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Longer-term associations of preschool education: The predictive role of preschool quality for the development of mathematical skills through elementary school

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ABSTRACT

This study investigates the longer-term associations of preschool quality with the development of mathematical skills during elementary school, taking into account early and subsequent learning environments at home and at elementary school. The arithmetic skills of a German sample of 554 children in grades 1–3 (ages 7:5–9:3 years) were analyzed using latent linear growth curve models to test the extent to which the quality of preschool math instruction is related to entry skills in grade 1 and rates of change over time from grades 1–3. In addition, we asked whether preschool quality interacted with quality of the home environment (HLE) during early or middle childhood in predicting math skills.

Results show that initial mathematical skills at grade 1 were predicted by numerical skills at preschool age, and socio-economic status of the family. Moderator analyses revealed that middle childhood HLE moderated the preschool quality effect on the initial status of mathematical skills in grade 1 in such a way that preschool quality was associated with mathematical skills at grade 1 when middle childhood HLE was in the higher range. Growth in mathematical skills between grade 1 and 3 of elementary school was positively predicted by preschool quality even when controlling for the quality of the subsequent learning environments. Furthermore, elementary school quality was positively related to growth in mathematical skills during the observed period between grade 1 and 3. Moderator analyses revealed that effects of elementary school and preschool are additive as no significant interactive effects between quality in elementary school and preschool have been found. The study highlights the importance of high quality preschools for child development during elementary school.

1. Introduction

Poor achievement in mathematics and science education is a major concern of the German educational system (KMK, 2009). Great efforts have been made to foster children's interest in the so called STEM subjects (science, technology, engineering, and mathematics) to ensure that Germany will have innovative and highly qualified personnel in the future. Unfortunately, many students in Germany show weaknesses in their mathematical competencies which, for example, lead to high dropout rates at university in engineering subjects (Heublein & Wolter, 2011). The PISA (Programme for International Student Assessment) study in 2012 showed that about 18% of the students in Germany aged 15 years were not able to exceed the competence level 1, which means they are not able to solve complex problems in a mathematical way (Salzer, Reiss, Schiepe-Tiska, Prenzel, & Heinze, 2013). Difficulties in mathematics at higher ages are acquired in a cumulative process starting long before formal school education (Geary, Hamson, & Hoard, 2000) and it has been well documented that children's mathematical competence development in elementary school is influenced by their pre-academic numeracy skills acquired during the early years (Duncan et al., 2007; Jordan, Glutting, & Ramineni, 2010). Moreover, it is well known that early mathematical competence also predicts later reading achievement, even better than early reading (Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi, 2005; Clements, Baroody, & Sarama, 2013). Thus, which environmental aspects in the early years might be associated with higher or lower skill levels

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in mathematical development is of special interest for pedagogues and policy makers.

When focusing on Germany, over the past few decades it heavily has been invested in a primarily publically funded child care system for children aged three to six years, and, in recent years, has begun to extend these efforts to children under three. Parallel to the efforts in reaching high provision rates, discussions regarding the quality of preschools have arisen (Tietze et al., 1998). The extensive Anglo-American research accumulated growing evidence regarding the importance of child care quality for children's mathematical development (Barnett, 1995; Gorey, 2001). Furthermore, the first large longitudinal study in Germany, conducted in the early 1990s, highlighted the importance of preschool quality for mathematical development through second grade of elementary school (European Child Care and Education (ECCE) Study Group, 1999). Despite these studies and although a large body of research regarding the association between child care quality and academic development currently exists, there are still controversies regarding the magnitude of those relations, especially when considering mathematics. For example, the "Head Start Impact Study" (U.S. Department of Health and Human Services, Administration for Children and Families, 2010) found that early benefits of the programme for mathematical outcomes found at age 4 dissipated till the end of 1st grade. However, this so called "fading out" effect overlooks the fact that many Head Start children move from a high-quality preschool into a low-quality elementary school. This clearly shows that child experiences in other learning environments (e.g. elementary school, family) has to be taken into account as Miller, Farkas, Vandell, and Duncan (2014) suggested when analyzing preschool or Head Start effects. However, empirical evidence regarding the question whether quality experiences in learning environments at home, at preschool, and at elementary school from early through middle childhood are additive or are moderated by one another in predicting mathematical outcomes in children is limited.

