [PubMed: 12626228]
- Rothbart, MK.; Posner, MI. Mechanism and variation in the development of attentional networks. In: Nelson, C.; Luciana, M., editors. *Handbook of developmental cognitive neuroscience*. Cambridge, MA: MIT Press; 2001. p. 353–363.
- Sabbagh MA, Xu F, Carlson SM, Moses LJ, Lee K. The development of executive functioning and theory of mind A comparison of Chinese and U.S. preschoolers. *Psychological Science*. 2006; 17:74–81. [PubMed: 16371147]
- Strang-Karlsson S, Räikkönen K, Pesonen AK, Kajantie E, Paavonen EJ, Lahti J, Hovi P, Heinonen K, Järvenpää AL, Eriksson JG, Andersson S. Very low birth weight and behavioral symptoms of attention deficit hyperactivity disorder in young adulthood: The Helsinki study of very-low-birth-weight adults. *American Journal of Psychiatry*. 2008; 165:1345–1353. [PubMed: 18628349]
- van de Weijer-Bergsma E, Wijnroks L, Jongmans MJ. Attention development in infants and preschool children born preterm: A review. *Infant Behavior and Development*. 2008; 31:333–351. [PubMed: 18294695]
- Wiebe SA, Espy KA, Charak D. Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*. 2008; 44:575–587. [PubMed: 18331145]
- Wocadio C, Rieger I. Phonology, rapid naming and academic achievement in very preterm children at eight years of age. *Early Human Development*. 2007; 83(6):367–377. [PubMed: 16979856]
- Wolke D, Ratschinski G, Ohrt B, Riegel K. The cognitive outcome of very preterm infants may be poorer than often reported: An empirical investigation of how methodological issues make a big difference. *European Journal of Pediatrics*. 1994; 153:906–915. [PubMed: 7532133]
- Zelazo PD. The dimensional change card sort (DCCS): A method of assessing executive function in children. *Nature Protocols*. 2006; 1:297–301.
- Zelazo PD, Müller U, Frye D, Marcovitch S. The development of executive functions. *Monographs of the Society for Research in Child Development*. 2003; 68(3)
- Zeger SL, Liang K-Y. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics*. 1986; 42(1):121–130. [PubMed: 3719049]

Appendix

Table A1

Distribution of Tests Across Test Age by Times Tested

Times Tested	Age when Tested (in months)				
	34	42	51	60	<i>n</i>
1	20	15	15	33	83
2	x	x			16

Times Tested	Age when Tested (in months)				<i>n</i>
	34	42	51	60	
3	x		x		2
		x	x		11
		x		x	1
	x	x	x		10
	x	x		x	2
	x		x	x	3
4		x	x	x	10
	x	x	x	x	6

Table A2

Across Study Comparisons of Percentage of ‘Silly’ Cards Sorted Correctly

Kloo study		Brooks study			Current study		
Age at test	‘silly’ second	Age at test	‘silly’ second	‘silly’ first	Age at test	‘silly’ second	‘silly’ first
2;6–3;0 n=8	60.0				2;8 n=30; n=30	58.9	48.3
3;1–3;6 n=7	85.6	3;1–3;5 n=7; n=5	74.3	71.4	3;6 n=34; n=37	66.7	60.8
3;7–3;11 n=8	95.0	3;7–3;11 n=5; n=7	98.0	100			
4;2–4;10 n=8	95.0				4;3 n=35; n=39	84.3	69.2
					5;0 n=37; n=34	91.9	75.5

Note. Age at test is years; months. Kloo et al. (2008) and Brooks et al. (2003) used 5 cards versus current 6, so percentages were calculated to allow comparisons. Kloo et al. only administered ‘same’/‘silly’ order. Age in the current study was corrected for gestation.

Figure 1.

Mean scores expressed as percentages correct by game order, i.e. whether game was played 1st or 2nd. 'Same' game rule is match to target and 'silly' game rule is non-match to target. Game order was counterbalanced across participants. 'Same' game performance was better when 1st as is typical for card sorts, but 'silly' game performance atypically was better when 2nd. Error bars reflect *SE*.

Figure 2.

