Chapter 6

General discussion
This dissertation aimed to answer the following main research questions: (1) To what extent are motor performance and EF related in 3- to 5-year-old children? and (2) to what extent does the operationalization of motor performance and EF influence their manifest and latent relationships? In this final chapter, the findings are summarized and discussed, including the limitations of the four studies and their implications for research and practice.

**Main findings**

We conducted a systematic literature review (Chapter 2) to provide insight into the relationship between motor performance and EF in young typically developing children and children with DCD, and the influence of the type of EF task response on this relationship. The results of this review unfolded highly variable correlations between motor performance and EF tasks with most of the correlations ranging from weak to moderate, regardless of developmental status (i.e., typically developing or DCD). The type of EF task response (i.e., motor or verbal) did not seem to affect the strength of correlations between motor performance and EF. This suggests that the strength of correlations between motor performance and EF cannot be attributed to the overlap in motor demands between the motor and EF tasks. However, it should be noted that the EF tasks requiring a motor response included only minimal motor loads.

Chapter 3 compared the motor performance of 3- to 5-year-old children on the ZNA-2 and MABC-2. On a general level, we found a moderate relationship between the total scores of the ZNA-2 and MABC-2. The strength of relationships between specific motor skill components of the ZNA-2 and MABC-2 varied from none to moderate. As expected, the strength of relationships between the pure motor skills component of the ZNA-2, measuring motor abilities, and the MABC-2 components (manual dexterity, aiming and catching, and balance), measuring motor skills, were none to weak. Analysis on item-level showed none to moderate relationships between individual items of fine motor skills and balance of both assessment tools. The findings suggest that the ZNA-2 and MABC-2 measure partly similar and partly distinct aspects of motor performance. Thus, the ZNA-2 and MABC-2 may provide different and complementary information regarding a child's motor performance. As the ZNA-2 is expected to be less dependent on practice and is also focused on the development of motor abilities (Kakebeeke et al., 2021), the ZNA-2 may detect different children as having motor coordination difficulties than the MABC-2.
Chapter 4 focused on the relationship between motor performance and EF in 3- to 5-year-old children on a spectrum of motor performance, thus including typically developing children and children at risk for motor coordination difficulties. Several weak-to-moderate relationships were found between motor performance and EF. Motor performance was measured with the MABC-2, a performance-based measure. EF was measured with the BRIEF-P, a rating-based measure. Once the confounding variables age, gender, ADHD symptomatology, and SES were taken into account, the only EF subscale of the BRIEF-P that was related to the MABC-2 Total Score was the Working Memory subscale. The comparison between the typically developing children and the children at risk for motor coordination difficulties with regard to EF scores (partly) confirmed these results. That is, children at risk for motor difficulties showed significantly worse scores on the Working Memory and Planning/Organize subscale of the BRIEF-P. No significant differences were found for the Inhibition, Shifting, and Emotion Regulation subscales.

Chapter 5 aimed to provide more insight into task-specific and latent relationships between motor performance and EF in 3- to 5-year-old children on a spectrum of motor performance. Motor performance was assessed with the MABC-2. EF was assessed with the performance-based tasks ‘Day/Night,’ ‘Hand Tapping,’ ‘Forward Corsi Block,’ ‘Forward Digit Recall,’ and ‘Conflict Task,’ and a rating-based EF measure (i.e., the BRIEF-P). Pearson correlation analyses showed statistically significant albeit weak correlations between specific motor and EF items. Structural Equation Modelling showed non-significant weak relationships between a general motor factor (as a unitary latent construct) on the one hand, and performance-based EF and rating-based EF (as latent EF components) on the other hand. The results indicate that both task-specific as latent relationships between motor performance and EF are weak in 3- to 5-year-old children.