Consequently, the purpose of the present study is to investigate (a) the persistence of preschool quality associations with mathematical development from grade 1 to grade 3, and (b) how quality experiences in different learning environments (family, preschool, and elementary school) through early and middle childhood interact in shaping mathematical development during elementary school using longitudinal data of children in a socioeconomically diverse sample in two federal states in Germany.

1.1. Potential interplay of different learning environments with child development—conceptual framework

According to bioecological theory (Bronfenbrenner & Morris, 1998), human development is a result of the interplay between Process, Person, Context and Time (PPCT). It emphasizes especially the interaction between the child and its multiple learning environments at home, preschool, and elementary school as the "engines of development" (p. 996), called "proximal processes" (p. 996). Accordingly, these proximal processes are dependent on characteristics of the person him or herself, the context, and the time those processes occur. When examining preschool effects, child and family background characteristics can be considered as Person and Context variables whereas the proximal process variables are the quality of the different learning environments. This theoretical approach is also supported by the work of Shonkoff and Phillips (National Research Council and Institute of Medicine, 2000) that has highlighted the important role of early experiences and caregiving relationships in early childhood on children's (brain) development. These environmental processes shape individual development during the early years and beyond. On the basis of this, Shonkoff (2010) builds an enhanced biodevelopmental framework for the understanding of the origins of disparities in child development. This framework highlights the shared early childhood roots of lifelong outcomes in learning, behavior, and both physical and mental health.

These theoretical approaches frame the present study analyzing the interplay between early and middle childhood learning environments at home, preschool, and elementary school and children's mathematical outcomes.

Fig. 1 gives an overview of assumed associations and related research topics designed to structure the research review regarding the interplay between early and middle childhood experiences and mathematical development referencing to Bronfenbrenner and Morris (1998). At the bottom there is a timeline representing the continuum from early to middle childhood (representing the time-component) with its learning environments (representing the process-component) in different contexts, and developmental outcomes. Child and family background characteristics (representing the person-component) can be seen as influencing factors that also have to be taken into account within the interplay of learning environments and child outcomes. While preschool learning environments and outcomes refer to early childhood elementary school environments and outcomes refer to middle childhood.

1.2. Independent preschool effects

Fig. 1 illustrates two possible pathways from which to examine longer-term preschool associations. The first pathway is represented by the arrow leading from preschool quality to academic state in math in elementary school. The second pathway is represented by the direct arrow leading from preschool quality to academic development in math in elementary school. When examining preschool quality effects over time, it is important to refer to different assumptions about the kind of persisting and positive relations of preschool quality; one can focus on the state of academic performance (e.g., *end* of preschool, *beginning* of elementary school), or on the progress (or development; e.g., *during* grade 1–3) in academic outcomes. From a theoretical point of view, three patterns of prediction of preschool quality concerning the subsequent elementary school phase are possible:

- First, preschool quality is related to the *academic state in math at the beginning of elementary school*. That means that preschool quality places children on an individual "track" from which development proceeds parallel.
- Second, preschool quality is not related to academic state but to *the further progress in math in elementary school*.
- Third, a *combination of state and progress relations* is possible. Preschool quality might influence academic state at the beginning of elementary school *and* also the further math development during elementary school.

1.3. Moderated preschool effects

In addition to the independent effect of preschool quality on mathematical development, represented by the continuous lines in Fig. 1, moderated effects through the other early and middle childhood learning environments (family and elementary school) are also possible, represented by the dashed lines. Moderated effects implicate that preschool effects differ according to the experiences in the other learning environments at home and at elementary school.

When examining the interplay of multiple learning environments on developmental outcomes, four types of relations are possible (Miller et al., 2014); (a) *additive* effects, i.e., independent effects of the learning environments (no interaction effect), (b) *compensatory* effects, i.e., children with worse quality in one learning