Effect of relative intrauterine growth (RIUG) on 'silly' score. RIUG was a proxy for stress in-utero and was calculated for each participant as the standard score of birth weight for gestational age based upon norms for infants 22 to 50 weeks (Fenton, 2003) with lower RIUG indicating lower birthweight for gestational age. Test age is in months. Lower RIUG was related to lower percentage correct and there was a marginally significant interaction between test age and RIUG reflecting a greater RIUG effect at the two younger ages.

Table 1

Descriptive Information for Children Completing the Card Sort Tests.

<i>n</i>		Age in Months						Total
		34	42	51	60	71	161	
RIUG	Mean	-0.49	-0.56	-0.68	-0.77	-0.77	-0.75	
	Range	-4.66 – +2.32	-4.07 – +2.32	-4.07 – +3.10	-4.07 – +4.60	-4.07 – +4.60	-4.66 – +4.60	
Gestational age (weeks)	Mean	34.2	34.7	35.0	35.2	35.2	34.7	
	Range	28.0 – 41.0	27.0 – 41.0	26.0 – 41.0	27.0 – 42.0	27.0 – 42.0	26.0 – 42.0	
Maternal Education (years)	Mean	15.3	15.0	14.6	14.2	14.2	14.8	
	Range	6 – 18	6 – 22	6 – 22	4 – 20	4 – 20	4 – 22	
Birth weight (g)	Mean	2243	2325	2346	2343	2343	2246	
	Range	510 – 4508	709 – 4508	822 – 4819	879 – 5131	879 – 5131	510 – 5131	
GMDS Score	Mean	119	115	112	112	112	115	
	Range	80 – 150	80 – 140	80 – 133	82 – 137	82 – 137	80 – 150	
Female	%	55.0	53.5	51.4	45.1	45.1	49.1	
CNS Injury Group								
None		53.3	57.7	52.7	50.7	50.7	50.3	
ABR only	%	36.7	33.8	35.1	32.4	32.4	35.4	
CUS		10.0	8.5	12.2	16.9	16.9	14.3	

Note: RIUG: relative intrauterine growth was calculated as a standard score of birth weight for gestational age based upon norms for infants 22 to 50 weeks (Fenton, 2003) with lower RIUG indicating lower birth weight for gestational age. GMDS: Griffiths Mental Development Scale (Griffiths, 1984). CNS Injury Group: None: no detected CNS injury; ABR only: auditory brainstem response (ABR) abnormal and cranial ultrasound (CUS) normal; CUS: varying degrees of structural abnormality on CUS.

Table 2

Percentage CNS Injury for Testable and Untestable

CNS Injury Group	Testable <i>n</i> = 158	Untestable <i>n</i> = 16
	GMDS score = 115 (12.2)	GMDS score = 99 (14.9)
None	50.0	25.0
ABR only	35.4	31.3
CUS	14.6	43.7

Note. None: no detected CNS injury; ABR only: auditory brainstem response (ABR) abnormal and cranial ultrasound (CUS) normal; CUS: varying degrees of structural abnormality on CUS. Testable: card sort completed at all ages tested; Untestable: at least one failure to complete a card sort after starting. GMDS: Griffiths Mental Development Scale (Griffiths, 1984) - *M*(*SD*)

Table 3

GEE Analysis of 'Same' Game Scores.

	Standardized Coefficient	Std. Error	z-score	p-value	95% Confidence Interval
Test Age (months)	-.02	.016	-1.54	.124	-.06 to .01
Game Order	-1.63	.49	-3.34	.001	-2.58 to -.67
RIUG (z-score)	.02	.04	0.59	.556	-.05 to .09
Maternal Education (years)	-.003	.02	-0.21	.837	-.04 to .03
Gestational Age (weeks)	-.003	.01	-0.22	.824	-.03 to .02
GMDS (score)	.01	.00	2.80	.026	.00 to .02
Gender	.04	.10	0.38	.70	-.16 to .24
CNS Injury Group	-.04	.08	-0.55	.582	-.20 to .11
Order * Test Age	.03	.01	2.80	.005	.01 to .05

Note. Game Order: 1 = 'same'/'silly', 2 = 'silly'/'same'; RIUG: relative intrauterine growth was calculated as a standard score of BW for GA based upon norms for infants 22 to 50 weeks (Fenton, 2003); GMDS: Griffiths Mental Development Scale (Griffiths, 1984); Gender: 0 = female, 1 = male; CNS Injury Group: 1 = no detected insult, 2 = neurofunctional abnormality only on auditory brainstem evoked response (ABR), 3 = neurostructural abnormality on cranial ultrasound (CUS)

Table 4

GEE Analysis of 'Silly' Game Scores.

