Chapter 1

General introduction
Early childhood is seen as a time of tremendous growth and development, with the young body and mind changing at an unprecedented rate (McCartney & Phillips, 2006). More specifically, both motor skills and executive functions follow a similar developmental timetable with substantial changes in the age period from 3 to 5 years (Howard et al., 2015; Piek et al., 2012), which may suggest that motor development influences the development of executive functioning (EF) and vice versa. Therefore, the age period 3 to 5 years is an important time to examine the relationship between motor performance and EF. Although the relationship between motor performance and EF has been actively studied in 3- to 5-year-old children (e.g., Cook et al., 2019; Michel et al., 2018), it is still not clear-cut why some studies found relationships between both domains in young children while others did not. Obviously, the relationship between motor performance and EF is complex and requires further examination. An unresolved challenge in capturing the complexity of the relationship between children’s motor performance and EF is finding measures that effectively assess the constructs of interest (McClelland & Cameron, 2019). This dissertation aims to gain more insight into the relationship between motor performance and EF in 3- to 5-year-old children, with a specific focus on the effect of the operationalization of motor performance and EF on their manifest and latent relationships.

Definition of terms and constructs

**Motor performance**

Motor performance can be defined as “observable goal-directed movement produced by voluntary actions or motor skills based on underlying motor abilities (Burton & Miller, 1998, p. 43; Schmidt & Wrisberg, 2008, p. 11). It includes planning, organizing, monitoring, and controlling motor coordination (Roebers & Kauer, 2009). Motor skills can be seen as the qualitative expression of a specific movement pattern (Burton & Miller, 1998, p. 43) and subdivided into fine and gross motor skills. Fine motor skills involve small muscle movements that occur in the hand, fingers, and/or arms and also include eye-hand coordination, such as in cutting and drawing (Exner, 2001; Luo et al., 2007; Magill, 1996). Gross motor skills involve large muscle movements, such as running and jumping (Burton & Rodgerson, 2001). Furthermore, motor abilities can be viewed as general traits or capacities that underlie the performance of a variety of motor skills (Burton & Miller, 1998, p. 43). However, the distinction of motor abilities and motor skills is not always clear. For example, as motor abilities underlie motor skills, they are inherently part of motor skills.
Executive functioning

There is currently no univocal scientific consensus on the definition of EF (Baggetta & Alexander, 2016), but it is often defined as a set of higher-order cognitive processes that contribute to effortful, purposeful, and problem-solving behavior by controlling and regulating thoughts, actions, and attention (e.g., Carlson et al., 2016; Diamond, 2013). Customarily, EF is comprised of three core components: inhibition, working memory, and cognitive flexibility (Diamond, 2013; Miyake et al., 2000). Diamond (2013) defined inhibition as the ability to control one’s attention, behavior, thoughts, and emotions to override inappropriate responses, and instead do what is more appropriate or needed, working memory as the ability to hold information in mind and mentally work with it, and cognitive flexibility as the ability to flexibly adapt to new demands, priorities, rules, or tasks.

There is an ongoing debate as to whether the three core EF components are already separable in early childhood (e.g., Karr et al., 2018). Factor analytic studies on the structure of EF in preschool children have shown inconsistent results. Most studies demonstrated a one-factor structure (Fuhs & Day, 2011; Masten et al., 2012; Shing et al., 2010; Wiebe et al., 2008, 2011; Willoughby et al., 2010, 2012). Other studies identified a two-factor structure with inhibition and working memory or working memory/cognitive flexibility as latent components (Lerner & Lonigan, 2014; Miller et al., 2012; Usai et al., 2014), or a three-factor structure with inhibition, working memory, and cognitive flexibility as latent components (Espy et al., 2004; Hughes, 1998; Monette et al., 2011). The variation in the number and nature of latent factors found may be due to the use of different EF tasks and age ranges of the children. In addition, cognitive flexibility tasks were not always included in the studies that examined the structure of EF (Lerner & Lonigan, 2014; Shing et al., 2010; Wiebe et al., 2008, 2011), which hampers the retrieval of a three-factor structure. A reason for not taking cognitive flexibility tasks into account might stem from the argument that cognitive flexibility emerges at the end of the preschool period (Garon et al., 2008; Müller & Kerns, 2015). To unravel the relationship between motor performance and EF in children aged 3 to 5 years, it is, as a consequence, irrefutable to include all three core components of EF.

