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ANTICIPATORY PLANNING IN CHILDHOOD

The development of anticipatory planning and its relationship to executive functions

Dissertation Thesis

in partial fulfillment of the requirements for the degree of doctor philosophiae (Dr. phil.) at the Faculty of Natural Sciences at the University of Paderborn

Anticipatory planning in childhood

The development of anticipatory planning and its relationship to executive functions

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The work described in this thesis originated between 2010 and 2014 in the research group of Prof. Dr. Matthias Weigelt. Until October 2011, the work originated in the Sport Psychology and Movement Science Unit at the Institute of Sport Science at Saarland University, from October 2011 until closing of the doctoral studies in the Sport Psychology Unit at the Department of Sport & Health at the University of Paderborn.

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To my father

† 27.12.2012

Contents

Abbreviations (alphabetical)

ABC	anticipative behavioral control
BRIEF	Behavioral Rating Inventory of Executive Function
CNS	central nervous system
DOF	degrees of freedom
EF	executive functions
e.g.	exempli gratia (for example)
ESC	end-state comfort
etc.	et cetera (and so on)
i.e.	id est (that is)
IMP	ideomotor principle
TEC	theory of event coding
TOH	Tower of Hanoi
ZNA	Zurich Neuromotor Assessment

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Summary

The end-state comfort (ESC) effect is an important aspect of anticipatory behavioral control. It reflects a person's strategy to avoid uncomfortable body positions at the end of movements. As the focus of previous studies primarily laid on young adults, there are only few studies on the ESC effect in children, which show divergent findings. By means of the systematic review (Chapter 2), possible reasons for these inconsistent findings were provided (e.g. age effects, the number of action-steps, precision requirements, or task differences). One assumption provided in the systematic review was examined in Chapter 3. This assumption implied that motor development relies on the development of cognitive control, mainly on the development of executive functions. Therefore, a test battery was designed, consisting of three motor tasks to measure ESC and three cognitive tasks to measure executive functions. Nevertheless, results were not able to approve the assumption. An important finding was that the performance in the different motor and cognitive tasks were not related to each other, suggesting an interindividually different developmental trajectory for each of them. The focus of future studies should rely on the examination of potential constraints on ESC planning, like those outlined in Chapter 2, which possibly influenced the developmental trajectories of the ESC effect in childhood and caused the inconsistent findings in the studies reviewed. Moreover, causes should be detected for the fact, that the tasks used in Chapter 3 were not related to each other. Another focus should be on the influence of other executive functions, like inhibition, on the development of ESC.

Zusammenfassung

Der End-State Comfort (ESC) Effekt als Aspekt antizipativer Verhaltenskontrolle spiegelt die Strategie einer Person wider, unangenehme Körperpositionen am Bewegungsende zu vermeiden. Bisher existieren nur wenige Studien zum ESC Effekt im Kindesalter, welche divergente Ergebnisse aufweisen. Mit Hilfe eines systematischen Reviews (Kapitel 2) konnten als mögliche Ursachen für diese inkonsistenten Befunde z.B. Alterseffekte, die Anzahl an nötigen Handlungsschritten, der Grad an erforderlicher Präzision, oder Unterschiede im Untersuchungsablauf, deklariert werden. In Kapitel 3 wurde eine weitere Annahme geprüft, welche besagt, dass die motorische Entwicklung auf der Entwicklung kognitiver (bzw. exekutiver) Funktionen beruht. Mit Hilfe einer Testbatterie, bestehend aus je drei Aufgaben zur Messung antizipativer Handlungskontrolle und zur Messung exekutiver Funktionen, konnte diese Annahme jedoch nicht bestätigt werden. Interessant ist außerdem, dass die unterschiedlichen Tests innerhalb der einzelnen Altersgruppen ebenfalls nicht miteinander zusammenzuhängen scheinen, was für eine interindividuell unterschiedliche Entwicklung der einzelnen Fähigkeiten spricht. Der Fokus zukünftiger Studien sollte daher in der Erforschung der in Kapitel 2 dargestellten Ursachen für die inkonsistenten Befunde liegen. Weiterhin sollten Ursachen dafür gefunden werden, dass die in Kapitel 3 verwendeten Sub-Tests keine Korrelationen aufweisen. Ein weiterer Fokus sollte auf dem möglichen Einfluss weiterer kognitiver Funktionen, wie z.B. der Inhibition, liegen.

Chapter 1

General introduction

Motor behavior is essential in people's everyday lives. In the first minutes of every morning, people implement a countless number of actions. First, one will wake up, open his/her eyes, before one will stretch him-/herself. Then sit up in bed, take out the feet, get up, walk into the kitchen in order to have a coffee, and so on. Obviously, one could continue this enumeration endlessly. Grasping is one of the basic motor skills everyone performs within these daily life activities. It is an observable outcome of motor behavior, which helps to attain action goals. Therefore, simply the action of drinking a coffee in the morning involves several grasping actions. Being in the kitchen, one needs to *grasp* the handle of the cabinet to open it, *grasp* a cup from its inside and place it under the machine, *grasp* the box with the coffee filters to put one into the machine, *grasp* the coffee box to put some coffee into the filter, press the button, *grasp* the handle of the refrigerator to open it, *grasp* for the milk to pour it into the cup, and so on. As one can see, there are a lot of grasping actions involved solely in the first few minutes of a day. Usually, people do not really "think" about what they do or how they grasp, this behavior is like an automatic mechanism in response to a stimulus. There are many ways to grasp the cup and to take it out of the cabinet, and this variety of grasping actions is accounted for in the degrees of freedom problem.

Independent of the action that has to be performed, the process of response selection implies the problem that a person involved in this process has to decide for one particular movement or a combination of movements although he or she has many alternative solutions. To get the cup out of the cabinet, no matter in which position it is in there, there are a lot of different solutions, including different hand orientations, movement trajectories, or grip strategies, for instance. This issue is traced back to what Bernstein (1967) referred to as the degrees of freedom (DOF) problem. Rosenbaum (2010, p. 12) gives an example for this problem, namely to "touch the tip of your nose". As in the action of grasping the cup, there are many different ways to tip your own nose. Solely for the movement of the arm there are seven different possibilities: three DOF in the shoulder, two in the elbow and two in the hand. The combination of these DOF lead to a great number of possible reaching strategies depending on arm position (Rosenbaum, Meulenbroek, & Vaughan, 1996). Taking the fingers into account makes this number even higher. As explained in the following paragraphs, the selection of a movement is due to the anticipation of action goals and to constraints concerning movement economy.

Though the focus of the present dissertation thesis is on the acquisition of motor (and cognitive) skills, it is of interest, how the ability of such grasping actions mentioned above emerges. Therefore, a short overview of motor learning theories will be given in the next paragraphs. Motor learning is described as an experience dependent, lasting change of the competence to reach desired effects in different situations through a certain behavior (Mechling & Munzert, 2003, p. 133). In this definition, motor actions (responses) are related with situational conditions (stimuli) on the one hand and with situational modifications (effects) on the other hand. Therefore, motor learning theories can be divided into theories with a focus on stimulus-response associations, or with a focus on action-effect associations.

1.1. From intentions to actions – Goal-driven motor behavior

Ideomotor approaches state that actions start with intentions, and movements are generated to realize those intentions (Keller et al., 2006). Accordingly, the cause of actions does not only rely on a stimulus (i.e. the cup standing in the cabinet), but on the to-be-attained goal (i.e. take the cup out to have a coffee; Kunde, Elsner, & Kiesel, 2007). The basis for grasping the cup is the visuo-spatial perception of its location and orientation. Where is it in the cabinet, and in which position? Modern theories assume that action and perception are closely related to each other (e.g. the perception-action theory, Gibson, 1966; the dynamic systems theory, Thelen, & Smith, 1994; or the theory of neuronal group selection, Edelman, 1987).

To form an intention to reach any goal, an anticipation of the desired goal is needed (Gollwitzer, Fujita, & Oettingen, 2004). Think about the person standing in front of the cabinet, ready to take out the cup. Surely, this person has often performed and watched others performing the act of taking out the cup. Therefore, the knowledge of this action (or the visualization in a persons' mind's eye) can produce the same effects as the actual production of this action.

Considering two people sitting at a table, facing each other, with a cup and a jar of coffee on it, and one of these two people picks up the jar and pours coffee into the cup while the other one watches, then both people would have a very similar representation of the action according to the common coding theory (Hommel, Muesseler, Aschersleben, & Prinz, 2001; Prinz, 1990, 1997). The core postulate of this theory is that perception and action rely on common codes. These codes do not represent actions per se, but instead reflect the perceptual events that these actions produce. Because actions are coded in terms of their perceptual effects, perception and action occupy a common representational domain. Given these information, and think about only one person sitting at the morning table with the cup and the jar of coffee in front. It is likely, that this person has former information of perceived outcomes at his/her disposal. Solely these information can produce the same effect, which would be determined as anticipation then. This person has often seen the action of pouring coffee into the cup and drinking it, and has very often conducted this action him-/herself. Therefore, the knowledge of this action (or the visualization in his/hers mind's eye) can produce the same effects as the actual production of this action. This means, that an action is represented like a perceived action, which is stated in the theory of event coding (TEC; Hommel et al., 2001). This assumption is in the tradition of ideomotor approaches (Lotze, 1852; Münsterberg, 1888; James, 1890; for an overview see Stock & Stock, 2004).

According to the ideomotor principle (IMP; James, 1890), movements of the body become connected with their sensory consequences in a way that the mere image of such consequences receives the power to trigger those movements, which formerly brought them about. In other words, body movements become determined by anticipations of their own sensory consequences, and therefore, it is a premise that one can experience his/her motor abilities only indirectly through perception of achievable sensory effects, which accompany or follow the execution of actions.

To this end, people initially have to learn about the sensory effects, which can be produced through motor actions (Elsner & Hommel, 2001). With the integration of motor programs and action effects, a functional unit is built (sensorimotor units). These units represent actions and provide a person cognitive access to voluntary actions: The motor program can be activated through the anticipation of the desired consequences. Therefore, motor activity relies on intentional control. But what exactly do “motor programs” account for?

Keele (1968) introduced the term “motor programs” for executive action structures. He defines a motor program as “a set of muscle commands that are structured before a movement sequence begins, and that allows the entire sequence to be carried out uninfluenced by peripheral feedback” (Keele, 1968, p. 387). In this sense, motor programs involve entire actions, which are programmed previously. This assumption is supported by the fact that simple reaction time will increase when the response movement is of greater complexity (Henry & Rogers, 1960). Therefore, the theory proposed a “nonconscious mechanism that uses stored information (motor memory) to channel existing nervous impulses from brain waves and general afferent stimuli into the appropriate neuromotor coordination centers, subcenters, and efferent nerves […]” (Henry & Rogers, 1960, p. 448). Furthermore, it is supported by the observation of anticipatory effects. Regularly, one can observe evidence for the next action step clearly before the subsequent action step is completed. Remember the example of grasping a cup from the cabinet: If one would register the trajectory of the grasping action, then it would be observable that the to-be-grasped object (here: the cup) is already represented in one's grip strategy, like in the distance of the fingers, for example, which would be greater if one would like to grasp a bigger object (i.e. a coffee cup) instead of a smaller one (i.e. an espresso cup) (Jeannerod, 1981), or in the speed of the movement (Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1978), which will be lower if the grasping action requires great precision. The grasping hand therefore anticipates the object to-be-grasped, which assumes that the grasping of the object is programmed in advance before it is actually reached. The same can be observed after the grasping action: Previous studies have demonstrated that what an adult is going to do with an object after picking it up affects not only the posture of the fingers, but also the kinematics of the reach toward the object (Marteniuk et al., 1987).

To this end, motor behavior needs anticipation. The anticipation of movements is always about predicting the future, or expecting a future event, or imagining a future state or event and can be defined as “a process, or behavior, that does not only depend on past and present, but also on predictions, expectations, or beliefs about the future” (Butz, Sigaud, & Gérard, 2003, p. 4; Hoffmann, 2003, p. 3). To approach the questions about when and where anticipatory behavior is useful, Hoffmann formulated the anticipative behavioral control theory (ABC theory, Hoffmann 1993, 2003; Hoffmann, Stöcker, & Kunde, 2004; Hoffmann et al., 2007), which will be derived below.

Most of the behavior in our everyday lives is goal directed. According to the IMP, human behavior is not triggered by stimuli, but by to-be-produced effects. Therefore, behavioral acts have to be connected to the effects they produce; otherwise it is impossible to see how an anticipated effect can affect our behavior. In contrast to behaviorism, the ABC theory assumes that behavioral competence relies predominantly on the acquisition of action-effect associations rather than stimulus-response associations (Hoffmann 1993, 2003; Hoffmann et al., 2004; Hoffmann et al., 2007). It is stated, that any voluntary action (like the goal-directed grasping for the cup) is preceded by corresponding effect anticipations. This assumption is in accordance with the IMP mentioned above, which states that body movements become determined by anticipations of their own sensory consequences, and therefore, it is a premise that one can experience his/her motor abilities through the perception of achievable sensory effects. After the performance of the action, like grasping the cup and taking it out of the cabinet, the actual effect is compared to the anticipated effect.

This comparison is supported by the principle of reafference (von Holst & Mittelstädt, 1950). This principle denotes a prescribed process in the central nervous system (CNS) for the control of and response to a stimulus. If an efferent signal, which leads to an action, is sent from a superordinate nervous center (motor cortex), then an efferent copy is produced in a more subordinate nervous center (cerebellum). This copy is an internal copy of an efferent, movement-producing signal generated by the motor system. It is then compared with the reafferent sensory input that results from the movement, enabling a comparison of the actual movement with the desired movement, and a shielding of perception from particular self-induced effects on the sensory input to achieve perceptual stability. Together with internal models (Wolpert, Ghahramani, & Jordan, 1995), efference copies can serve to enable the brain to predict the effects of an action. So, if there is sufficient coincidence between what was desired and what really happened (i.e. holding the cup in a comfortable position to pour the coffee), then representations of the action and experienced effects become interlinked, or an already existing link is strengthened (James, 1890). The anticipation of effects is therefore represented as being appropriate to produce a desired action, taking the situational context into account. To sum up, the ABC theory takes the primacy of action-effect learning, as well as the conditionalization of action-effect relations into account, meaning that the same action can have different effects depending on environmental circumstances ((Hoffmann 1993, 2003; Hoffmann et al., 2004; Hoffmann et al., 2007).