	Standardized Coefficient	Std. Error	z-score	p-value	95% Confidence Interval
Test Age (months)	.07	.01	5.76	.000	.05 to .10
Game Order	-.75	.22	-3.45	.001	-1.18 to -.33
RIUG (z-score)	.94	.42	2.26	.024	.12 to 1.76
Maternal Education (years)	.12	.04	2.83	.005	.04 to .21
Gestational Age (weeks)	.01	.03	.36	.719	-.05 to .08
GMDS (score)	.01	.01	1.13	.258	-.01 to .04
Gender	.04	.24	.15	.880	-.43 to .50
CNS Injury Group	-.09	.18	-.51	.611	-.45 to .27
RIUG by Test Age	-.02	.01	-1.89	.058	-.03 to .00

Note. Game Order: 1 = 'same'/'silly', 2 = 'silly'/'same'; RIUG: relative intrauterine growth calculated as a standard score of BW for GA based upon norms for infants 22 to 50 weeks (Fenton, 2003); GMDS: Griffiths Mental Development Scale (Griffiths, 1984); Gender: 0 = female, 1 = male; CNS Injury Group: 1 = no detected insult, 2 = neurofunctional abnormality only on auditory brainstem evoked response (ABR), 3 = neurostructural abnormality on cranial ultrasound (CUS)

Table 5

GEE Analysis of ‘Same’ Game Repetition of Directions Scores.

	Standardized Coefficient	Std. Error	z-score	p-value	95% Confidence Interval
Test Age (months)	-.01	.004	-2.10	.035	-.01 to -.001
Game Order	.20	.07	2.86	.004	.06 to .33
RIUG (z-score)	.003	.03	.13	.897	-.05 to .05
Maternal Education (years)	.02	.01	1.40	.162	-.01 to .04
Gestational Age (weeks)	.01	.01	.82	.415	-.01 to .03
GMDS (score)	-.01	.003	-3.62	<.001	-.02 to -.01
Gender	-.11	.07	-1.57	.117	-.26 to .03
CNS Injury Group	.15	.06	2.72	.007	.04 to .26

Note. Game Order: 1 = ‘same’/‘silly’, 2 = ‘silly’/‘same’; RIUG: relative intrauterine growth calculated as a standard score of BW for GA based upon norms for infants 22 to 50 weeks (Fenton, 2003); GMDS: Griffiths Mental Development Scale (Griffiths, 1984); Gender: 0 = female, 1 = male; CNS Injury Group: 1 = no detected insult, 2 = neurofunctional abnormality only on auditory brainstem evoked response (ABR), 3 = neurostructural abnormality on cranial ultrasound (CUS)

Table 6

GEE Analysis of ‘Silly’ Game Repetition of Directions Scores.

	Standardized Coefficient	Std. Error	z-score	p-value	95% Confidence Interval
Test Age (months)	-.05	.01	-7.66	<.001	-.06 to -.03
Game Order	-.04	.12	-0.37	.709	-.27 to .18
RIUG (z-score)	-.02	.04	-0.49	.621	-.10 to .06
Maternal Education (years)	-.02	.02	-0.79	.431	-.06 to .02
Gestational Age (weeks)	-.01	.02	-0.34	.735	-.04 to .03
GMDS (score)	-.02	.01	-3.74	<.001	-.03 to -.01
Gender	-.16	.12	-1.38	.168	-.39 to .07
CNS Injury Group	.13	.09	1.48	.139	-.04 to .31

Note. Game Order: 1 = ‘same’/‘silly’, 2 = ‘silly’/‘same’; RIUG: relative intrauterine growth calculated as a standard score of BW for GA based upon norms for infants 22 to 50 weeks (Fenton, 2003); GMDS: Griffiths Mental Development Scale (Griffiths, 1984); Gender: 0 = female, 1 = male; CNS Injury Group: 1 = no detected insult, 2 = neurofunctional abnormality only on auditory brainstem evoked response (ABR), 3 = neurostructural abnormality on cranial ultrasound (CUS)