The relationship between motor performance and EF

A relationship between motor performance and EF seems self-evident from a definitional point of view, as they both concern action control, such as monitoring, planning, and
sequencing of actions (Koziol et al., 2012). For example, quickly shifting the focus of attention is needed in fast changing situations (Tomporowski et al., 2015) such as learning to cycle or playing tag.

It is notable that since the last two decades there exists more and more theoretical and empirical evidence about the relationship between motor performance and EF. Embodied cognition theories offer a theoretical framework in which cognitive development (including EF) is grounded in sensorimotor development (Foglia & Wilson, 2013). According to these theories, cognition is developed through the bodily interaction between the child and the environment (Adolph & Hoch, 2019; Barsalou, 2008). Considered through such a lens, motor development provides children new opportunities for actively exploring their physical and social environment through ongoing perception-action cycles, which support cognitive development (von Hofsten, 2007). The acquisition of new cognitive capacities, in turn, allows for the acquisition of more varied and complex motor skills (Adolph & Hoch, 2019). The relationship between motor performance and EF, as part of cognition, is thus understood as being bidirectional and recursive over time.

In addition, support for a relationship between motor performance and EF has been provided by brain studies (e.g., Pangelinan et al., 2011). Brain studies have demonstrated that motor performance and EF share activation of common brain structures, such as the basal ganglia, cerebellum, and dorsolateral prefrontal cortex. These brain structures are co-activated when performing motor or EF tasks (Abe & Hanakawa, 2009; Hanakawa, 2011). Due to such a neurological overlap, it is suggested that stronger relationships exist between motor performance and EF in children with developmental disorders (Dyck et al., 2006). Empirical studies on motor and EF difficulties in children with neurodevelopmental disorders support this suggestion. For example, Leonard et al. (2015) and Wilson et al. (2013) identified EF difficulties in children with Developmental Coordination Disorder (DCD), a disorder characterized by motor coordination difficulties and has a significant negative impact upon the activities of daily living and academic performance (American Psychiatric Association, 2013). Also, children with Attention-Deficit-Hyperactivity Disorder, a disorder that is characterized by age-inappropriate, impairing and persisting levels of inattention and/or hyperactivity/impulsivity that negatively impacts children's functioning in academic, occupational or social settings, often show EF and motor difficulties (Craig et al., 2016; Kaiser et al., 2015).
Several studies have examined the relationship between motor performance and EF in 3- to 5-year-old children\(^1\) (Abuin-Porras et al., 2018; Alesi et al., 2019; Fang et al., 2017; Heibel-Witte, 2016; Lehmann et al., 2014; Livesey et al., 2006; Maurer & Roebers, 2019; Michel et al., 2011, 2018, 2019; Niederer et al., 2011; Roebers et al., 2014; Rosey et al., 2010; Stöckel & Hughes, 2016). These studies have shown inconsistent results with the relationships found varying from strongly positive\(^2\) (Alesi et al., 2019; Livesey et al., 2006) to even negative (Livesey et al., 2006; Michel et al., 2011; Stöckel & Hughes, 2016). However, mostly weak or moderate positive relationships were found (Abuin-Porras et al., 2018; Fairbairn et al., 2020; Fang et al., 2017; Heibel-Witte, 2016; Lehmann et al., 2014; Maurer & Roebers, 2019; Michel et al., 2018, 2019; Niederer et al., 2011; Roebers et al., 2014; Rosey et al., 2010; Stöckel & Hughes, 2016).