Chapters 4 and 5 showed that there were no-to-weak relationships between motor performance and rating-based EF. When EF was measured with performance-based measures, highly varying relationships between motor performance and EF were found with most of the correlations ranging from none to moderate (Chapter 2). The results of Chapter 5 showed that the type of EF measure (i.e., performance-based or rating-based) does not seem to affect the strength of the relationship between motor performance and EF. However, the highly varying correlations between motor performance and performance-based EF imply that the relationship between motor performance and EF might be dependent on the kind of performance-based EF measure, such as whether inhibition is measured with a Stroop like task or with a Go/NoGo task (Chapter 2).
All in all, the included studies in the dissertation suggest that weak relationships exist between motor performance and EF in 3- to 5-year-old children (Chapters 2, 4, and 5). The type of EF task response (i.e., motor or verbal) and the type of EF measure (i.e., performance-based or rating-based) seems to have little effect on the relationship between motor performance and EF.

**General reflections**

The low to modest relationships that were found between the ZNA-2 and MABC-2 (Chapter 3) may be explained by different task demands imposed on the child. Stemming from Newell’s theory of constraints, the production of movement is influenced by characteristics of the individual, the environment, and the task (Adolph & Hoch, 2019; Newell, 1986). Derived from this theory, differences in task demands were considered to be a reason why the relationships were found to be modest between items that at first sight seemed comparable. The low to modest relationships between the items and components of the ZNA-2 and MABC-2 suggest that they provide different and complementary information regarding a child’s motor performance.

Weak relationships between specific motor and EF items and weak latent relationships suggest that motor performance and EF may be largely distinct developmental domains in 3- to 5-year-old children. The weak relationships found in this dissertation may be explained by the fact that early development is characterized by non-linearity. For some children increases in performance in one developmental domain may be accompanied by decreases in performance in other developmental domains because the child has to divert energy toward the emerging skill at the expense of other skills (Ben-Sasson & Gill, 2014), whereas for other children increases in performance in one developmental domain are accompanied by increases in performance in other developmental domains. Due to non-linearity of development, cross-sectional studies measuring motor performance and EF at the same time point may, therefore, not find a relationship or may even find a negative relationship. However, it is possible that the relationship between motor performance and EF does exist longitudinally. Several empirical studies have supported a longitudinal relationship between motor performance and EF. For example, Piek et al. (2008) found that infant gross motor performance was strongly related to working memory at 6 to 11 years of age. Wu et al. (2017) found that gross motor performance at 2 years of age was strongly related to inhibition at 3 years of age and fine motor performance at 2 years of age was moderately related to inhibition at 3 years of age. Roebers et al. (2014) showed
that fine motor performance and EF were reciprocally moderately related in a sample 5- to 6-year-old children over a period of one year. Thus, although there seems to be only a weak relationship between motor performance and EF cross-sectionally in young children as shown in this dissertation (Chapters 2, 4, and 5), these developmental domains may still influence each other recursively over time due to cascading effects (Roebers et al., 2014).

In Chapter 2, we examined whether the relationship between motor performance and EF was influenced by the type of EF task response. One of the reasons why the type of response demands used in specific EF tasks (i.e., motor or verbal) did not explain the varying relationships between motor performance and EF could be that motor demands included in EF tasks requiring a motor response are less apparent than expected (see Chapter 2). The theory of automaticity suggests that tasks involving automatized and well-learned motor skills require limited use of EF, but that EF is especially required in motor tasks that are either novel, require a fast response, or when conditions and demands of a motor task change (Ackerman, 1988; Diamond, 2000; Floyer-Lea & Matthews, 2004). Thus, EF tasks requiring a complex motor response may be more difficult because of the higher cognitive load than EF tasks requiring a simple motor response. In early childhood, some motor demands are expected to be experienced as more difficult than other motor demands. For example, pencil skills are not yet fully developed in early childhood (Lin et al., 2017), which may hamper the actual execution of the EF task. However, motor demands such as pointing or pushing a button are automated in most young children and may only have a limited influence on the execution of EF tasks. Unfortunately, we could not unravel the differential effect of the level (i.e., complex or simple) of the motor response of EF tasks on the relationship between motor performance and EF, because of only one correlation with an EF task requiring a complex motor response in the data.