Such anticipatory behavior can be observed in a lot of different everyday-life situations. Each time we switch on the radio, we anticipate that it will play some music, or if we press a door handle, we anticipate the door to open. Consider the example above, with the cup standing in the cabinet, it can be placed either with the opening facing upwards or downwards. Grasping the cup with the thumb pointing upwards will end in different end orientations, depending on the initial orientation of the cup. Thus, before reaching for the cup, we should anticipate the outcome of our chosen grasp, depending on the action to-be performed (i.e. pouring coffee into it). This assumption is accounted for in the end-state comfort (ESC) effect. Besides other factors (like the kinematics of the action, speed, or grip force; Marteniuk et al., 1987), the ESC effect is one possible measure, which signifies anticipatory planning in grasping actions.

1.1.1. The End-State Comfort Effect

When considering the grasping action described above, it is apparent that the control of this behavior is not haphazardly, but depends on different underlying mechanisms. Depending on the position of the cup in the cabinet (upright or upside-down), a thumb-up grip would result in two different grasping postures after the cup was taken out of the cabinet (in the same way, if the cup was standing upside-down, a thumb-up and a thumb-down grip would result in different outcomes). These options are depicted in Figure 1 below.

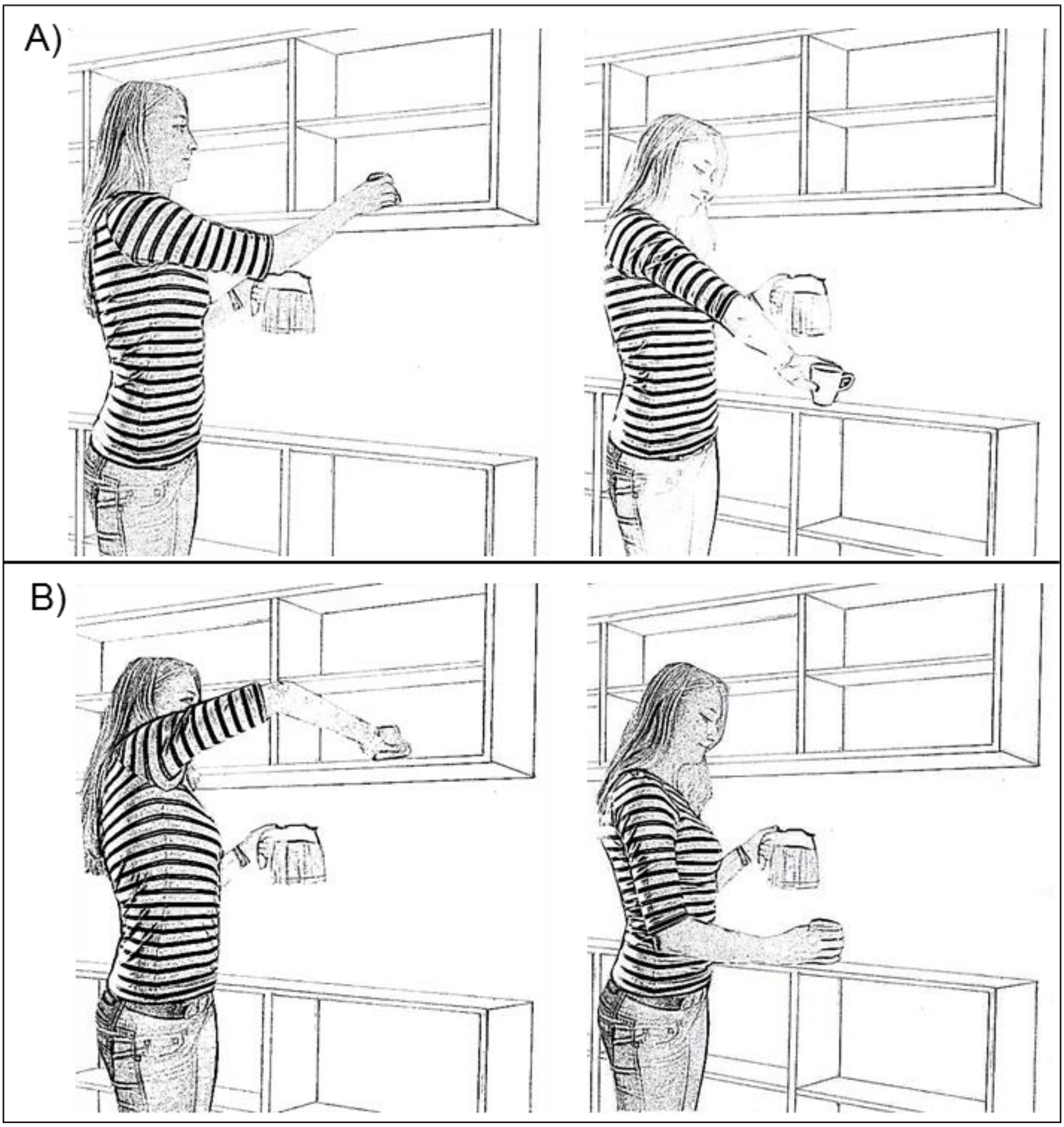

Figure 1. Different outcomes depending on start posture. A) An initially comfortable grasp results in an uncomfortable end-posture. B) Adjusting the grip at the beginning results in a comfortable end posture, enabling the person to pour coffee into the cup.

In Figure 1A), grasping the upside-down standing cup with a comfortable thumb-up grasp results in a very uncomfortable thumb-down position after taking it out of the cabinet, making it difficult to pour the coffee into it. But, when grasping with an initially uncomfortable grasp with the thumb pointing downwards (Figure 1B), a comfortable end position is reached, in which the coffee can easily be poured into the cup. This phenomenon, that people tend to avoid uncomfortable positions at the end of goal-directed movements, is called the ESC effect (Rosenbaum et al., 1990). Besides the above mentioned examples, this effect signifies anticipatory planning skills in many everyday-life tasks.

For the first time, the ESC effect was observed in a restaurant by David Rosenbaum. While he sat at the bar, he observed a waiter taking glasses out of a shelf, which were standing upside-down, as the cup in the example above. He noticed, that the waiter always used the initially uncomfortable thumb-down grasp (as depicted in Figure 1A) in order to put the glasses comfortably down onto the bar. Rosenbaum and his colleagues (1990) took this observation into laboratory. They designed the so called bar-transport-task, in which a horizontally oriented bar with one black and one grey end laid on two supports. This bar had to be placed on either a red or a blue target disc, which was placed to the right and to the left of the supports, respectively. Thereby, it was of interest, how participants reached for the bar, depending on the intended target location and position of the bar. Results revealed that right-handed participants chose a comfortable overhand-grip to place the right end of the dowel on the target (irrespective of bar and target color), and that they used an initially uncomfortable underhand-grip when the left end of the bar had to be placed on the target. The flexible selection of the initial grasp type allowed participants to end the object manipulation in a more comfortable thumb-up posture (as opposed to an awkward thumb-down posture), even if this meant to tolerate an awkward posture at the beginning of the action.

The ESC effect provides an efficiency constraint on motor planning (Rosenbaum, van Heughten, & Caldwell, 1996). The cognitive mechanisms underlying the effect have been sketched out in the posture-based planning account (Rosenbaum et al., 2007). According to this account, a set of stored postures is scrutinized for their usability in the upcoming action. Then, the best candidate stored posture is optimized to attain a better goal posture. Once a goal posture is selected, people form a specific movement to attain this goal posture. If an internal simulation of the planned movement shows any obstruction, the planned movement is reshaped by superimposing another, expedient movement on it. This movement is made from the starting posture to a planned “bounce posture”, and back to the starting posture again. If a movement is made in this way, from the start posture to the “bounce posture” and back, while the main movement is made from the start posture to the goal posture, the combined movement can have a shape that depends on all, the start posture, the bounce posture, and the goal posture account (Rosenbaum et al., 2007).

Several hypotheses have been raised to explain the ESC effect. Besides the “working backwards hypothesis” and the “fatigue hypothesis” (Rosenbaum et al., 1990), as well as the “minimizing time in awkwardness postures hypothesis” and the “exploiting potential energy hypothesis” (Houk & Rymer, 1981; Rosenbaum & Jorgensen, 1992; for an overview see Short & Cauraugh, 1999), the “precision hypothesis” is one possible explanation for the ESC effect (Rosenbaum, Vaughan, Jorgensen, Barnes, & Stewart, 1993). This hypothesis predicts that goal-directed positioning movements at or near the middle of the range of motion is easier than at or near the extremes and that precision increases, while being in a comfortable posture, and movements can be made more quickly within that range (Rosenbaum et al., 1996). The general prediction, which Rosenbaum and colleagues (1993) evidenced in their study, is that the likelihood of people showing the ESC effect is inversely related to the precision requirement of the task.

In a study conducted by Short and Cauraugh (1999), this prediction was examined. Participants had to point a horizontally suspended bar with one black and one white end onto one of fourteen different targets on a wall, which differed in height and in target width, resulting in a low precision condition and a high precision condition. The authors found that ESC (depending on awkwardness ratings) increased with increased precision requirements. Another study on the precision hypothesis conducted by Hughes, Seegelke, and Schack (2012) investigated the influence of precision demands at the start and at the end of movements. Here, participants had to reach for a bar, which was standing in a start-disc, and had to move it to the target disc with either hand. Precision requirements at the start and at the end of the movement were either identical (low-low, high-high) or different (low-high, high-low). Participants showed more ESC planning if the precision requirement at the end of the movement was high.

Since its discovery two decades ago (Rosenbaum et al., 1990), a growing body of research has shown the significance of the ESC effect on motor planning in healthy adults across a variety of either unimanual (e.g. Cohen & Rosenbaum, 2004; Rosenbaum & Jorgensen, 1992; Rosenbaum et al., 1990, 1996; Weigelt, Cohen, & Rosenbaum, 2007) or bimanual tasks (e.g. Fischman, Stodden, & Lehman, 2003; Janssen, Crajé, Weigelt, & Steenbergen, 2010; Weigelt, Kunde, & Prinz, 2006; van der Wel & Rosenbaum, 2010). It has also been investigated within different clinical populations, such as autism (Hughes, 1996), cerebral palsy (Crajé, van Elk, van Schie, Bekkering, & Steenbergen, 2010; Mutsaarts, Steenbergen, & Bekkering, 2006; Steenbergen, van Nimwegen, & Crajé, 2007), apraxia (Goldenberg & Hagmann, 1998; Randerath, Li, Goldenberg, & Hermsdörfer, 2009) or developmental coordination disorder (Smyth & Mason, 1997; van Swieten et al., 2010). Moreover, the ESC effect seems to affect action planning (even) in nonhuman animals, such as lemurs (Chapman, Weiss, & Rosenbaum, 2010), cotton-top tamarins (Weiss, Wark, & Rosenbaum, 2007), as well as in squirrel monkeys and tufted capuchins (Zander, Weiss, & Judge, 2013), and in chimpanzees (Frey & Povinelli, 2011). Besides these more general demonstrations of the ESC effect, recent studies started to focus on factors that modulate it, such as habitual vs. goal-directed factors (Herbort & Butz, 2011) or the degree of object rotation required (Hughes, Reißig, & Seegelke, 2011; Hughes et al., 2012; Seegelke, Hughes, & Schack, 2011). A summary of the findings pertaining to the ESC effect is provided in a recent review article by Rosenbaum and colleagues (Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012).

However, as mentioned above, the ESC effect is not the only phenomenon to examine anticipatory planning skills. Besides ESC, the grasp-height effect is another feature to measure anticipatory planning, which will be addressed in the next section.

1.1.2. The grasp-height effect

Given the example of the coffee cup above, showing that people tend to avoid uncomfortable final postures at the end of goal-directed movements, such an anticipation of future body postures can also be observed when this person puts the coffee box back into the kitchen shelf. When placing the box on a high shelf, one would grasp the box very low on its side and very high when it is brought to a low shelf in order to end the action as comfortable as possible, without the need to stretch oneself or to crouch down. Therefore, the future orientation of an object, which should be placed onto targets of varying heights, in order to end the action near the middle of their possible range of movement, is also anticipated. This so called “grasp-height effect” (Cohen & Rosenbaum, 2004), depicted in Figure 2, describes the tendency of people to choose a designated grasp-height on to-be manipulated objects, in order to end the movement in a most comfortable position.

Cohen and Rosenbaum (2004) investigated the grasp-height effect, asking their participants to grasp a plunger standing on the middle platform of a shelf and to bring it to another platform (a higher one, a lower one or one right beside the starting platform), and to bring it to the home platform back again. The authors found an inverse linear relation between target height and grasp height, revealing that participants grasped the plunger near its base, when transporting it to a high platform, and near the top, when transporting it to a low platform. But when participants returned the plunger from the target position to the home position, they did not fully display the grasp-height effect, as they grasped the plunger close to where they had grasped it before.

