Summary

This thesis focuses on the process of automatization in children’s learning of simple additions and multiplications. There are large individual differences in the ability to store arithmetic facts in long-term memory. Especially children with mathematical difficulties are often unable to solve simple arithmetic problems with retrieval from memory. The research presented in this thesis aims to answer several questions that are related to automatization in mathematics.

In the first study, automaticity in basic number processing was studied in 7-, 8-, and 9-year-old children, as well as in adults (Chapter 2). Two experimental tasks were used that are known to cause the so-called SNARC (spatial-numerical association of response codes) effect in adults. The SNARC effect refers to the finding that small numbers facilitate left responses, whereas larger numbers facilitate right responses. In the first task, number magnitude was essential to perform the task. In this task, a SNARC effect was found in all age groups. In the second task, number magnitude was irrelevant. In this task, a SNARC effect was found only in 9-year-olds and in adults. The findings are taken to suggest that (a) 7-year-olds represent number magnitudes in a way similar to that of adults and that (b) when perceiving Arabic numerals, children have developed automatic access to magnitude information by around 9 years of age.

It is often assumed that the ability to estimate magnitude and quantity is related to skill in mathematics. The development of numerical estimation and the relationship between numerical estimation and mathematical achievement was studied again in 7-, 8-, and 9-year-old children (Chapter 3). Four domains of numerical estimation were tested: number line, numerosity, length, and area. Principal components analysis revealed two different factors: (1) estimation of length and area, (2) number line and numerosity estimation. The two factors corresponded to different developmental trajectories over grades. Mathematics achievement scores correlated with 3 of the 4 estimation domains in 7-year-olds, but the relation between estimation and mathematics disappeared in higher age groups. It is concluded that estimation skill and general ability in mathematics are more intertwined in younger children than in older children.

In the three studies described next, the acquisition of arithmetic facts is studied with a learning task design. In Chapter 4, children practiced simple addition problems with three different methods: (a) writing down the answer, (b) choosing between two alternative answers, and (c) filling in the second missing addend. On a test with simple addition problems, children who practiced with the Choice method showed positive transfer: choosing between two answers was about as effective for learning addition facts as the conventional method of writing down the answer. There was no transfer effect for children who practiced with the Missing Addend method. The results are in accordance with network theories on

arithmetic fact learning and specifically the Identical Elements (IE) model of arithmetic fact representation. The IE model predicts no positive transfer when the numerical elements of a test problem do not match exactly with those of a practice problem.

The second practice study takes a closer look on transfer effects in children's arithmetic (Chapter 5). In two experiments, children practiced simple addition or multiplication problems. A positive transfer effect was found for problems with an operand order change; improvement was just as high as for practiced problems. No transfer effect was found for problems with one of the operands increased with one unit; improvement did not differ from problems unrelated to the practice problems. Analogous results were found for addition and multiplication, suggesting that storage and retrieval processes in both domains are highly similar in children.

The last practice study tries to find an explanation for the observation that some children seem to learn arithmetic facts almost automatically and other children keep struggling with basic addition and multiplication (Chapter 6). Recent research has shown that individual differences in working memory, counting speed, and rapid automatized naming are related to mathematical ability. In two experiments, children practiced simple addition or multiplication problems. The results showed that most children improved on the practiced problems. It was not possible to predict individual learning effects on the practice task from differences between children on measures of cognitive processing. However, correlational analyses revealed that Digit span forward, Digit span backward, Counting speed, and Rapid automatized naming seem to be related to mathematical ability. Furthermore, a domain-specific relationship was found between verbal short-term memory span and mathematical ability.

In the General discussion (Chapter 7), the findings of the research presented in this thesis are summarized and discussed.