In line with the theory of automaticity, it could also be argued that the relationship between motor performance and EF may depend on the complexity of the actual motor task. For example, Maurer and Roebers (2019) showed stronger relationships between complex motor tasks (i.e., adapted tasks of the MABC-2 and KTK) and EF than between simple motor tasks (i.e., original tasks of the MABC-2 and KTK) and EF in children aged 5 to 6 years. Most of the studies that were part of the review data linked a latent component of motor performance to specific EF tasks (Chapter 2). It may be possible that the specific motor tasks, as part of the latent component of motor performance, are differently related to the specific EF tasks because of the differential complexities of the motor tasks that require different loads of EF.
The relationship between motor performance and EF could be regarded as complex, with many child and environmental factors influencing each of these domains and their relationship. With respect to child factors, previous studies have demonstrated that gender, attention, and ADHD symptomatology attenuated the relationship between motor performance and EF (Houwen et al., 2017; Piek et al., 2008; Wassenberg et al., 2005). In addition, several studies have mentioned possible moderating effects of gender, non-verbal intelligence, reaction time, visual perception, and fitness (Aadland et al., 2017; Gandotra et al., 2021; Michel et al., 2018). In other words, the relationship between motor performance and EF seems to be stronger in children with certain characteristics than in children with other characteristics. As a consequence, the need for motor and/or EF intervention may be different for different subgroups of children. However, hardly any studies examined the possible confounding and moderating roles of environmental factors on the relationship between motor performance and EF. Previous studies on the influence of environmental factors on motor performance and EF provide support for environmental factors playing confounding and moderating roles in the relationship between motor performance and EF. For example, empirical studies have shown that mothers’ educational level, presence of siblings (Venetsanou & Kambas, 2010), availability of motor play materials (Barnett et al., 2013; Saccani et al., 2013; Valadi & Gabbard, 2020), and physical space inside the home (Saccani et al., 2013; Valadi & Gabbard, 2020) were related to motor performance in early childhood. Furthermore, empirical studies have shown that more attachment security (Bernier et al., 2012), autonomy support, maternal sensitivity, mind-mindedness (Bernier et al., 2010), and parents’ EF-specific practices with children (Korucu et al., 2019) were related to better EF in young children. Parents play an important role in creating situations that are supportive to the development of motor performance and EF, such as spending time with their children, promoting interaction with other children, providing space and safety for the children to move freely, and providing access to play materials (Freitas et al., 2013). Since child and environmental factors differ per child, with different experiences per child as a result, it is difficult to demonstrate relationships between motor performance and EF at a (general) group level. This is supported by embodied cognition theories which suggest that the relationship between motor performance and EF is shaped by features of the physical body and grounded in the unique experiences within the environment (Adolph & Hoch, 2019).
Limitations

Despite the rigorous attempts to provide the best possible test administration for young children, the data of the Chapters 3 and 5 contained quite some missing values. It is commonly known that assessing preschoolers is challenging due to fluctuations in behavior, attention, motivation, and mood (Malina, 2004; Williams et al., 2019). As a consequence, it is difficult for some young children to show their optimal functioning. We put forth our best effort to reduce the impact of the missingness by using methods such as multiple imputation and maximum likelihood estimation. These methods have shown to be beneficial in improving statistical power and reducing bias (Graham, 2009; Li et al., 2015). Unfortunately, we were not able to perform all analyses that we had planned, such as the examination of the relationship between motor abilities and EF, and whether EF is related differently to motor abilities than to motor skills. Consequently, we were not able to examine to what extent the operationalization of motor performance influences the relationship between motor performance and EF.