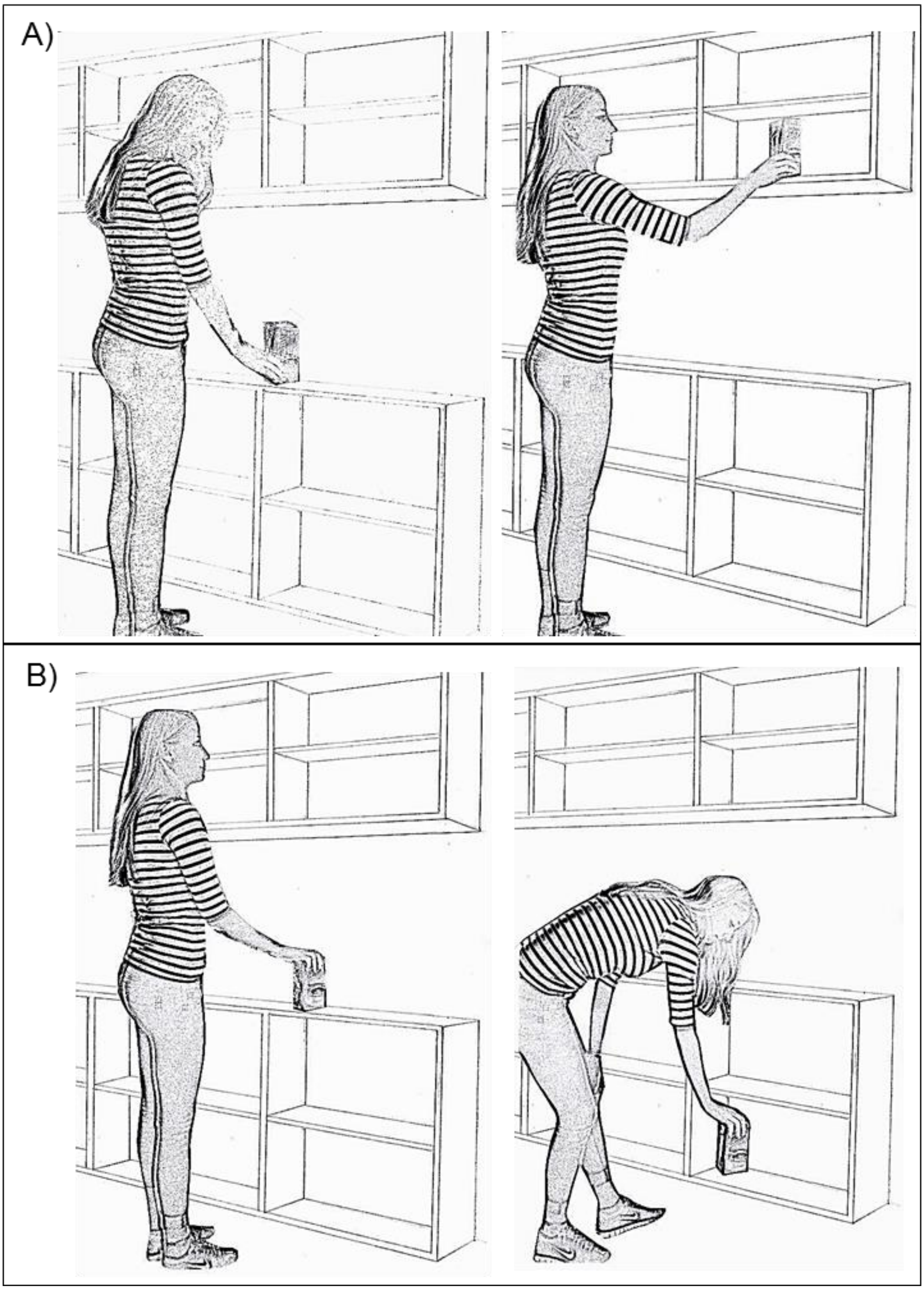

Figure 2. In the upper half, picture A) shows a person grasping the coffee box very low, in order to put it into a high shelf; in picture B), the person adjusts his/her grasp height, grasping the box on the top, when putting it into a lower shelf.

Rosenbaum, Halloran, and Cohen (2006) raised the precision requirements for this task by adding rings of varying diameters to the home platform and to the target platforms. Results showed that when more precision is needed (independent of the start position or the target position), the grasp-height effect was reduced and the grasp heights were lowered. Therefore, the grasp height is chosen to promote control, and not just comfort, but also reflects effects of memory, as was shown when the home platform, rather than the target platforms, was varied in height. Here, the grasp heights for the return moves were close to the position for the home-to-target moves and therefore, the target-to-home moves diverged in grasp-height from the mean grasp height and did not converge toward the mean grasp height. Participants in the study of Cohen and Rosenbaum (2004) may have relied on recall to choose grasp heights for target-to-home moves.

Weigelt and colleagues (2007) examined whether these recall strategies rely on postures (full body positions) or on locations (where the object was grasped). These authors used the same task as described above, with the difference, that participants had to take a sidestep after the home-to-target move, and to step either onto a platform, down from a platform or just horizontally. Results showed that participants grasped the plunger close to where they had grasped it in the home-to-target move, relative to the base of the plunger and therefore, used extrinsic rather than intrinsic coordinates for movement execution in these moves. These results can be explained by minimizing the DOF (see Chapter 1). The number of configurations (DOF) to-be stored when remembering a location is less than the number of configurations to-be stored in remembering a configuration of body postures.

1.2. The role of cognitive control in motor behavior

Motor behavior is a field of study, which is commonly examined in behavioral research. But only little attention is usually paid to the (cognitive) processes underlying these behavioral outcomes. One domain in which these links between cognition and action have been explored is the manipulation of objects. The results of studies on motor planning and the ESC effect mentioned above indicate that humans, as well as nonhuman animals, grasp objects in a way that reflects their intentions. The way, in which people (or animals) grasp an object, depends on what they plan to do with this object and on the position at which they grasp an object depends on the height where the object is planned to be positioned. Therefore, grasping actions are all about planning, and planning per se relies on cognitive control, which takes a multiplicity of factors into account. The fact, that cognitive control needs to be an underlying factor of efficient planning, is sustained by clinical studies, for example in participants, which suffer from cerebral palsy. Here, research showed that some of their motor problems do not only relate to movement execution, but also to motor planning (Mutsaarts et al., 2006). Furthermore, concomitance of object manipulation and memory tasks showed a reduced recall ability, which suggests that planning for grasping objects needs cognitive resources (e.g. Spiegel, Koester, Weigelt, & Schack, 2012; Weigelt, Rosenbaum, Huelshorst, & Schack, 2009; Logan & Fischman, 2011). The most important domain of cognition, which might be the driving force for anticipatory planning, is the domain of executive functions (EF). This assumption is made in recent literature (Rosenbaum et al., 2012; van Swieten et al., 2010) and can also be drawn from clinical research, as from cases of brain damage, like cerebral palsy. Here, motor and executive functions are impaired, which suggests a (anatomically) link between both functions (e.g. Mutsaarts et al., 2006; Steenbergen & Van der Kamp, 2004).

When looking for a generally applicable definition of EF, one will be stretched very soon to one’s limits, as there is no common definition. But what they all coincide about is that EF is an umbrella term, incorporating a collection of inter-related processes responsible for purposeful, goal-directed behavior (Gioia, Isquith, & Guy, 2001). They refer to higher order, self-regulatory, cognitive processes that operate the monitoring and control of thought and action, and are often described as control processes (Monsell & Driver, 2000). Processes associated with EF are numerous, but the principle elements include anticipation, goal selection, planning, inhibitory control, attention, attentional and mental flexibility, error correction and detection, the utilization of feedback, and resistance to interference (Dempster, 1992; Welsh, Pennington, & Groisser, 1992; Zelazo, Carter, Reznik, & Frye, 1997). Besides these processes, the executive system organizes learning processes and strategies for problem solving. Therefore, it is actively involved in conceptual thinking processes, decision making, and in the maintenance of anticipatory planning processes, as well as in the implementation of action, the chronological structuring of actions, and in error detection and correction (Andreasen, 2002; Baddeley & Della Salla, 2003; Carlson, 2003; Roberts, 2003).

Today, there are several different frameworks trying to account for EF. These have conceptualized EF either as a construct, in which EF are a kind of central executive responsible for multi-modal processing, or as multiple process related systems, that are interrelated, interdependent, and function together as an integrated supervisory control system (Stuss, 2011; Stuss & Alexander, 2000). Results from studies using different EF tasks revealed that they all can be loaded onto three to four factors (Kelly, 2000; Levin et al., 1991; Welsh, Pennington, & Groisser, 1991). Based on these results, Anderson (2000) proposed a model of EF, which describes EF as four distinct domains: 1) attentional control, 2) information processing, 3) cognitive flexibility, and 4) goal setting. He states that these functions work in an integrative manner, in order to execute certain tasks, and that they can be conceptualized as an overall control system when taken together. Anderson's model is depicted in Figure 3.

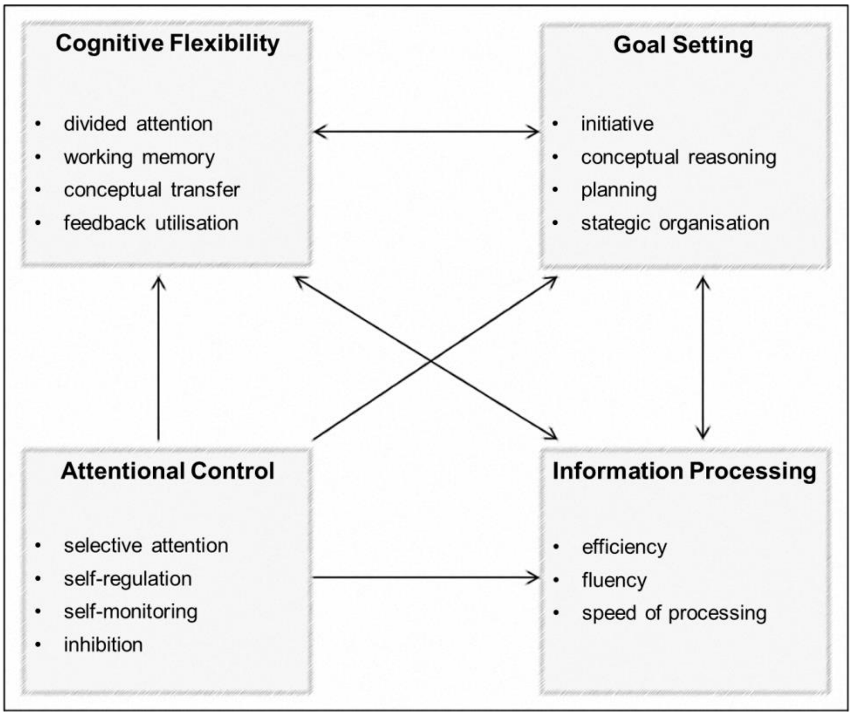

Figure 3. Proposed model of executive functions (adapted from Anderson, 2002, p. 73).

The *attentional control* unit includes the capacity to selectively attend to specific stimuli and inhibit proponent responses, as well as the ability to focus attention for a long period of time. Furthermore, the regulation and monitoring of actions are included, so that plans can be executed as they were planned, errors can be identified, and goals can be achieved. Impairments relate to people being impulsive, having a lack of self-control, failing to complete tasks, committing procedural mistakes and not correcting them, and responding inappropriately.

The *information processing* domain refers to fluency, efficiency, and the speed of the output. Here, the integrity of neural connections and the functional integration of frontal systems are displayed. Information processing can be measured by the speed, the quantity, and the quality of output. Deficits display itself in reduced output, false responses, hesitancy, and slowed reaction times.

Cognitive flexibility refers to the ability to shift between responses, to learn from mistakes, to invent alternative strategies, to divide attention, and to process multiple sources of information concurrently. Here, working memory is also a part of cognitive flexibility. Inflexible people are generally considered to be rigid and ritualistic, struggling when activities or procedures are changed and failing to adapt to new demands. Impairment in this domain of cognitive flexibility is often associated with preservative behavior, when people continue to make the same mistakes or breaking the same rules again and again.

Goal setting relies on the ability to develop new initiatives and concepts, as well as the capacity to plan actions in advance and approach tasks in an efficient and strategic manner. Impairments show up in poor problem solving abilities, disorganization, difficulties in developing efficient strategies, reliance on previously learned strategies, and poor conceptual reasoning (Anderson, 2002).

Depending on former studies it is argued, that EF are activated in novel or complex tasks, as they require the individual to formulate new plans and strategies to monitor their effectiveness, whereas in simple or routinized tasks, people perform instinctively, relying on plans that already exist (Shallice, 1990). As studies found different clinical populations to have reduced EF (especially patients with frontal, parietal, and cerebella lobe impairments), it has been assumed, that EF rely on different brain regions (see Nowrangi, Lyetsos, & Munro, 2014, for a review).

Having the principles of motor planning and cognitive control in mind, the question remains, how and when these abilities develop. Former studies suggest, that both develop during sensory-motor maturation (von Hofsten, 2004; Stuss, 1992), until they are fully matured in adulthood. In the following Chapter, light will be shed on the development of both, cognitive and motor development during childhood.

1.3. Developing voluntary control over the environment

When screening the literature on child development, a bulk of research is found, addressing many aspects of development, like social development (e.g. Ryan & Deci, 2000), emotional development (e.g. Grusec, 2011), and language development (e.g. Cole, Armstrong, & Pemberton, 2010). Besides these aspects, motor development (e.g. Blauw-Hospers, & Hadders-Algra, 2005) and cognitive development (Fischer, 1980) play an important role in our field of studies. Theorists have proposed different theories in the development of each field, but development is not uniform, and does not influence only one of these components at a time. Therefore, it is difficult to indicate theories on motor and cognitive development separately; every theory takes both parts into account, but with different weights. Therefore, theories in the following section will be divided due to their main area of interest.

1.3.1. Development of cognitive control

Plenty of different theories account for the development of cognitive control. Based on the assumptions made by these theories (e.g. Piaget, 1936; Vygotsky, 1977), executive functions (EF) -as an area of cognitive control- develop at different rates over the course of development (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Stuss, 1992). Some abilities start to develop very early in childhood, whereas others do in late childhood or adolescence. EF are shaped to life experiences, as assumed by cognitive theories, as well as due to maturation of the brain with building up connections until adulthood. Their development corresponds to the neurophysiological development of brain regions, as when the processing capacity of the frontal lobes and other brain regions increases, the core EF emerge (Anderson, 2002, 2008). This development may not progress in a linear way, but might demonstrate different developmental trajectories, which may occur in spurts. Suggestions, that EF may not operate until the brain reaches maturity in the second decade of life, have been refuted (Golden, 1981), as neuroimaging studies have demonstrated prefrontal activation in infancy (Bell & Fox, 1992). Neuropsychological studies found a developmental trajectory for EF across childhood (Becker, Isaac, & Hynd, 1987; Levin et al., 1991; Passler, Isaac, & Hynd, 1985; Welsh, Pennington, & Groisser, 1991).

