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The predictive value of developmental assessments at 1 and 2 for intelligence quotients at 6

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ABSTRACT

Intelligence is an important individual difference factor related to mental health, academic achievement, and life success, yet there is a lack of research into its early cognitive predictors. This study investigated the predictive value of infant developmental assessment scores for school-age intelligence in a large, heterogeneous sample of single- and twin-born subjects (N = 521). We found that Early Learning Composite (ELC) scores from the Mullen Scales of Early Learning have similar predictive power to that of other infant tests. ELC scores at age 2 were predictive of Stanford-Binet abbreviated intelligence (ABIQ) scores at age 6 ($r = 0.46$) even after controlling for sex, gestation number, and parental education. ELC scores at age 1 were less predictive of 6-year ABIQ scores ($r = 0.17$). When the sample was split to test robustness of findings, we found that results from the full sample replicated in a subset of children born at ≥32 weeks gestation without birth complications (n = 405), though infant cognitive scores did not predict IQ in a subset born very prematurely or with birth complications (n = 116). Scores at age 2 in twins and singletons showed similar predictive ability for scores at age 6, though twins had particularly high correlations between ELC at age 1 and ABIQ at age 6.

1. Introduction

Decades of research have revealed that intelligence is related to mental health, academic achievement, occupational status, life success, and longevity (Deary, Pattie, & Starr, 2013; Gottfredson, 1997; Keyes, Platt, Kaufman, & McLaughlin, 2016; Whalley & Deary, 2001). Twin and family studies find that the continuity of intelligence across the lifespan is driven largely by genetic factors, though environmental influences are notable during childhood (Bartels, Rietveld, Baal, & Boomsma, 2002; Bishop et al., 2003; Brant et al., 2013). Intelligence is also a marker of brain development and functioning, including trajectories of structural maturation across the lifespan (Schnack et al., 2015; Shaw et al., 2006) and patterns of functional brain activation (Gray, Chabris, & Braver, 2003) differing based on cognitive ability. Genome-wide association studies show that genes linked to brain development are markers of individual differences in cognitive ability (Davies et al., 2016), and that genetic correlations between intelligence in childhood and old age are high (Deary et al., 2012). This body of research highlights that intelligence is dynamically influenced by biological and environmental processes that contribute to unique developmental trajectories.

Much work has been done to understand the continuity and stability of intelligence across the lifespan, and it has been found that school-age intelligence quotients (IQs) are fairly stable predictors of adult ability (Bradway & Thompson, 1962; Deary et al., 2013; Deary, Whiteman, Starr, Whalley, & Fox, 2004; McCall, 1977). However, studies in younger children and infants have been less conclusive. In a sample of roughly fifty children, the Berkley Growth Study revealed that infant test scores (averaged between ages 10, 11, and 12 months) modestly correlated with school age scores (averaged between ages 5, 6, and 7 using different assessments; $r = 0.20$), while scores averaged between ages 18, 21, and 24 months correlated highly ($r = 0.50$) with school-age scores (Bayley, 1949). In a 1972 review (McCall, Hogarty, & Hurlburt, 1972), data were combined from four studies (including the

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[1] Dr. J. Steven Reznick is recognized posthumously for his contributions.

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Berkley Growth Study) using different cognitive tests; the median correlation reported between 19 and 30 month test scores and 5–7 year scores ($r = 0.41$) was similar to those observed by Bayley (1949), while the correlation between school-age scores and scores from 7 to 12 month-olds was notably smaller ($r = 0.06$). In general, it was found that the later a test is given during infancy and toddlerhood, the better its predictive ability for subsequent outcomes (McCall et al., 1972).

Recent studies of the predictive value of such assessments focus almost exclusively on at-risk populations such as premature and very-low-birth-weight cohorts (Bode, D'Eugenio, Mettelman, & Gross, 2014; Hack et al., 2005; Leversen et al., 2012; Potharst et al., 2012; Soysal et al., 2014). Results from these studies provide conflicting evidence about the predictive ability of early tests for subsequent performance, which may be due to the unique characteristics of these at-risk populations, where some children overcome early deficits while others remain on a delayed trajectory. For example, infant scores from very premature children (Bode et al., 2014), those with neurological impairments (Hack et al., 2005) or perinatal complications (Potharst et al., 2012) were more highly correlated with their subsequent school-age performance, whereas infant scores showed limited predictive value for premature children without major impairments (Leversen et al., 2012).

Other recently published work reporting correlations between infant and school-age cognitive scores include large-scale twin and family studies. In a sample of over 1000 twins and biological and adopted siblings, Bishop et al. (2003) found that infant scores at ages 1 and 2 correlated with principal components derived from cognitive tests at age 7 ($r = 0.18$ and 0.37, respectively; related participants included in correlations). Another study of 14,000 twins in the UK found that parent reports of 2-year-olds' cognitive ability was correlated with phone-administered portions of cognitive tests at age 7 ($r = 0.23$) (von Stumm, Gale, Batty, & Deary, 2009). It is important to note that determining the predictive ability of infant cognition for subsequent intelligence scores was not the primary purpose of either of those studies.

