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Early mathematical skill profiles of prematurely and full-term born children

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ABSTRACT

Preterm birth is associated with low mathematical skills in children. This study on five-year-old Finnish children investigated whether mathematical skill profiles would differ between prematurely and full-term born children and how such profiles and other cognitive skills would be related. Mathematical skills included digit knowledge, spontaneous focusing on numerosity, arithmetic, counting and geometric skills. The investigated cognitive skills were phonological processing, working memory, instruction comprehension, speeded naming, inhibition and visuomotor skills. The participants were 119 preterm children with birth weight <1501 g and 100 full-term born children with normal birth weight. The results of latent profile analyses showed that preterm and full-term born children differed in both number and shape of latent mathematical skill profiles, indicating quantitative and qualitative disparities. After controlling for birth weight or gestational age, maternal education, and other cognitive skills phonological processing, visuospatial working memory and speeded naming were uniquely associated with prematurely born children's five mathematical profiles. In full-term born children, only verbal working memory was related to their four mathematical profiles.

1. Introduction

Advances in medical care favour increasing survival rates of children who are born preterm or with a very low birth weight (VLBW) (Zeitlin et al., 2013). A recent action report involving 184 countries shows that more than one out of 10 babies are born preterm, and preterm birth rates are rising in most of these countries (Blencowe et al., 2013). In addition to the increased risk of severe disabilities, many of these children have neurodevelopmental problems that are reflected in persistently lower academic achievement. Specifically, when comparing prematurely and full-term born children in various academic areas, the largest difference has been found in mathematics (Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009). Despite increasing research on prematurely born children's mathematical skills at a general level, little is known about the variability of mathematical skill profiles in this population or how domain-general cognitive skills are related to different strengths and weaknesses in their mathematical skills. Furthermore, most studies have investigated prematurely born children's mathematical skills only during formal schooling. This is problematic since early intervention before school entry would be the most effective way to prevent specific problems in mathematical development, and a better understanding of the unique issues of this population would aid in developing diagnostic tools for the recognition of at-risk children and designing targeted, early mathematical interventions. The current study aims to fill these knowledge gaps concerning VLBW prematurely born children's mathematical skill profiles and their cognitive correlates well before formal schooling.

1.1. Mathematical skills and other cognitive skills – evidence from research on prematurely born children

Several studies have reported prematurely born and/or VLBW children's lower performance in mathematics, which could not be exclusively explained by general cognitive functioning indicated by the intelligence quotient (IQ) (Guarini et al., 2014; Johnson, Wolke, Hennessy, & Marlow, 2011; Simms et al., 2015; Taylor, Espy, & Anderson, 2009) or by serious neurocognitive impairments (Grunau, Whitfield, & Fay,

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2004; Jaekel & Wolke, 2014; Johnson et al., 2011; Pritchard et al., 2009). It has been suggested that mathematical difficulties of prematurely born children are related to subtle cognitive deficiencies (Simms et al., 2013; Taylor et al., 2009), such as visuospatial processing (Geldof, van Wassenaer, de Kieviet, Kok, & Oosterlaan, 2012; Johnson et al., 2011) and perceptual motor abilities (Verkerk, Jeukens-Visser, van Wassenaer-Leemhuis, Kok, & Nollet, 2013), and executive functions, such as processing speed and working memory (Mulder, Pitchford, & Marlow, 2010; Rose, Feldman, & Jankowski, 2011). Birth weight was a robust predictor of calculation and problem solving in early school years (Espy, Fang, Charak, Minich, & Taylor, 2009).

Cross-sectional findings on the relations between prematurely born and/or VLBW children's mathematical and other cognitive skills have been confirmed by longitudinal studies, which indicate that their mathematical skills at school age are predicted by preschool, general cognitive skills such as IQ, perceptual motor skills and phonological processing (Breslau, Johnson, & Lucia, 2001; Johnson et al., 2011), motor performance (Sullivan & McGrath, 2003), global cognitive functioning and visuospatial processing skills (Assel, Landry, Swank, Smith, & Steelman, 2003; Johnson et al., 2011).

In these previous studies, all mathematical skills were measured when the children were already enrolled in formal education. Only a few studies on prematurely born and/or VLBW children have examined how different domain-general cognitive skills were related to mathematical skills before school. Espy et al. (2004) studied the relation between pre-schoolers' mathematical skills and executive functions in a sample of both full-term and preterm born children. Working memory and inhibition were related to a mathematical composite score after controlling for maternal education and child vocabulary (Espy et al., 2004). In a nationally representative panel study involving over 10,000 four-year-old children, late preterm children had significantly lower composite scores than their full-term born peers in terms of mathematical skills covering number sense, counting, operations, geometry and pattern recognition, even after controlling for parents' education, socioeconomic status and complications at birth (Nepomnyaschy, Hegyi, Ostfeld, & Reichman, 2012). In an Austrian sample, five-year-old prematurely born children scored significantly lower in numerical skills than their full-term peers (Kiechl-Kohlendorfer, Ralser, Pupp Peglow, Pehboeck-Walser, & Fussenegger, 2013). Among prematurely born children, 20% had numerical skill deficits; half of them also had a global cognitive deficit.