Dennis (1989) provided a model of EF development, which he divided into three stages: 1) emerging (early stage of acquisition and not functional), 2) developing (capacity is partially acquired, but not fully functional), and 3) established (ability fully matured). Only the functional skills are measureable using EF tasks, meaning that in the emerging stage no function can be detected, even if it is already “in progress”. When looking back at Figure 3, it is known that cognitive flexibility (in the upper left of Figure 3) develops in early and middle childhood until adolescence. Therefore, preservative behavior is commonly found in infancy and declines upon development until it is rarely found in adulthood (Chelune & Baer, 1986, Levin et al., 1991). Between three and four years of age, children start to be able to switch between two simple response sets, and are able to switch in multi-dimensional tasks between ages 7 and 9 (Anderson et al., 2000). In early childhood, the ability to learn from mistakes and to provide other strategies emerges and develops throughout middle childhood. In terms of goal setting (upper right of Figure 3), children as old as four years exhibit simple planning skills (Welsh, Pennington, & Groisser, 1991) and can generate new concepts in terms of conceptual reasoning (Jaques & Zelazo, 2001). Skills of planning and organization develop rapidly between 7 and 10 years of age (Anderson, Anderson, & Lajoie, 1996). Whereas young children often use simple strategies, which are usually inefficient, older children between 7 and 11 years show more strategic behaviors and reasoning abilities (Anderson, Anderson, & Garth, 2001; Levin et al., 1991). This refinement of strategies and improved decision making continues during adolescence (Anderson et al., 2001; Levin et al., 1991). In the attentional control domain (in the lower left part of Figure 3), infants as old as 12 months of age begin to inhibit previously learned behavior and shift to new responses (Diamond, 1985; Diamond & Doar, 1989). At the age of three years, children can inhibit instinctive behaviors well, although they continue to make preservative errors (Diamond & Taylor, 1996). Up to six years of age, improvements in speed and accuracy can be observed in impulse control tasks (Diamond & Taylor, 1996). Children from 9 years and older can regulate their actions well and show inhibitory behavior (Anderson et al., 2000). In information processing (lower right part of Figure 3), increments in response speed and verbal fluency can be observed between three and five years of age (Welsh, Pennington, & Groisser, 1991), and processing speed continues to improve between 9 and 12 years (Kail, 1986). Efficiency and fluency development is further delayed into adolescence (Anderson et al., 2001; Kail, 1986), although increments are minimal after the age of 15. Based on these findings, Anderson (2002) proposed different developmental trajectories for these domains, which are illustrated in Figure 4.

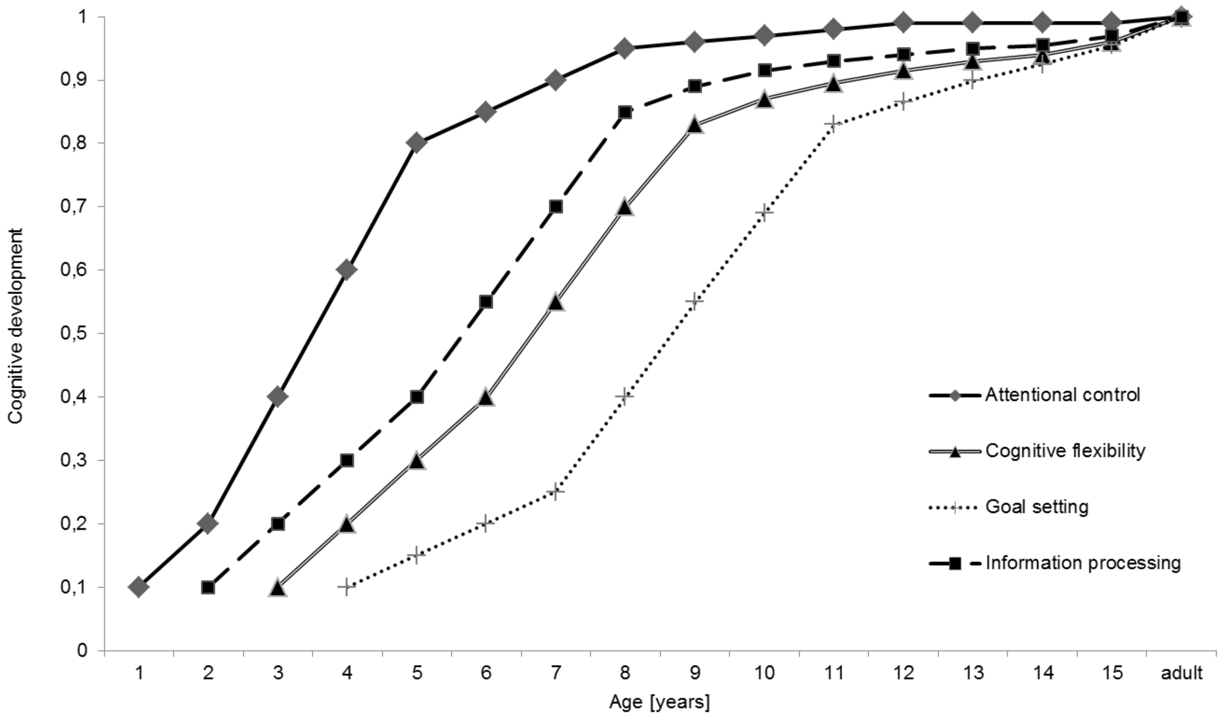

Figure 4. Projected developmental trajectories of the executive domains (adapted from Anderson, 2002, p. 78).

With regard to the developmental trends suggested, attention control would be the first EF to have matured to more than 80% at about five years of age, followed by information processing abilities, which are mostly matured by the age of 8 years, and cognitive flexibility, which is only little protracted in development (at about 9 years). Last, goal setting abilities develop, which are almost matured at about 11 years. All abilities, however, develop further after these ages during adolescence, until they are fully matured in adulthood (Anderson, 2002).

If EF do not develop regularly, this is called executive dysfunction (EDF). This disorder represents deficits in one or more areas of EF and a variety of presentations is possible. In children, EDF is observable through poor impulse control, difficulties in monitoring or regulating motor performance, a poor reasoning ability, mental inflexibility, and feedback utilization, difficulties in generating or implementing strategies to achieve any goal, and reduced working memory (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Barrash, Tranel, & Anderson, 2000; Eslinger & Damasio, 1985; Grattan & Eslinger, 1991).

Besides cognitive development, motor development also plays an important role in the maturation of children. Therefore, theories with a focus on motor development will be introduced below.

1.3.2. Motor development

The traditional study of motor behavior was characterized by observations of changes in different motor actions like grasping, rolling, crawling, climbing, and walking (Heriza, 1991). Today, a neuromaturational theory of development is prevalent, based on the assumptions made by Gesell (1933; Gesell & Thompson, 1934), describing normative timetables for motor achievements, and by McGraw (1935), who examined the determinants of these patterns. The dynamic systems approach suggests that new motor skills may emerge from the confluence of many interacting factors, each with its own developmental trajectory (Thelen & Smith, 1994).

When talking about motor development, one can distinguish two main areas of interest: the development of motor skills, and the development of motor abilities. Skills are learned and are sort of expertise on a specific motor task, while abilities are genetically predetermined characteristics that affect movement performance. Abilities are enduring, and therefore difficult to change in adults. They differ from skills in the sense that skills are learned, whereas abilities are a product of both, learning and genetic factors (Fleishman, Quaintance, & Broedling, 1984). In our case, grasping (i.e. for the coffee cup in the morning) is a skill, as grasping efficiently with regard to control precision, manual dexterity or arm-hand steadiness, for example (see Fleishman’s taxonomy of motor abilities; Fleishman et al.,1984), needs to be learned early during the ontogenetic development. Anticipatory planning on the other side is an ability, as it is shaped by biological and physiological factors and affected by environmental factors. The rate, at which abilities develop, varies across childhood and adolescence, both within and across individuals (Fleishman et al., 1984), which is largely due to growth and maturation changes, including the development of cognitive control. Both areas will be shortly addressed in the next two sections, using the development of grasping as a motor skill and the development of anticipatory planning as a motor ability.

1.3.2.1. Development of motor skills – grasping

Arm movements and grasping actions are observable even before birth. After birth, infants have to cope with gravity, and with about four to five months of age children are capable of adjusting their hands in vertical and horizontal positions, depending on the object to-be grasped (von Hofsten & Fazel-Zandy, 1984). Now, they become successful in reaching to objects (Oztop, Arbib, & Bradley, 2006).

When reaching towards an object, children aged five to six months begin to close their hands prior to the approach of the object (von Hofsten & Ronnquist, 1988), but the anticipatory opening of the hand, depending on object size, is not adjusted prior than the age of 13 months. The development of anticipatory grasping is due to the development of the ability to visually anticipate the to-be grasped object, which emerges somewhere around 8 months (Adolph, Eppler, & Gibson, 1993).

However, visual information is only needed about the object, not for the way of grasping (Adolph & Berger, 2006).

Bower (1977) proposed a phase model of the development of reaching and grasping behavior. He divided the developmental pattern into two phases. The contents of Phase 1 and 2 are summarized in Table 1 below (according to Payne & Isaacs, 1999).

Table 1. Bower's (1977) Phase 1 and 2 Reaching and Grasping Behavior Characteristics (adapted from Payne & Isaacs, 1999, p. 230).

	Phase 1	Phase 2
1.	Simultaneous reaching and grasping	Differentiated reaching and grasping
2.	One-handed reaching	Two-handed reaching
3.	Visual initiation of the reach	Visual initiation and guidance of the reach
4.	Visual control of the grasp	Tactile control of the grasp

The complete anticipation and execution of grip-formations develops over time, until it is fully present in adolescence. Even six to seven year old children are more dependent on visual feedback than adults are (Kuhtz-Buschbeck, Stolze, Boczek-Funcke, Joehnk, Heinrichs, & Illert, 1998). Once infants master the motor components of grasping, they use these skills to extend their own abilities and to bring about rewarding outcomes (like bringing food to their mouth with a spoon). Piaget was the first to describe how older infants separate reaching and grasping into means for achieving ends (Piaget, 1936). He was also one of the leading investigators regarding cognitive development in childhood.

1.3.2.2. Development of motor abilities - anticipatory planning

As mentioned above, planning is observable in a lot of daily activities. People do not only use anticipatory planning skills when they take their cup out of the cabinet for a coffee in the morning, they also use anticipatory planning skills in a lot of other actions. For example, if people are on the way to work, sitting in their car, they automatically try to anticipate what the car in front is doing. This is foresighted driving in order to prevent an accident when the car in front is suddenly braking. Or, if one is going down stairs, he/she will anticipate the step-width and will adapt his or her step-length, so that he/she can comfortably walk down the stairs. Hence, the ESC effect is only one possibility to measure anticipatory planning skills.

In recent years, there has been an increased interest in uncovering the developmental pattern of the ESC effect (e.g. Hughes, 1996; Thibaut & Toussaint, 2010; Weigelt & Schack, 2010). Overall, the findings of these studies suggest an increase of ESC planning in preschool children between three and five years (e.g. Weigelt & Schack, 2010) and a continuation of this trend in primary school children until they reach the age of ten (e.g. Crajé, Aarts, Nijhuis-Van der Sanden, & Steenbergen, 2010; Stöckel, Hughes, & Schack, 2012; Thibaut & Toussaint, 2010). When taking a closer look at these studies, however, it is hard to identify a specific pattern of development. Also, there are considerable differences between the tasks used and the procedures followed, which makes a direct comparison between most of these studies difficult. Moreover, some of the findings are controversial, as a number of studies were not able to replicate the ESC effect in children of the same age (Adalbjornsson, Fischman, & Rudisill, 2008; Manoel & Moreira, 2005). Therefore, a systematic review of the research on ESC planning in children is needed.

As both, ESC and EF, account for planning, and motor planning is impaired in patients with EDF, it can be assumed that ESC and EF are related in their development.

1.4. The possible relationship of anticipatory planning and cognitive control

Traditionally, the developmental trajectories of intellectual (cognitive) skills and (perceptual-) motor skills were examined separately, but in recent publications a relationship between their development has been suggested (Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012). There are two principal approaches to examine this assumption: 1) a deficit approach, and 2) a developmental approach. Until today, most studies examined both factors separately, within one of these two principle approaches.

The deficit approach has been used to study impairments of motor planning abilities (i.e. ESC) and cognitive skills (i.e. EF). For example, recent studies found in people with hemiparetic cerebral palsy, that motor deficits do not only manifest themselves in motor execution, but also in action planning (Gordon, Charles & Steenbergen, 2006; Steenbergen & Gordon, 2006; Steenbergen, Verrel & Gordon, 2007). From clinical studies on motor planning, it is known that planning skills are also impaired in a range of neurological disorders like in attention deficit hyperactivity disorder (ADHD, Scheres et al., 2004), in autism (Hill, 2004; Hughes, 1996), and in developmental coordination disorder (DCD, Smyth & Mason, 1997). Therefore, results suggest that people with different neuropsychological disorders show a decreased ability for motor execution and motor planning skills. The same approach is taken for the examination of EF. In a variety of studies, EF is used to characterize a diverse set of processes, which can be impaired by damage of the prefrontal cortex and other brain regions (for an overview see Stuss & Benson, 1986). Moreover, it is known that suffering from ADHD may be caused by delayed maturation of the prefrontal cortex or by brain injuries in this area, which is the primary seat of EF (National Institute of Mental Health, 2012). A study of the Johns Hopkins Medical Institutions (2008) also suggests, that autism may be caused be prenatal brain damage. Therefore, it can be assumed, that poor executive planning skills (not only due to brain injury or brain damage) is linked to poor motor skills.

With the second, the developmental approach, both, the development of ESC and the development of EF can be examined. Results suggest, that there is a positive developmental trajectory with the onset of ESC planning abilities found in children ranging from three years (e.g. Jovanovic and Schwarzer, 2011) until 10 years of age (e.g. Thibaut and Toussaint, 2010). As some studies were not able to find ESC planning until the age of 14 (e.g. van Swieten et al., 2010), the development seems to be protracted until adolescence, depending on different constraints, like task specifications. For EF tasks, a similar result emerges. Studies on EF development found a positive increase in EF during childhood until adolescence, with some sub-functions maturing early and others maturing later during the ontogenetic development (e.g. Anderson, 2002; Davidson, Amso, Anderson, & Diamond, 2006).