Comparing the results of the empirical studies on the relationship between motor performance and EF in 3- to 5-year-old children is difficult, because these studies have examined the relationship in different ways. First, previous studies on the relationship between motor performance and EF in preschool children have mainly focused on a limited set of motor performance and EF components. For example, some studies have linked only fine motor skills to the three core components of EF (Fang et al., 2017; Michel et al., 2011; Roebers et al., 2014), while other studies have linked only gross motor skills to one or multiple EF components (Cook et al., 2019; Heibel-Witte, 2016). Second, previous studies in preschool children have examined the relationship between motor performance and EF on varying levels or exclusively on one level (i.e., on an item-level or on a construct-level). Most studies have linked specific component scores of a motor test (on a construct-level) to specific EF task scores (on an item-level) (e.g., Alesi et al., 2019; Lehmann et al., 2014; Livesey et al., 2006; Michel et al., 2011), while some studies examined latent relationships between motor skills and EF by linking latent components of motor skills (that is, fine motor and/or gross motor skills) to a unitary latent factor of EF created from inhibition, working memory, and cognitive flexibility tasks (Maurer & Roebers, 2019; Oberer et al., 2017; Roebers et al., 2014). Fourth, previous studies have used many different motor and EF measures, making it difficult to unambiguously compare the results between studies. In order to get a more comprehensive and fine-grained view of how motor performance and EF are related in 3- to 5-year-old children, it is important to include a comprehensive

\(^1\) Some of these studies also include 6-year-old children (Alesi et al., 2019; Fang et al., 2017; Heibel-Witte, 2016; Lehmann et al., 2014; Livesey et al., 2006; Maurer & Roebers, 2019; Michel et al., 2011, 2018, 2019; Roebers et al., 2014; Stöckel & Hughes, 2016).

\(^2\) In this dissertation the relationship between motor performance and EF is considered positive when better motor performance is related to better EF. Their relationship is considered negative when better motor performance is related to worse EF.
variety of motor skills and executive functions and focus on both task-specific as well as latent relationships between motor performance and EF. Indeed, another challenge in capturing the complexity of the relationship between children's motor performance and EF is finding measures that effectively assess the constructs of interest (McClelland & Cameron, 2019).

**Operationalization of motor performance and EF**

**Motor performance**

There are several different approaches to motor assessment stemming from different frameworks (Wilson, 2005). For example, assessment based on the normative functional skill approach focuses on functional motor skills, which are motor skills essential for daily living in the home, school, community, and/or recreation and leisure environment (Wilson, 2005). Assessment tools based on the neurodevelopmental theory include tasks representing motor abilities which reflect internal neurological and neuromotor processes and thus provide information about the neurological basis of a child's motor functioning (Largo et al., 2001). It is suggested that tasks measuring motor abilities are not easily modified by experience or practice and are relatively stable across the lifespan (Burton & Miller, 1998).

As a result of varying theoretical frameworks, motor performance has been operationalized in many different ways (Bonney & Smits-Engelsman, 2019). It is thus not surprising that there are also several assessment tools available to measure motor performance in 3- to 5-year-old children (Piek et al., 2012). These assessment tools may vary in the inclusion of the content and amount of items. Some motor assessment tools focus on gross motor performance (e.g., Kiphard & Schilling, 2007; Ulrich, 2013). Others focus on both fine and gross motor performance (e.g., Bruininks-Oseretsky Test of Motor Proficiency-2, MABC-2, ZNA-2). Unlike other motor assessment tools, the MABC-2 and ZNA-2 are both comprehensive instruments for assessing motor performance by focusing on both fine and gross motor performance, and both cover the entire age range 3 to 5 years. The MABC-2 and ZNA-2 are both based on the normative functional approach (Wilson, 2005); that is, they both yield a quantitative measure (e.g., response time, proficiency rating, and accuracy scores) that indicates performance level (norm-referenced), and they both focus on functional motor skills. In addition, the ZNA-2 is also partially based on assumptions of the neurodevelopmental theory; that is, it also includes tasks representing motor abilities (Kakebeeke et al., 2018), which reflect internal neurological and neuromotor processes.
and thus provide information about the neurological basis of a child’s motor functioning (Burton & Miller, 1998). Hence, the ZNA-2 and MABC-2 may provide different information about a child’s motor performance.

**Executive functions**

EF can be assessed by performance-based measures that focus on processing efficiency or by rating-based measures that focus on goal pursuit in everyday situations (Toplak et al., 2013). The choice of an EF measure may thus result in assessing different EF constructs. For example, a child may show good EF in standardized and structured situations with very few distractions, but has difficulty with EF in everyday less structured situations with many distractions. In other words, a child may thus perform well on performance-based measures but low on rating-based measures. Empirical studies comparing performance-based with rating-based EF measures in preschool children have, however, shown inconsistent results with correlations varying from zero to moderate (Garon et al., 2016; Loe et al., 2015; Miranda et al., 2015). Thus, research until now indicates that the extent to which performance-based and rating-based EF measures assess different or similar aspects of EF in this age range remains unclear. Additionally, the relationship between motor performance and EF has been thus far examined almost exclusively through performance-based assessments. It can be concluded that a comprehensive picture of how performance-based and rating-based measures of EF are related to motor performance in young children is lacking.