The study samples of Chapters 3, 4 and 5 have been recruited from the general population. However, it might still be possible that some of the children in these study samples have a developmental disorder. For example, DCD occurs in approximately 5 to 6 percent of children and ADHD occurs in approximately 5 percent of children (American Psychiatric Association, 2013). In the samples of Chapters 3 and 5, a relatively high percentage of 5-year-old children scored at or below the 16th percentile of the MABC-2, putting them at risk for having motor coordination difficulties. The research project might have unintentionally attracted parents who had concerns about their child's development resulting in relatively many children with developmental difficulties. Another explanation might be the high intra-individual variability in early motor development (Adolph et al., 2015; Piek et al., 2012). There is empirical evidence that 50 percent of young children scoring below a certain cut-off score on a standardized assessment of motor performance, putting them at risk for having motor coordination difficulties, scored average at a later point in time (Michel et al., 2018). We have also found that 50 percent of the children who scored at or below the 16th percentile of the MABC-2, putting them at risk for having motor coordination difficulties, scored average at a later point in time (Houwen et al., 2021). Therefore, the EACD recommends to base diagnostic conclusion on motor assessment on multiple time points to examine the stability of a young child’s developmental motor problems (Blank et al., 2019; Eldred & Darrah, 2010).
Implications and recommendations for future research

Based on our finding of highly varying relationships between motor performance and performance-based EF without an effect of the type of EF task response (Chapter 2), it is recommended to further explore the role of task demands on the relationship between motor performance and EF, such as the complexity of the motor response of EF tasks and the complexity of the actual motor tasks. This is important to be able to examine more pure relationships and provide explanations for the highly varying relationships between motor performance and EF that were found.

Furthermore, it is important to further examine the role of potential confounding, mediating, and/or moderating factors in the relationship between motor performance and EF in young children. In addition to the child factors that previous studies focused on (e.g., Michel et al., 2018), future research should focus on the potential confounding and moderating role of environmental factors in the relationship between motor performance and EF, such as mothers’ educational level, access to play materials, physical space inside the home, and parent-child interaction (e.g., maternal sensitivity, autonomy support).

Our findings of highly varying strengths of relationships between motor performance and EF in early childhood underscores the importance of subgroup analysis. Different relationships between motor performance and EF may exist in different subgroups of children, such as typically developing children and children with developmental disorders (e.g., DCD, ADHD, ASD, Non-Verbal Learning Disorder). It has been suggested that stronger relationships between developmental domains are to be expected in children with developmental disorders (Dyck et al., 2006). This is supported by the results of Chapter 4 showing that ADHD symptomatology, together with age, gender and SES, confounded relationships between the total motor score of the MABC-2 and EF domains. Subgroup analysis may unveil various relationships between motor performance and EF in different subgroups.

Finally, longitudinal research is needed to explore whether relationships between motor performance and EF in young children exist over time. If longitudinal relationships exist between motor performance and EF, motor coordination problems in early childhood could lead to EF problems at later ages.
Implications and recommendations for practice

The results of this dissertation offer several practical implications for practitioners working with young children. Since the relationship between motor performance and EF is only weak in 3- to 5-year-old children (see Chapters 2, 4, and 5), but EF problems exist in children with DCD (Lachambre et al., 2021), it is crucial for practitioners to comprehensively assess both motor performance and EF when there are concerns with regard to a child's development, and look at all of these scores in concert. Based on this developmental profile, a child's strengths and weaknesses can be identified to plan intervention or monitor progress. In addition, it is important to monitor all developmental domains conjointly and look at developmental patterns over time. For practitioners, it remains important to keep in mind that difficulties in one developmental domain (i.e., motor performance or EF) may affect the other (Dyck et al., 2006).

The findings of Chapters 2, 4 and 5 suggest that it may be important that children with both motor and EF difficulties receive intervention targeted at both developmental domains. In preschool settings, education should be focused on development as a whole. Both motor performance and EF are important predictors of later school success (Blair & Razza, 2007; Grissmer et al., 2010). However, because motor performance and EF are cross-sectionally only weakly related in 3- to 5-year-old children, it is of utmost importance that both developmental domains should be stimulated in early childhood.

In research and practice we want to understand development as early as possible in order to be able to intervene children with developmental delays in a timely manner. It, however, is challenging to assess young children's true capabilities due to fluctuations in behavior, attention, motivation, and mood (Malina, 2004; Williams et al., 2019), as was also experienced by the testers of the studies of Chapters 3 and 5. In order to gain insight in a young child's true capabilities, it is important to obtain a comprehensive picture of the strengths and weaknesses of a young child's functioning by using a holistic approach, that is, using rating-based and observational methods in addition to performance-based measures.