However, a review assembled by Rosenbaum, Carlson, and Gilmore (2001) suggested that both, intellectual and (perceptual-) motor skills, are acquired in similar ways. Until today, there are only few studies investigating the relationship of the development of motor and cognitive skills. In a study conducted by Jenni, Chaouch, Calfish, and Rousson (2013), children between 7 and 18 years were tested using the Zurich Neuromotor Assessment (ZNA) and standardized intelligence tests. The correlations found between the performances in both parts were generally weak, which led the authors to suggest that motor and intellectual domains are largely independent. Another recent study conducted by Gonzalez and colleagues (2014) examined children between five and 10 years, using the Behavioral Rating Inventory of Executive Function (BRIEF) and two motor tasks with a focus on grasping. Results revealed significant correlations between the strength of right hand preference for grasping and numerous elements of the BRIEF, showing an interconnectedness of lateralization and EF. Moreover, Jansen (2014) conducted a review study, where she summarized results on studies on the relationship of motor activity and cognitive functions. She concluded, that there is a positive effect of motor activity on the development of EF, and that specific physical activity can help to enhance specific cognitive functions in children. Altogether, motor (or better: physical) activity can play an important role in the development of EF and therefore, can act as a mediator on the relationship of ESC and EF.

Therefore, results on the development of motor planning and cognitive functions, as well as their relationship at different ages, are inconclusive. Further research is needed on this topic. Below, the motivation of the current research project is constituted, which will be addressed in the following Chapters.

1.5. Motivation of the current research endeavor

When researching on the developmental pattern of anticipatory planning, especially in terms of the ESC effect, it becomes obvious, that all studies find a positive developmental trajectory of anticipatory planning abilities in childhood. Nevertheless, results are quite different, regarding the slope of this development. It is hard to identify a specific pattern out from the existing literature. Moreover, all studies are considerably different, regarding the tasks and procedures applied, making it even more difficult to interpret the results on a common level. Some of the findings are controversial, as a number of studies were not able to replicate the ESC effect in children.

Therefore, the first aim of the research project is to provide a systematic review of the research on ESC planning in children. The systematic review of the literature will be provided in Chapter 2 of this dissertation.

Differences in grasp selection between adults and children have been construed as indicating a deficit in children’s planning abilities (see Hughes, 1996; Smyth & Mason, 1997), with the presence of ESC as an indicator for “thinking ahead”, referring somewhat ambiguously to some kind of cognitive planning skills. This led to an important debate, initially raised by van Swieten et al. (2010), about whether performance in grasp selection tasks is driven by the development of executive planning (i.e. actively planning ahead to solve actions correctly or to avoid mistakes, for example) or the development of motor planning (i.e. planning motor actions in advance in order to solve them correctly or most economically), or both (Scharoun & Bryden, 2013; Stöckel et al., 2012). In this regard, theories of child development assumed for a long time that the developmental origins of perceptual-motor skills and intellectual skills are closely related, for example by Piaget (1936) and Vygotski (1977), who based the development of intelligence upon the emergence of skilled action. Such a potential relationship in the development can be expected from the similarity of the developmental trajectories of EF and the ESC effect (see Anderson, 2002, for the projected developmental trajectory of the different EF, and Chapter 2, for an overview of the developmental trajectories for different ESC tasks).

Hence, the second aim of the research project is to investigate the possible influence of executive functions on the developmental trajectory of the ESC effect. To this end, an experimental study examining the development of motor planning abilities and cognitive skills in children from 3- to 10-years of age was conducted. The experimental study will be reported in Chapter 3.

Chapter 2

The end-state comfort effect in childhood - a systematic review

This chapter is based on the publication of Wunsch, K., Henning, A., Aschersleben, A., & Weigelt, M. (2013). A systematic review of the end-state comfort effect in normally developing children and in children with developmental disorders. *Journal of Motor Learning and Development*, *1*(3), 59-76.

However, all data presented in this chapter was checked again and updated on the 15th of October, 2014.

2.1. Introduction into the systematic review

Adults reach for objects in an anticipatory manner, taking the future states of their body during the sequence of motor actions into account, while planning the intended maneuver (Lashley, 1951; Rosenbaum, Cohen, Jax, Weiss, & van der Wel, 2007). Remember the person, who is picking up an overturned cup out of the kitchen cabinet in the morning to pour coffee into it. Most likely, he/she will reach for the cup in a way that ensures a comfortable posture of the hand at the end of the maneuver (see Chapter 1.2.1.). To this end, he/she will use an initial grip with the thumb pointing downward, in order to hold the glass comfortably with the thumb pointing upward when the rotation is completed. He/she will thus tolerate an uncomfortable posture of the hand at the beginning of the grasping action in anticipation of the final posture that ensures a comfortable position for the following action of pouring coffee into the cup. This sensitivity to avoid uncomfortable postures at the end of object manipulations has been first reported by Rosenbaum and colleagues (Rosenbaum et al., 1990) and has been termed the end-state comfort (ESC) effect. Ever since its first discovery, this effect has been taken to signify the presence of anticipatory motor planning skills.

While there is a large body of research showing the ESC effect in adults, surprisingly few studies have assessed the ESC effect in children. In fact, the developmental pattern of the ESC effect and its relation to the maturation of higher cognitive abilities are largely unknown. The findings of studies on tool use and object manipulation in infants and young children are inconclusive. While McCarthy, Clifton, and Collard (1999) found 19-month old children to reliably alternate their hands in a spoon-handling task, which suggests efficient effector selection to be present in children of this age, a number of studies showed that many other action features (like the arm's end posture) are not planned in advance at this age (Barrett, Traupman, &

Needham, 2008; Claxton, McCarty, & Keen, 2009; Lockman, 2000; Manoel & Conolly, 1997). For example, Connolly and Dalgleish (1989) examined grasp behavior in a spoon handling task in children aged between 11 and 18 months and observed that these children did not select their grasps in a way that favors a more comfortable posture in the end of the action. Instead, they most often selected a comfortable initial grip. The fact that young children appear to be biased towards minimizing initial discomfort, however, cannot be taken as evidence for a planning deficit per se, because these children were generally able to solve the particular task. It is therefore of interest, when and at what rate more sophisticated motor planning skills develop.

As mentioned in Chapter 1.3.2.2., research on the development of ESC is meager and results seem to be inconclusive. Therefore, light will be shed on the topic of ESC development in the following sections of Chapter 2. A first impression on the studies suggest an increase of ESC planning in preschool children (Weigelt & Schack, 2010) and a continuation of this trend in primary school children until the age of ten (Crajé, Aarts et al., 2010; Stöckel et al., 2012; Thibaut & Toussaint, 2010). On the other hand, a number of studies were not able to replicate the ESC effect in children of the same age (Adalbjornsson et al., 2008; Manoel & Moreira, 2005). Therefore, the general aim of Chapter 2 is to provide a systematic review of the research on ESC planning in children. More specific goals of the present review are: (1) to identify and provide a detailed overview of the existing studies on the ESC effect in children, (2) to compare the various tasks and procedures employed in order to highlight differences and similarities between these studies, (3) to examine the different developmental patterns of ESC planning in normally developing children and in children with developmental disorders, 4) to discuss possible factors influencing the development of ESC planning, and 5) to provide new directions for future research.

2.2. Method

In order to identify studies assessing the ESC effect in children, a search procedure (based on other systematic reviews like the one of Blauw-Hospers & Hadders-Algra, 2005 or Greaves, Imms, Dodd, & Krumlinde-Sundholm, 2010, for example) containing eight distinct steps was applied on three databases to acquire and further process the data. These eight steps and the resulting data set at each step are depicted in Figure 5.

First, a keyword search was performed for journal articles and book chapters on the ESC effect in the databases of *Medline*[1], *PubMed*[2] and *Scopus*[3] by using the following keywords, which were carried over from known papers on ESC planning: *end-state comfort, anticipatory planning, end-posture comfort, end-posture planning, grip selection, bar-transport-task, handle-rotation-task, start-state comfort and start-posture comfort.* As a result, three separate data sets were generated, with the results of all keyword searches summarized; one set for *Medline* (2592 articles and book chapters), one for *PubMed* (971 articles and book chapters), and one for *Scopus* (1617 articles and book chapters).

Second, to reduce each of the three data sets to studies conducted with children, a search with the original keywords and three additional keywords, c*hildren*, *childhood* and *development*, was conducted. The new data sets of *Medline* included 519, of *PubMed* 249, and of *Scopus* 497 journal articles and book chapters.

Because there were still articles and book chapters in the reference bases without any relevance to motor development in children (such as articles named *End-of-life discussions and advance care planning for children on long-term assisted ven-*

[1] https://portal.dimdi.de/websearch/, last access on October, 15th, 2014
[2] http://www.ncbi.nlm.nih.gov/pubmed/, last access on October, 15th, 2014
[3] http://www.scopus.com/home.url, last access on October, 15th, 2014

tilation with life-limiting conditions, for example, which contain single words of the keywords, but do belong in another field of interest), the content of each database was further scrutinized in a third step and manually separated into studies on motor development and studies on other topics. Other topics included medicine (e.g. end-of life discussions, well-child care, advance-care planning), psychology (e.g. cognitive-behavioral therapy, gaze behavior, skill acquisition in music), neuroscience (e.g. oc-culomotor abnormalities, attention shifts), nursing (e.g. nutrition intake, depressive distress), and/or health professions (e.g. syllable planning, social participation ac-quirement). The latter ones were then excluded from the databases. This resulted in 91 studies in *Medline*, 78 in *PubMed*, and 89 in *Scopus*.

Fourth, all databases were further scrutinized to ensure that all studies on adults and on animals were excluded from the following analysis. This resulted in 48 studies on children in *Medline*, 57 in *PubMed*, and 74 in *Scopus*.

Fifth, the remaining data sets of the three databases were then combined into a single data set, consisting of 179 studies on children. As the studies on ESC in children appeared in every data set, 57 studies can be subtracted from this amount. The remaining 122 studies almost included studies on anticipation in infants and tod-dlers, whereas ESC was not explicitly measured. As most of these studies appeared in all three databases, the break-down from 179 to 19 studies can be explained. While making sure that every study only appeared once, a preliminary set of 19 stud-ies was formed. Each study of this preliminary data set was scrutinized for tasks em-ploying grasping actions and focusing on children's grip selection at the beginning and/or the end of the movement. One study, which did not fulfill this criterion (i.e. Cowie, Smyth, & Braddick, 2010, who examined anticipatory planning in a locomotor task) was also excluded in this step. This resulted in a final set of 18 studies on man-ual ESC planning in childhood (see Figure 5).

Sixth, the reference lists of all 18 articles retrieved on children were checked one by one for further related references, which were potentially missing from the previous search. No additional publications were identified.

Seventh, the combined data set was further partitioned into studies on children with a focus on normal development (n = 12) and on developmental disorders (n = 6)[4], which included children with cerebral palsy (CP), developmental coordination disorder (DCD), mild learning deficits (MLD), and autism.

Eighth, all studies were evaluated for the type(s) of ESC tasks used in combination with the child population tested. Three different tasks were identified: the bar-transport-task, the handle-rotation-task, and the overturned-glass-task.

[4] Please note that studies on children with different developmental disorders (n = 6) usually contained also of a group of normally developing children. The focus of the studies, however, was on the developmental disorders and the normally developing children were only included as a control group.

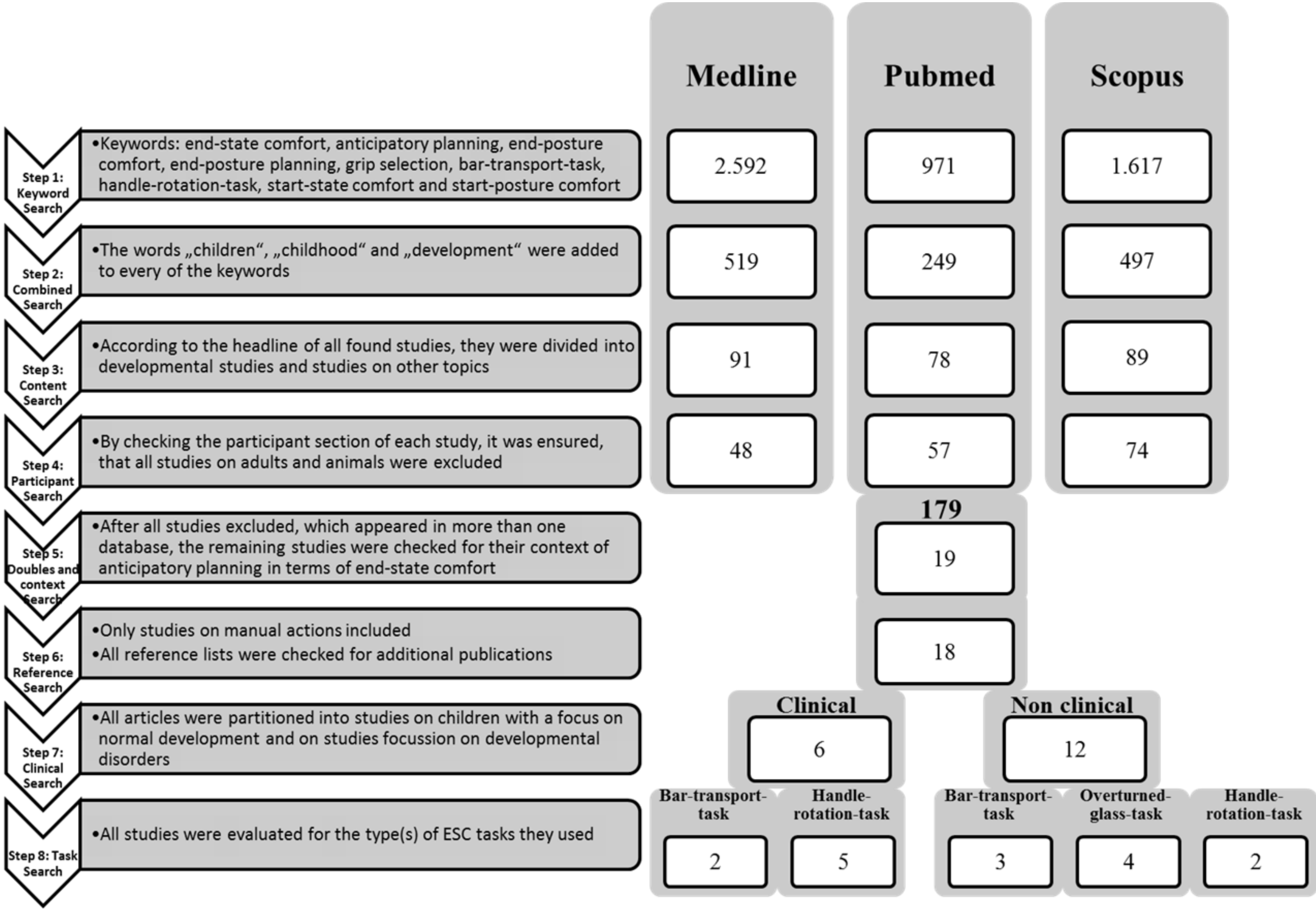

Figure 5. Schematic overview of the distinct steps to analyze the reviewed studies.