The generalizability of much of the previous work is limited by small sample sizes (Bayley, 1949; Fagan, Holland, & Wheeler, 2007; McCall, 1977), focus on special populations (Bode et al., 2014; Hack et al., 2005; Leversen et al., 2012; Potharst et al., 2012; Soysal et al., 2014), or lack of participant diversity (Bishop et al., 2003; Sutcliffe, Soo, & Barnes, 2010). Results from twin-only studies, while large-scale, may also be difficult to generalize to other populations given that twins have lower IQs in childhood (Bishop et al., 2003; Ronalds, De Stavola, & Leon, 2005), and potentially different cognitive developmental trajectories than single-born children. Therefore, it remains unknown how well the correlations between infant and school-age intelligence reported in the literature generalize across more diverse samples.

The goal of the present study is to investigate the predictive value of cognitive assessments at 1 and 2 years of age for subsequent IQ at age 6 in a relatively large, heterogeneous, longitudinal sample of single- and twin-born children. This study is novel in several respects. First, it is one of the largest studies of the predictive ability of infant cognitive scores for school-age intelligence to date, with 521 subjects in the sample. Second, results are derived from a sample that is generally representative of the U.S. population (US Census, 2016a), whereas many previous studies were conducted in predominantly Caucasian-only samples, or those with < 10% of participants from other racial or ethnic groups. Finally, to our knowledge, this is the first study to test the predictive ability of the Early Learning Composite (ELC) from the Mullen Scales of Early Learning (MSEL) (Mullen, 1995) for school-age intelligence scores in a healthy sample, despite its use in several longitudinal studies of development in the context of brain-behavior relations and its widespread use in autism spectrum disorders research (Deoni et al., 2014; Gilmore et al., 2007; Lee et al., 2017; Wolff et al., 2012). We expected ELC scores to show similar correlations with school-age intelligence scores as those reported using other infant tests, with scores at age 2 being a stronger predictor of IQ at age 6 than measures at age 1. In order to test the robustness of our findings and compare our results with those previously published, we also ran sensitivity analyses subdividing the sample into subsets with and without birth complications (prematurity and/or perinatal complications), and split by gestation number into twins and singletons. We expected that our results would be similar between the full sample and the subset without birth complications, but hypothesized that the premature subset may show a different trend based on previously reported inconsistencies in the literature with this at-risk group. We also expected similar predictive patterns between early cognition and later IQ in twins and singletons given the similarity in effect sizes reported across samples in the literature. Finally, we explored the effects of demographic factors on infant and school-age cognitive scores, expecting that variables related to socioeconomic status (SES) and perinatal characteristics would be both predictive of and related to individual differences in ability.

2. Methods

2.1. Participants

Participants were part of the UNC Early Brain Development Study of early childhood brain development in singletons and twins (Gilmore et al., 2007; Lee et al., 2017). Pregnant women were recruited during the second trimester of pregnancy at the Prenatal Diagnostic Clinics of the University of North Carolina Hospital and Duke University Medical Center by flyers and study staff. Mothers were excluded from the current study for pregnancy complications (major illness, using illegal drugs, or severe infection), or a diagnosis of a major psychiatric disorder. All offspring participants, born between 2003 and 2014, underwent cognitive testing at ages 1, 2, and 6 years. We retrospectively identified 521 children with at least cognitive test scores from at least two ages, no major medical issues, and no psychiatric diagnoses up to age 6. We chose to exclude subjects on the basis of maternal and child psychiatric diagnoses as we have a substantial enrichment of this population in our total subject pool due to recruiting mothers with psychiatric illness as part of other lines of research in the lab. Our sample is generally representative of the local area (US Census, 2016b) and the U.S. population (US Census, 2016a) in terms of race and ethnicity, though our sample over-represents African Americans in both regards (12.9% of local population, 13.3% of national population, 21.3% of our sample), and under-represents Asians (5.7% of national population, 1.5% of our sample) and American Indians (1.3% of national population, 0.4% of our sample), compared to current national statistics. Hispanics are underrepresented in these data (8.4% of national population, 4.8% of our sample) because some children could not undergo cognitive testing in English. Table 1 outlines the demographic characteristics of the entire sample. Informed written consent and parental permission were obtained for all participants and all study protocols were approved by the Institutional Review Boards of UNC Chapel Hill and Duke University.

In sensitivity analyses testing the robustness of our results, we subdivided the sample into subsets with and without birth complications and split by gestation number into twins and singletons. Those with birth complications (n = 116, 22% of entire sample) included all subjects born at < 32 weeks gestation and spending > 24 h in the neonatal intensive care unit (NICU). Twin versus singleton analyses were only conducted on subjects without birth complications (n = 405, 78% of entire sample) to avoid an over-representation of very premature subjects in the twin sample. We compared a sample of 175 twins to 230 singletons. For details on demographics for the subsets, see Supplement S1.A.

2.2. Cognitive assessments

Cognitive ability was assessed in the Infant and Child Assessment lab at the Frank Porter Graham Child Development Institute at UNC-