One of the most frequently cited challenges of assessing performance-based EF is that multiple processes, both EF and non-EF related, contribute to individual differences in the actual EF task performance (Zelazo et al., 2016). Many, if not all, EF tasks require multiple executive functions (Baggetta & Alexander, 2016). For example, the Day/Night task is typically described as an EF task measuring both inhibition and working memory, because inhibition of the first response entails holding the task rules in mind (Garon et al., 2008; Gerstadt et al., 1994). In addition, non-EF related processes may be implicitly tapped by EF tasks, such as motor performance (McClelland & Cameron, 2019). For example, fine motor skills are required in tasks such as the TRAILS-P in which children are asked to draw a trail from the smallest mouse to the biggest mouse, connecting with each mouse's cheese before proceeding to the next mouse (Monette et al., 2015), or the Knock-tap task in which children are asked to respond by knocking when the tester taps the table and vice-versa (Luria, 1980). Therefore, it could be questioned whether EF tasks requiring
a motor response also unintendedly measure motor performance. Subsequently, the relationships between motor performance and performance-based EF might be inflated due to the overlap in motor demands between the motor and EF tasks. It is still unclear to what extent motor demands in EF tasks play a role in the relationship between motor performance and EF.

In sum, the choice of measurement influences what aspect of motor performance or EF is examined. Subsequently, different measurement choices may lead to the examination of different relationships between motor performance and EF.

Relevance of the study

Gaining more insight into the relationship between motor performance and EF in preschool children has both scientific and practical relevance. Understanding the relationships between these developmental domains and the role of their operationalization provides clinicians and researchers with a critical perspective for the choice of motor and EF measures in the context of clinical and research diagnostics. Furthermore, it provides information whether assessment in children with motor coordination difficulties should be focused on only (specific domains of) motor performance, because of no expectation of a generic effect on other developmental domains, or also on specific domains of or general EF due to the expectation of generic negative effects on other developmental domains. Also, it provides information if development of the other domain and what aspects of that domain should be monitored in addition to the development of the domain that a child has a delay in. In addition, insight in the role of operationalization of motor performance and EF on their relationship is critical to the design of early interventions for children with motor coordination difficulties and/or EF difficulties. More specifically, it provides information whether interventions should be focused on only one developmental domain (i.e., motor performance or EF) or on both.

Aim and outline of the dissertation

The aim of this dissertation is to gain insight into the relationship between motor performance and EF in children aged 3 to 5 years, with a specific focus on the effect of the operationalization of both developmental domains on their relationship. This dissertation attempts to answer the following main research questions: (1) To what extent are motor performance and EF related in children aged 3 to 5 years?, and (2) to what extent does operationalization of motor performance and EF influence their relationship? In order to
understand how different operationalizations of motor performance and EF affect their outcomes and their relationship, the following studies were carried out:

- Chapter 2 describes the results of a systematic literature review focusing on the effect of response demands of EF tasks on the relationship between motor performance and EF in 2- to 6-year-old children with and without developmental disorders.
- Chapter 3 focuses on the operationalization of motor performance. The motor performance of 3- to 5-year-old children on the ZNA-2 and MABC-2 are compared.
- Chapter 4 presents the findings of a study on the relationship between motor performance and rating-based EF in 3- to 5-year-old children. In addition, potentially confounding variables (i.e., age, gender, SES, and ADHD symptomatology) are taken into account.
- Chapter 5 concentrates on the multi-level nature of the relationship between motor performance and EF in 3- to 5-year-old children. A range of motor skills (i.e., manual dexterity, aiming and catching, and balance skills) and EF (i.e., inhibition, working memory, and cognitive flexibility) are included. In addition, different operationalizations of EF are included (i.e., performance-based and rating-based measures).
- Chapter 6 presents the general discussion in which the findings of the different studies are combined and discussed. Reflection on the studies, implications for future research and clinical practice are provided.