2.3. Results

As a result of the search procedure described above, a total of 18 studies investigating the ESC effect in children in manual actions were identified. Twelve of these studies assessed ESC planning in normally developing children (Adalbjornsson et al., 2008; Jongbloed-Pereboom, Nijhuis-van der Sanden, Saraber-Schiphorst, Crajé, & Steenbergen, 2013; Jovanovic & Schwarzer, 2011; Knudsen, Henning, Wunsch, Weigelt, & Aschersleben, 2012; Manoel & Moreira, 2005; Robinson & Fischman, 2013; Scharoun & Bryden, 2013; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Toussaint, Tahej, Thibaut, Possamai, & Badets, 2013; Weigelt & Schack, 2010; Wilmut & Byrne, 2014b). The remaining six studies focused on the ESC effect in children with different developmental disorders, including children with autism (Hughes, 1996; van Swieten et al., 2010), children with developmental coordination disorder (Smyth & Mason, 1997; van Swieten et al., 2010; Wilmut & Byrne, 2014a), with mild learning deficits (Hughes, 1996), and with cerebral palsy (Crajé, Aarts, et al., 2010; Kirpatrick, Pearse, Eyre, & Basu, 2013). Across these studies, three different kinds of basic tasks (or versions thereof) were employed: the bar-transport-task, the handle-rotation-task, and the overturned-glass-task. In the following section, the original version of each of these tasks is described in more detail. Then, all 18 studies on the development of planning skills in children are reviewed, with a focus on the particular modifications of the task used and the procedure employed, as well as on the results of each study. Studies on normally developing children are presented first, followed by studies on children with developmental disorders. Finally, the results for the two child populations are reviewed in relation to the tasks employed. For an overview of all studies and their results, see Table 2.

Table 2. Overview of the mean percentage of ESC behavior found in the different studies.

<table>
<tr><th rowspan="2">Task</th><th rowspan="2">Author(s)</th><th rowspan="2" colspan="2">Dev. Disorders / Condition</th><th colspan="12">Age</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11-12</th><th>13-14</th></tr>
<tr><td rowspan="14">BTT</td><td rowspan="3">Hughes (1996)</td><td colspan="2">Normally developing</td><td></td><td></td><td>14</td><td>71</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">MLD</td><td></td><td></td><td></td><td></td><td>42</td><td></td><td>70</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Autism</td><td></td><td></td><td></td><td></td><td>28</td><td></td><td></td><td></td><td></td><td>6</td><td></td><td></td></tr>
<tr><td>Jovanovic and Schwarzer (2011)</td><td colspan="2">Normally developing</td><td>8</td><td>0</td><td>60</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Knudsen et al. (2012)</td><td rowspan="2">Normally developing</td><td>AE</td><td></td><td></td><td>0</td><td>38</td><td>75</td><td>75</td><td>86</td><td>88</td><td></td><td></td><td></td><td></td></tr>
<tr><td>No-AE</td><td></td><td></td><td>25</td><td>38</td><td>88</td><td>75</td><td>89</td><td>100</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Manoel and Moreira (2005)</td><td rowspan="2">Normally developing</td><td>LC</td><td></td><td>40</td><td>50 | 50</td><td>50 | 50</td><td>50 | 50</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>HC</td><td></td><td>25</td><td>38 | 29</td><td>50 | 29</td><td>50 | 49</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Smyth and Mason (1997)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td>60</td><td>65</td><td>70</td><td>65</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">DCD</td><td></td><td></td><td></td><td>60</td><td>65</td><td>65</td><td>60</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Stöckel et al. (2011)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td></td><td></td><td></td><td>50</td><td>67</td><td>92</td><td></td><td></td><td></td></tr>
<tr><td>Thibaut and Toussaint (2010)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td>45</td><td></td><td>65</td><td></td><td>50</td><td></td><td>80</td><td></td><td></td></tr>
<tr><td>Toussaint et al. (2013)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td></td><td></td><td>55</td><td></td><td>75</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Weigelt and Schack (2010)</td><td colspan="2">Normally developing</td><td></td><td></td><td>20</td><td>45</td><td>70</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="12">HRT</td><td rowspan="2">Crajé et al. (2010)</td><td colspan="2">Normally developing</td><td></td><td></td><td>10</td><td>30</td><td>65</td><td>75</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">CP</td><td></td><td></td><td>10</td><td>30</td><td>35</td><td>24</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Jongbloed-Pereboom et al. (2013)</td><td colspan="2">Normally developing</td><td></td><td></td><td>21</td><td>35</td><td>41</td><td>50</td><td>42</td><td>55</td><td>50</td><td>62</td><td></td><td></td></tr>
<tr><td>Kirpatrick et al. (2013)</td><td colspan="2">CP</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">61</td><td></td><td></td></tr>
<tr><td rowspan="2">Smyth and Mason (1997)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td>20</td><td>35</td><td>40</td><td>35</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">DCD</td><td></td><td></td><td></td><td>20</td><td>35</td><td>45</td><td>40</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Van Swieten et al. (2010)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td></td><td colspan="4">20</td><td colspan="4">35</td></tr>
<tr><td colspan="2">DCD</td><td></td><td></td><td></td><td></td><td></td><td colspan="3">10</td><td colspan="3">25</td><td></td></tr>
<tr><td colspan="2">Autism</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">35</td></tr>
<tr><td rowspan="2">Wilmut & Byrne (2014a)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">65</td><td></td><td></td></tr>
<tr><td colspan="2">DCD</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">55</td><td></td><td></td></tr>
<tr><td>Wilmut & Byrne (2014b)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td colspan="3">62</td><td colspan="3">71</td><td colspan="2">82</td><td></td></tr>
<tr><td rowspan="6">OGT</td><td>Adalbjornsson et al. (2008)</td><td colspan="2">Normally developing</td><td></td><td colspan="2">20</td><td></td><td colspan="2">35</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Knudsen et al. (2012)</td><td rowspan="2">Normally developing</td><td>AE</td><td></td><td></td><td>75</td><td>69</td><td>88</td><td>88</td><td>86</td><td>100</td><td></td><td></td><td></td><td></td></tr>
<tr><td>No-AE</td><td></td><td></td><td>57</td><td>69</td><td>94</td><td>75</td><td>93</td><td>94</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Robinson & Fischman (2013)</td><td colspan="2">Normally developing</td><td></td><td></td><td></td><td colspan="2">65</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Sharoun and Bryden (2013)</td><td rowspan="2">Normally developing</td><td>unimanual</td><td></td><td></td><td colspan="2">10</td><td colspan="2">35</td><td colspan="2">50</td><td colspan="2">90</td><td>95</td><td></td></tr>
<tr><td>bimanual</td><td></td><td></td><td colspan="2">30</td><td colspan="2">62</td><td colspan="2">81</td><td colspan="2">90</td><td>95</td><td></td></tr>
</table>

Note. AE = action effect, BTT = bar-transport-task, CP = cerebral palsy, DCD = developmental coordination disorder, HRT = handle-rotation-task, MLD = mild learning deficits, OGT = overturned-glass-task, LC = low precision requirements, HC = high precision requirements.
Note further: The ages declared in the table for the study of Hughes (1996) for the MLD- and the autistic children do not match their chronological ages. They are the nonverbal mental ages (NVMA), assessed by the Matrices task of the British Abilities Scale (Elliot et al., 1983). The NVMA of the MLD group correspond to a chronological age of 10 years for those with a low NVMA of 4.7 and to 11 years of age for those with a high NVMA of 6.9. In the autistic group, the children with low NVMA (4.7) correspond to the chronological age of 12 years, those with high NVMA (9.8) to 13 years of age. Furthermore, in the Scharoun and Bryden (2013) study, data is collapsed over critical and uncritical trials. In the studies of Wilmut and Byrne (2014a, 2014b), only data for one-step movements are provided, not for two-step and three-step movements. In the study of Kirpatrick et al. (2013), data was collapsed across left- and right-handers and across clockwise and counterclockwise rotations. In the study conducted by Robinson and Fischman (2013), data shows the percentage of participants, who showed ESC in at least one of the two similar tasks.

2.3.1. Tasks used to investigate the ESC effect in children

In the next section, the tasks used and the procedures employed to investigate the development of motor planning skills in children are described for their original versions, respectively. In the sections to follow, this should help to better highlight the modifications to the original tasks and to better understand the possible implications this may have had on some of the results on children.

2.3.1.1. Bar-transport-task

This task was originally developed by Rosenbaum et al. (1990) (see Figure 6A). They instructed adult participants to take hold of a bar with one grey and one black end, which was suspended horizontally on two supports, and to place it in a vertical position with either its white or black end onto either a blue or red target circle to the left or right side of the supports on the table surface[5]. Importantly, participants were not instructed how to grasp the handle and therefore, it was of interest if they chose an overhand or an underhand grasping posture at the beginning of the action,

[5] The use of different colors for bar ends or target locations is reported for the sake of completeness. However, there is no evidence whether or not the colors used in a particular experiment (additionally) affected children’s task performance.

resulting in a comfortable thumb-up vs. an uncomfortable thumb-down end position. Also note, that participants only held the bar's end briefly on the target circle (no inserting action), before returning it. There were no familiarization trials and participants performed the task standing throughout the experiment.

2.3.1.2. Handle-rotation-task

This task was introduced by Rosenbaum et al. (1993). Participants were presented with a disk with eight target numbers (1-8), which were distributed equidistantly around the disk (similar to the numbers of a clock). A handle was fixed at the center of the disk and could be rotated 360 degrees like the arm of a clock (see Figure 6B). One end of the handle was marked by a cardboard tab. The apparatus was positioned on the wall in a 45 degree angle and participants were instructed to reach out and rotate the handle with their right hand to a particular target position, i.e. to cover the designated target number with the marked end of the handle. Participants were not instructed how to grasp the handle and therefore, it was of interest, whether participants grasped the handle with the thumb towards the mark or away from it, enabling them to finish the rotation in a comfortable or in an uncomfortable posture of the arm and hand. The task was performed standing.

2.3.1.3. Overturned-glass-task

The overturned-glass-task was already conceptualized by Rosenbaum et al. (1990), after the first author observed a waiter manipulating glasses in a restaurant, just as described in the introduction to this dissertation. Fishman (1997) was the first to bring this observation into the laboratory. The task was to pick up a drinking cup that was placed upside down on a table, to turn it over, and to pour water from a pitcher into it (see Figure 6C). In half of the trials, the glass needed to be held while pouring water into it, and in the other half, it had to be put on a coaster. Participants were not instructed how to grasp the cup and thus, were free to select any grasping posture. It was of interest, if participants grasped the glass with an uncomfortable thumb-down grasp, before turning it over to pour water into it, to ensure a comfortable end-posture with the thumb pointing upwards. Participants performed the task sitting.

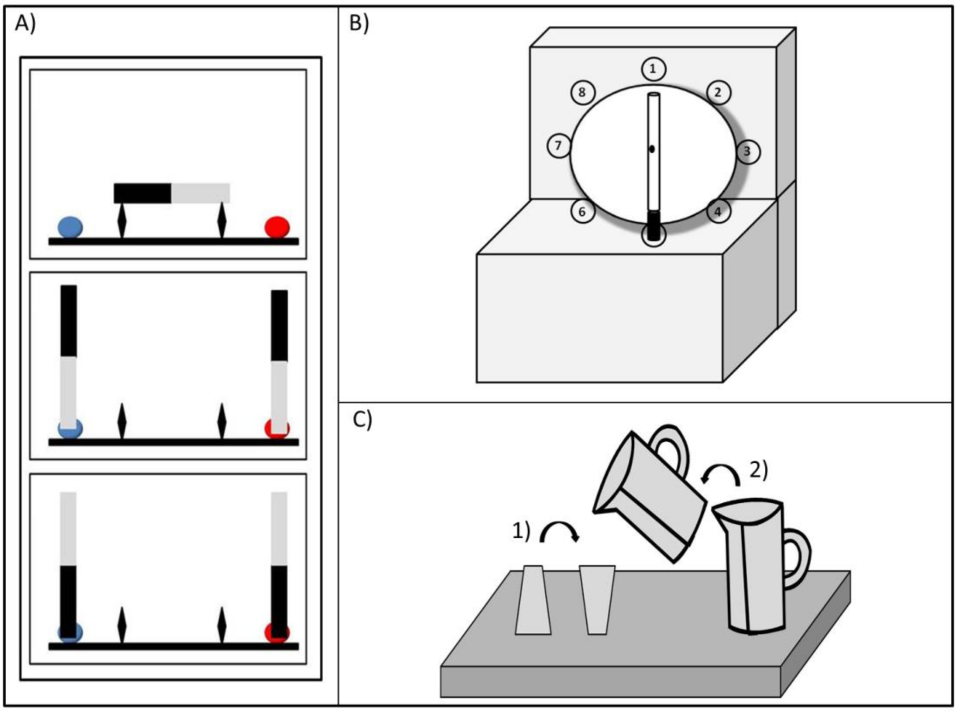

Figure 6. Schematic illustration of the original versions of the three tasks used to examine the ESC effect in children. A) Bar-transport-task (Rosenbaum et al., 1990) with initial position (1) and four possible end positions (2, 3). B) Handle-rotation-task (Rosenbaum et al., 1990). C) Overturned-glass-task (Fischman, 1997) with first turning action (1) and subsequent pouring action (2).