Altogether, these research studies pinpoint early childhood as a period when prematurity already affects mathematical skills, even if children's cognitive development is within the normal range. This effect is higher for children with lower socioeconomic status and lower gestational age and seems consistent across cohorts born decades apart (Moore et al., 2012; Nepomnyaschy et al., 2012; Wolke et al., 2014). This emphasises the need for a deeper understanding of prematurely born children's mathematical and other cognitive skills before school age so that effective early interventions could be developed.

1.2. Early mathematical skills

Mathematical knowledge develops in a cumulative manner, and both informal and formal numerical and basic geometrical skills constitute the foundation of formal mathematical skills (e.g., Clements & Sarama, 2009). Ample studies show counting skills as particularly significant predictors of later mathematical skills when children enter school (Hannula-Sormunen, Lehtinen, & Räsänen, 2015; Koponen, Salmi, Eklund, & Aro, 2013; LeFevre et al., 2010; Martin, Cirino, Sharp, & Barnes, 2014). Before school age, children typically learn to produce an increasingly long list of number words, are able to use the number word sequence for determining the cardinality of a set of items by counting objects one at a time, and can solve simple arithmetical tasks based on their understanding of numbers (e.g., Fuson, 1988). Five principles govern and define counting of objects, as follows: one to one, stable-order, cardinal, abstraction and order-irrelevance principles (Gelman & Gallistel, 1978). These object-counting skills form the basis for connecting numerical magnitudes with number words and are thus developmentally important. The verbal number sequence elaboration skills include counting accurately forward and backward from a given number (for a review, see Fuson, 1988). Number sequence elaboration skills before school age are related to arithmetical skills measured concurrently (Fuson, Richards, & Briars, 1982; Johansson, 2005) and several years later in school (Hannula-Sormunen et al., 2015; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Lepola, Niemi, Kuikka, & Hannula, 2005). Arithmetical story problems are used for assessing contextualised numerical knowledge and skills (Jordan et al., 2007), and they are widely applied in mathematics education (Clements & Sarama, 2009). In addition to verbal number skills, learning written number symbols has been linked to later success in arithmetical skills (Baker et al., 2002; Purpura, Baroody, & Lonigan, 2013).

Hannula and Lehtinen (2005) demonstrated that the development of counting skills from the age of three to six years was facilitated by self-initiated practice produced by children's spontaneous focusing on numerosity (SFON). The SFON refers to a separate attentional process, whereby persons spontaneously (i.e., self-initiated, not prompted by others) focus their attention on the exact number of a set of items or incidents and use this numerosity information in their action (Hannula & Lehtinen, 2005; Hannula, Lepola, & Lehtinen, 2010). The SFON tendency indicates the amount of a person's spontaneous practice of using exact enumeration in her or his natural surroundings (Hannula, Mattinen, & Lehtinen, 2005). Individual differences in children's SFON have been demonstrated to be positively and domain specifically related to mathematical skills before school age and from kindergarten to much later in primary school (Batchelor, Inglis, & Gilmore, 2015; Hannula, Räsänen, & Lehtinen, 2007; Hannula et al., 2010; Hannula-Sormunen et al., 2015). Studies about prematurely born children's SFON tendency have not yet been published. Considering the evidence on SFON's significant role in early numeracy, it would be important to include SFON as one of the investigated mathematical subskills in the study.

Young children can identify basic geometric forms although they still struggle with integrating distance and angle information (Dillon, Huang, & Spelke, 2013; Izard & Spelke, 2009; Spelke, 2011). Commonly found among prematurely born children, impaired capacity in spatial reasoning (Geldof et al., 2012; Goyen, Lui, & Woods, 1998) could be related to difficulties with geometry, a less investigated mathematical domain among prematurely born children in preschool age.

1.3. Research context and aims

To our best knowledge, this research is the first to use a person-centred approach, i.e., multigroup latent profile analyses (Bergman & El-khouri, 2003; Taylor et al., 2009) to examine prematurely and full-term born children's mathematical skill profiles across a wide range of mathematical skills in preschool age. This kind of approach is needed since prematurely born children may form a heterogenic group, and it is unknown whether separate mathematical subskills forming various skill profiles differ from full-term born children's profiles. Some indications towards these hypotheses came from a longitudinal study investigating prematurely born children with and without school problems, which brought evidence that these children could follow different developmental pathways compared to full-term born children (Van Baar, Ultee, Gunning, Soepatmi, & De Leeuw, 2006).

The general cognitive variables measured in this study were based on the theoretical frameworks of Krajewski and Schneider (2009) and LeFevre et al. (2010), who documented the unique contributions of linguistic, spatial and quantitative abilities to early mathematics, such as enumeration, calculation, measurement and geometry. This study also referred to the work of Geary (1993), who proposed that visuospatial ability, semantic memory and executive processing contribute to mathematical performance.