2.3.2. The ESC effect in children of various populations

After the tasks used to study ESC planning in children have been described, the focus in the following section will now be on the results of studies with normally developing children and of studies with children of different developmental disorders. Please note that the focus will only be on children's motor performance, while the findings regarding other intellectual competencies are not reviewed here. As operational definitions greatly varied across studies within and across tasks, the presence of ESC planning in a particular group of children (e.g. children of a certain age or with a particular developmental disorder) is supported when more than half of these children show the ESC effect in the majority of trials (i.e. ≥ 50% of participants showed in ≥ 50% of all trials anticipatory planning behavior) under critical conditions (i.e. when an initial uncomfortable grip is tolerated in order to finish the action comfortably).

2.3.2.1. Studies on normally developing children

In a most recent study, Toussaint et al. (2013) examined the link between action planning and motor imagery in 6- to 8-year old children. Therefore, they correlated the results of these tasks, finding that the ability to engage sensorimotor mechanisms when solving a motor imagery task was concomitant with action planning efficiency. To test ESC, they used the original bar-transport-task conducted by Rosenbaum and colleagues (1990). Here, the bar rested on two cradles, with one blue and one red end. On the left and the right of the supports, a black and a white target disk was placed. A noticeable detail of the procedures was that all children performed the task sitting (and not standing as in the original study by Rosenbaum et al., 1990). Before each trial, children were asked to put their hands on their knees. Then, each child performed five blocks of four randomly presented trials, resulting in a total of 20 trials. There were no familiarization trials and the task was not demonstrated by the experimenter.

Sixty-four children were divided by half into two age groups, resulting in one group of 6-year old children, and one group of 8-year old children. Almost all children used an overhand grip if this resulted in ESC. In the critical conditions, however, 55% of the 6-year-olds and 75% of the 8-year-olds showed sensitivity for ESC planning. This difference was found to be statistically significant.

Manoel and Moreira (2005) examined whether young children between 2½ and 6 years of age plan motor actions on the basis of the ESC effect and whether an increasing demand for precision would make the effect more apparent. To this end, they used a modified version of the original bar-transport-task by Rosenbaum et al. (1990). Specifically, Manoel and Moreira (2005) presented only a single target hole on top of a squared box, which was positioned behind the supports. In addition to the cylindrical bar (low precision condition, LC) used in the original version, a second bar with semi-cylindrical distal parts (high precision condition, HC) was introduced to increase precision requirements. Importantly, the bar end had to be inserted into the target disk. The authors tested six conditions in their study: In the two LC conditions, participants had to insert the green or red end of the cylindrical bar into the target hole. In the four HC conditions, the bar was initially presented either with the flat sides facing upwards or downwards on the supports and then, either the green or the red end of the semi cylindrical bar had to be inserted into the target hole. ESC depended on initial grip selection (overhand vs. underhand) relative to the bar's end orientation. Again, children performed the task sitting. Each child completed five trials in each of the conditions, resulting in a total of 30 trials. All trials were randomly presented. There were no familiarization trials and the task was not demonstrated by the experimenter.

Forty children were divided into seven age groups, with mean ages of 2 years 8 months (n = 5), 3 years 4 months (n = 6), 3 years 11 months (n = 6), 4 years 2 months (n = 5), 4 years 10 months (n = 6), 5 years 2 months (n = 6), and 5 years 10 months (n = 6). Results did not show the ESC effect to be present in the children of all age groups, irrespective of whether they performed in the low or high precision condition. Instead, all children preferred an initial-state comfort, i.e. to grasp the bar with an overhand grip across all conditions. According to these results by Manoel &

Moreira (2005), children of up to 6 years of age do not plan their object manipulations with regard to ESC.

A modified version of the original bar-transport-task with only a single target location was also used by Weigelt and Schack (2010). The target hole was on top of a squared box, which was placed on the table in front of the support. The bar was marked with one black and one white end, and was presented in a horizontal orientation. All children performed the task standing in front of the apparatus. They completed a total of six trials, in which each bar end (black vs. white) had to be inserted into the target hole three times. The initial orientation of the bar was kept constant for each child across all trials (e.g. black end always pointing to the right), while the color to be inserted was randomized. Thus, depending on the bar’s final orientation, with either the left end or right end inserted, ESC could be reached with either an initial overhand grip in the uncritical trials or with an initial underhand grip in the critical trials.

Fifty-one right-handed children were tested by Weigelt and Schack (2010), being 3, 4, or 5 years of age (n = 17 in each age group). The ESC effect was considered to be present if a child showed ESC in at least two out of the three trials in each condition. There were no familiarization trials. All children reached for the bar with an overhand grip if this resulted in ESC in the uncritical trials. In the critical trials, 18% of the 3-year-olds, 47% of the 4-year-olds, and 70% of the 5-year-olds selected an underhand grip and finished the object manipulation in a manner consistent with ESC. Interestingly, 11 (65%) of the 3-year-olds never used an underhand grip and therefore, inserted the bar always with an awkward hand posture. The same was true for 7 (41%) of the 4-year-olds and 4 (24%) of the 5-year-olds. Also, none of the 3-year-olds selected an underhand grip when the critical trial was presented for the first time. By the third trial, however, 5 (29%) of these children used an underhand grip and thus, had changed their grip strategy. Such a systematic pattern of grip adjustment was not present in the 4- and 5-year-old children. Different to the results of Manoel and Moreira (2005), Weigelt and Schack (2010) showed the presence of ESC planning in preschool children, as well as an increase of these planning abilities in these children from 3 to 5 years of age.

In a more recent study, Stöckel et al. (2012) used a modified version of the bar-transport-task that was similar to the one by Weigelt and Schack (2010). A difference, however, was that participants had to hold the bar in the final position for five seconds. Thirty-six primary-school children in three age groups (7-year-olds, 8-year-olds and 9-year-olds), with 12 children in each age group, were tested. They performed two trials in each of the four conditions (i.e. each end had to be inserted twice for each start orientation of the bar), resulting in a total of eight trials, which were presented in a randomized order. There were no familiarization trials before testing. In the uncritical condition (i.e. an initial overhand grip resulted in a comfortable finial posture), 33 (92%) of the children of all three age groups showed the ESC effect. However, in the critical conditions (i.e. an initial underhand grip was required to end in a comfortable finial position), 6 (50%) of the 7-year-olds, 8 (67%) of the 8-year-olds and 11 (92%) of the 9-year-olds showed the ESC effect. These differences in grip behavior between the age groups in the latter condition were significant and thus, demonstrate a steady increase of the ESC effect in primary school children.

Thibaut and Toussaint (2010) tested children's planning skills in two different experiments. In Experiment 1, they used the original bar-transport-task by Rosenbaum et al. (1990), with the only difference being that their participants were sitting. A horizontal bar was always presented with the red end facing to the left and the blue end facing to the right. This resulted in four types of trials: blue end onto white disk, blue end onto black disk, red end onto white disk and red end onto black disk. A block consisted of these four trial types, which were presented in random order. Five blocks resulted in a total of 20 trials. There were no familiarization trials.

They tested 120 right-handed children, aged 4, 6, 8, and 10 years (n = 30 in each age group), as well as twenty adults (mean age = 33 years). Almost all participants grasped the bar with an overhand grip when this resulted in ESC in the uncritical trials. In the critical trials, in which an underhand grip had to be adopted, all adults showed the ESC effect. A different pattern was found for children, which suggested that the ESC effect was present in 12 (40%) of the 4-year-old, in 21 (70%) of the 6-year-old, in 15 (50%) of the 8-year-old, and in 24 (80%) of the 10-year-old children. This pattern of results supports the notion of motor reorganization, which takes place around the age of 8 years, as suggested by other authors (Bard, Hay, & Fleury, 1990; Meulenbroek & van Galen, 1988).

In Experiment 2, Thibaut and Toussaint (2010) varied the original bar-transport-task and replaced the bar with a two-tailed pencil, with one end red and the other end blue. Participants were asked to take the pencil and make a dot (pointing-with-pencil-task) or to draw a line without constraints (tracing-with-pencil-task), or to draw a line within a given alley (pencil-alley-task) in a particular color (red vs. blue) on a sheet of paper. For all three tasks, the blue end of the pencil always faced to the right. There were two types of trials, either tracing with the blue end or tracing with the red end. In each task, each trial was presented two times in random order. They tested 80 right-handed children between 4 and 10 years of age (n = 20 in each group). In the pointing-with-pencil-task, 45% of the 4-year-old, 75% of the 6-year-old, 50% of the 8-year-old, and 95% of the 10-year-old children performed in a manner consistent with ESC. Results were similar in the tracing-with-pencil-task. Here, 50% of the 4-year-old, 75% of the 6-year-old, 55% of the 8-year-old, and 90% of the 10-year-old children grasped the pencil ending comfortably. Therefore, the pointing-with-pencil-task and the tracing-with-pencil-task replicated the results of Experiment 1, with the performance of 8-year-old children being lower than those of 6- and 10-year-olds. In contrast, in the pencil-alley-task 45% of the 4-year-old, 80% of the 6-year-old, 80% of the 8-year-old, and 95% of the 10-year-old children behaved in an anticipatory manner. Hence, motor reorganization seemed to affect task performance of the 8-year-old participants to a smaller degree in the pencil-alley-task task.

Jovanovic and Schwarzer (2011) employed a largely modified version of the original bar-transport-task. They presented children with a vertically oriented bar whose two ends differed in diameter, such that only the narrow end of the bar, but not the large end, fitted into an empty cylinder (single target object). Children's task was always to fit the narrow end into the cylinder. Also, the correct insertion of the bar into the target cylinder resulted in a light effect, which could be readily noticed by the child. Children sat in front of the apparatus on the lap of their parents and completed a total of six trials. In the three uncritical trials, no rotation was required and the bar could be grasped with the thumb pointing upwards to place it into the target hole by a simple translation movement. In the three critical trials, however, a 180 degree rotation (instead of the 90 degree rotation in the original task version) had to be completed, before inserting the bar's end into the target hole. To finish the object manipulation comfortably in the critical trials, the bar had to be grasped with the thumb pointing down. Also, two types of grip adaptations with respect to grasp height were helpful: In the uncritical condition without rotation, it was better to grasp the bar high, whereas, in the critical condition, it was better to grasp the bar low (i.e. close to the narrow end or close to the large end, respectively).

Both trial conditions (critical vs. uncritical) were presented in alternation. Thus, children were allowed a familiarization trial in a way that the experiment always started with an uncritical trial, in which the bar could be transferred "easily" and inserted without a rotation. The experimenter grasped the bar, lifted it, and put it into the cylinder, which caused the lights to switch on. As this demonstration always took place in the uncritical condition, the experimenter used a comfortable grip when transferring the bar into the target hole. Furthermore, the task was demonstrated twice, before the child was encouraged to perform the same action. In the subsequent trials, the child was then only encouraged to ‘‘switch on the lights again’’. The study included 81 children, which were divided into one of three age groups: 1½ years (n = 36), 2 years (n = 25), and 3½ years (n = 20). Results showed that 3 (8%) of the 1½ -year-olds, none of the 2-year-olds, but 12 (60%) of the 3½-year-olds demonstrated the ESC effect. These results suggest that the ESC effect is not present in the majority of children below the age of three years.

Knudsen et al. (2012) used a similar version to Jovanovic and Schwarzer (2011). At their body midline, participants were presented a box with an insertion hole on its top and a smiley configuration of LED’s inserted at its front facing the participant. To the left and to the right of this box, a bar holder was placed, which held the bar in an upright position when placed into it with the narrow side down. Only this side was able to be inserted into the hole; the other side had a platform at its end. Participants were asked to insert the bar into the opening of the box with their preferred hand. Half of the six trials were critical trials, in which the bar rested on its platform at the beginning of the trials and then had to be rotated by 180 degrees to fit with its narrow end into the target hole. Here, an initial thumb-down grip was required to end the action comfortably.

Every testing session started with a demonstration of the starting state and the desired end state by the experimenter. However, the child never saw the experimenter grasped the bar, as the set-up and all actions of the experimenter were covered. Participants performed the task standing, starting approximately 70 cm away from the apparatus. The starting position of the bar was always opposite to side of the hand, which the participant was about to use in the upcoming trials.

Knudsen et al. (2012) tested 116 participants between 3 and 8 years, divided into nine age groups (3-year-olds, 4-year-olds, 5-year-olds, 6-year-olds, 7-year-olds, 8-year-olds [all n = 16], and adults [n = 20]). Each group was divided by half; an AE-group (receiving action effects, e.g. turning on the lights of the smiley on the box when inserting the bar) and a no-AE group (receiving no action effect). Results revealed no differences between the two groups in each age group. In the uncritical trials, where the bar could be translated without any rotation, almost all participants in all age groups grasped the bar with a thumb-up grip. In the critical trials, however, where a 180 degree rotation was required, 13% of the 3-year-olds, 38% of the 4-year-olds, 81% of the 5-year-olds, 75% of the 6-year-olds, 88% of the 7-year-olds, 94% of the 8-year-olds, and 100% of the adults used an initial awkward thumb-down grip to end the action comfortably (averaged over both AE- and no-AE conditions; for detailed results please see Table 1).

In another most recent study conducted by Jongbloed-Pereboom et al. (2013), a modulated version of the handle-rotation-task was used, adapted from the Crajé, Aarts, et al. (2010) study (see below). In their study, the bar was replaced by a wooden sword, which was presented on a table in front of the participants, in one of six possible orientations. Two orientations represented the critical condition in which only an uncomfortable initial grip resulted in ESC. The remaining four orientations resembled the uncritical condition in which a comfortable initial grip resulted in ESC. Participants had to grasp the handle of the sword and to stick it into a tight hole in a wooden block, which was positioned behind the sword on the table. Thus, this task additionally incorporated a transport phase and an insertion action. To familiarize themselves with the task, each child was asked to demonstrate the insertion of the sword once from the 12 o’clock position. Then, 18 test trials (3 trials for each of the 6 initial positions) were performed in random order. Participants performed the task sitting.

351 participants were tested in one of eight age groups: 3-year-olds (n = 27), 4-year-olds (n = 36), 5-year-olds (n = 44), 6-year-olds (n = 50), 7-year-olds (n = 52),

8-year-olds (n = 46), 9-year-olds (n = 51), and 10-year-olds (n = 45). Whereas almost all participants used a comfortable grip in the uncritical conditions, 21% of the 3-year-olds, 35% of the 4-year-olds, 41% of the 5-year-olds, 50% of the 6-year-olds, 42% of the 7-year-olds, 55% of the 8-year-olds, 50% of the 9-year-olds, and 62% of the 10-year-olds used an awkward initial grip in the critical trials, which resulted in ESC.

Wilmut & Byrne (2014b) also examined ESC planning in normally developing children using the handle-rotation-task. A modified version of the task introduced by Rosenbaum and colleagues (1993) was used. Participants were seated in front of a wooden octagon, which was surrounded by eight different colors. The size of the octagon was adjusted to hand size. It could be rotated about its center, so that an arrow could be turned to one of the eight colors on the board. Then, a color, or a sequence of colors, was named and participants were instructed to grasp hold of the octagon and rotate it so that the arrow pointed to the color(s) in the order they were listed. Sequences of one, two, and three colors were used, beginning with the shortest for all participants. Sequences were presented in a blocked rather than in a randomized fashion, making the procedure exactly the same for all participants. The eight color positions were rated by an independent sample using different participants as either comfortable or uncomfortable, similar as done in the study of Rosenbaum and colleagues (1993). Based on these ratings, ESC could be detected for every start- and end- posture of the grasping hand.

They tested sixty children within three age groups (each n = 20): 4- to 6- year-olds, 7- to 9-year-olds, and 10- to 12-year-olds. Results showed that ESC increased with age, with 62% of the youngest children, 71% of the 7- to 9-year-olds and 82% of the oldest children showing ESC. The data demonstrated that 10- to 12-year-olds ended movements with the same degree of comfort as adults, but younger children showed movements ending in less comfortable position.

Adalbjornsson et al. (2008) employed the overturned-glass-task to test children`s planning skills. They sat in front of the table with a plastic drinking cup and a pitcher on it. The task was to pick up the cup that was sitting upside down on the table, turn the cup over, and pour water from the pitcher into it. Each child performed three trials, without any familiarization trials before the testing. The task was performed while children sat at the table. Altogether, 40 children (n = 20 per group) were tested. The younger group aged from 2 to 3½ years, the older group from 5 to 6 years. Only 4 (20%) of the children in the younger group and 7 (35%) of the older group used a thumb-down grip to grasp the overturned cup. According to these results, the majority of 5- and 6-year-old children do not show the ESC effect in the overturned-glass-task.

Besides the bar-transport-task, Knudsen et al. (2012) also examined anticipatory planning skills in the overturned-glass-task. At their body midline, participants were presented a pod coaster, which lid up when a cup was placed onto it. To the left and to the right of the coaster, white cardboard circles were placed on the table, with a plastic cup standing on one of the two circles. Participants were asked to put the glass right side up on the coaster. Half of the six trials were preferred-hand trials, the other half was performed with the non-preferred hand. To reach ESC, a thumb-down grip was required followed by a 180 degree rotation of the glass.

The same participants were tested as for the bar-transport-task described above. Again, the influence of action effects was examined (when placing the glass upright, the light of the coaster turned on in one group of subjects) but again no difference between groups was obtained. Moreover results revealed no difference between preferred-hand and non-preferred-hand trials. In critical trials, 63% of the 3-year-olds, 69% of the 4-year-olds, 82% of the 5-year-olds, 82% of the 6-year-olds, 75% of the 7-year-olds, 100% of the 8-year-olds, and 100% of the adults used an initial awkward thumb-down grip to end the action comfortably (averaged over both AE- and no-AE conditions; for detailed results please see Table 2).

In a most recent study, Scharoun and Bryden (2013) asked participants to complete two different tasks, each involving the manipulation of a cup: The one task required to pick up the cup and pour water from a pitcher into it (bimanual task). The other entailed to pick up the cup and pass it to the experimenter (unimanual task), who then poured water into it. The cup's placement was altered between upright and inverted, and it was 15cm away from the participant (the pitcher was 25 cm away). Neither the pitcher nor the cup had a handle. Each participant completed 12 trials (each trial type three times, e.g. upright or upside down, unimanual or bimanual). Participants were free to use either hand and performed the task sitting. Also, hand preference consistencies were examined due to a second testing session after 24 hours.

112 participants were tested, divided into 6 age groups: 3- to 4-year-olds (n = 13), 5- to 6-year-olds (n = 19), 7- to 8-year-olds (n = 23), 9- to 10-year-olds (n = 17), 11-to 12-year-olds (n = 20), and adults (n = 20). Results revealed a significant main effect of age group in both the upright- and the inverted-cup condition. Collapsed over these two conditions, 10% of the 3- to 4-year-olds, 35% of the 5- to 6-year-olds, 50% of the7- to 8-year-olds, 90% of the 9- to 10-year-olds, 95% of the 11- to 12-year-olds, and 95% of the adults showed sensitivity for ESC planning in the unimanual trials. In the bimanual trials, however, 30% of the 3- to 4-year-olds, 62% of the 5- to 6-year-olds, 81% of the 7- to 8-year-olds, 90% of the 9- to 10-year olds, 95% of the 11- to 12-year-olds, and 98% of the adults showed sensitivity for ESC planning[6].

[6] Please note that no data are provided for the critical trials only, therefore the comparison with other studies is limited.

Recently, Robinson and Fischman (2013) conducted another study using the overturned-glass-task. Participants were instructed to use one hand to pick up a plastic drinking cup that was placed upside-down on a table, turn the cup over, and pour water from a measuring cup into it. Children were tested in two conditions: a no-visual cue condition, which was as described above, and a visual-cue condition, where yellow cardboard was glued to the bottom of the drinking cup as well as on the board in front of the cup. Each child performed three trials per condition, and ESC was declared as being present when shown in at least two out of these three trials. Participants were seated in this experiment.

They tested 17 preschool children with a mean age of 4.4 years (SD = 4.75 months). The task was similar to the ones used by Adalbjornsson et al. (2008) and Fischman (1997). Out of the 17 children, 8 (47.1%) used a thumb-down grip in both conditions, 3 (17.6%) used it in only one condition, and 6 children (35.3%) never used it. The visual cue had no effect on planning in this sample.

To sum up the results on studies with normally developing children, 9 of the 12 studies provided evidence for the presence of ESC planning in the majority of children beginning from 3 years (Jovanovic & Schwarzer, 2011; Knudsen et al., 2012) up to 12 years of age (Jongbloed-Pereboom et al., 2013; Knudsen et al., 2012; Robinson & Fischman, 2013; Scharoun & Bryden, 2013; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Toussaint et al., 2013; Weigelt & Schack, 2010; Wilmut & Byrne (2014b). The results further suggest an increase of motor planning skills within this age range. Two studies, however, did not find the ESC effect to be present in children of these ages (Adalbjornsson et al., 2008; Manoel & Moreira, 2005). Figure 7 shows a scatter diagram of the results separated for the different tasks used for normally developing children. It can be said, that the developmental trajectories for children tested in the bar-transport-task and in the overturned-glass task are similar, with the ESC effect to be fully present at about 8 years of age. Results of children tested with the handle-rotation-task, however, show a protracted development of the ESC effect, with the effect being present in only half of the children at 12 years of age.

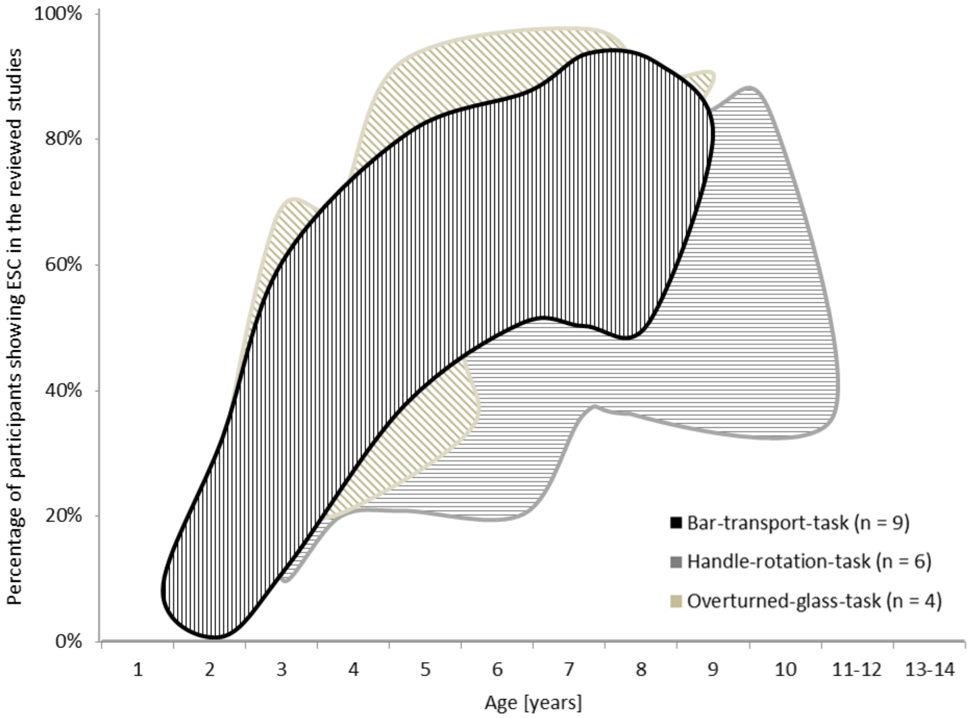

Figure 7. Scatter diagram of the results of the three tasks used to assess ESC planning in normally developing children across all studies reviewed here.

2.3.2.2. Studies comparing normally developing children and children with developmental disorders

Hughes (1996) was the first to examine motor planning skills for children with autism (n = 36) and with mild learning deficits (MLD; n = 24), as well as for a control group of normally developing children (n = 28). All groups were further subdivided with regard to their verbal and nonverbal mental age (NVMA), assessed by the matrices task of the British Abilities Scale (BAS; Elliot, Murray, & Pearson, 1983), but not by their chronological age. This resulted in a total of six subgroups: (1) 18 autistic children of 5 years with low NVMA's (score = 4.86); (2) 18 autistic children of 10 years with high NVMA's (score = 9.78); (3) 12 MLD-children of 5 years with low

NVMA’s (score = 4.72); (4) 12 MLD-children of 7 years with high NVMA’s (score = 6.92), (5) 14 normally developing children of 3 years (NVMA score = 3.28); and 14 normally developing children of 4 years (NVMA score = 4.02), according to the BAS.

Hughes (1996) used the original version of the bar-transport-task, without any modifications. Before testing, children were given up to five practice trials, or until they appeared confident. Then, all children received a total of eight test trials, half of which were uncritical trials (i.e. an overhand grip resulted in ESC) and the other half were critical trials (i.e. requiring an initial underhand grip for ESC). All trials were presented in random order. Results for the uncritical trials showed that all children used an overhand grip in at least three out of the four trials. For the critical trials, there was an increase in the ESC effect from two children (14%) of the 3-year-olds to ten children (71%) in 4-year-olds of the normally developing group. In the MLD-children, the ESC effect rose from five children (42%) in the group with a low NVMA to six children (50%) in the group with a high NVMA. Similarly, in the children with autism, the ESC effect increased from only one child (6%) in the group with a low NVMA to five children (28%) in the group with a high NVMA (10 years). Thus, Hughes (1996) provided evidence for motor planning deficits in children with developmental disorders.

Smyth and Mason (1997) tested 96 children (4 to 8 years old) with developmental coordination disorder (DCD) and compared their performance with 91 normally developing children (4 to 8 years old). All of these primary school children were distributed into four age groups. Motor planning skills were assessed for two tasks, the bar-transport-task and the handle-rotation-task. In the bar-transport-task, Smyth and Mason (1997) used red and blue disks, which were lying behind the supports, and not besides them, as in the original task version. No demonstration was given by the experimenter, but participants received four practice trials. In the 16 experimental trials, each colored end was placed on each disc four times. All conditions were presented in random order. In the handle-rotation-task, the authors modified the original task version a little, as they replaced the numbers for the target positions with little pictures (depicting a horse, a penny, a clock, an apple, a tree, a clown, a flower, and a car) and mounted the apparatus on a nursery chair. Children were asked to grasp and turn the handle until it covered a specific picture on one of the eight positions. Trials could start from each of the eight positions and involved a handle rotation of 180 degrees. Four blocks of eight trials, each presented in random order, resulted in a total of 32 trials. Children were allowed two practice trials in this task.

Unfortunately, the mean values for children`s performance in both tasks were only provided graphically by Smyth and Mason (1997). Therefore, it is not possible to tell the exact number of children (or the proportion thereof), who finished the action comfortable, neither for the bar-transport-task, nor for the handle-rotation-task. For the bar-transport-task, however, the graphic depiction (cf. Figure 4 in Smyth and Mason, 1997) indicates that more than half of the children in each group demonstrated the ESC effect. Any differences between the DCD group and the normally developing group, as well as between the different age groups, were not statistically significant. For the handle-rotation-task, the graphic depiction does also not provide a hint for any differences in planning skills between the DCD group and the group of normally developing children. However, children seem to improve with age. Both observations are supported by the statistical analyses.

Most recently, Wilmut and Byrne (2014a) investigated ESC abilities in children with DCD, as well as in adults with DCD. Therefore, a version of the handle-rotation-task was applied, the same as the one describe above (Wilmut & Byrne, 2014b). They tested 20 children with DCD (mean age = 9 years) and 20 typically developing children with the same age. Moreover, 17 adults with DCD with a mean age of 25 years, and 17 age-matched normally developing adults (mean age = 25 years) were tested. Results showed, that in both, children and adult groups, participants with DCD showed significantly less grasps ending in ESC than their typically developing counterparts. 65% of the normally developing children showed ESC, whereas this amount is decreased to 55% in the DCD group. This result was independent of the length of the movement (i.e. one-step, two-step, or three-step movements, see Chapter 2.3.2.1 in the other study conducted by Wilmut and Byrne, 2014b).

Kirpatrick and colleagues (2013) used a version of the handle-rotation-task, but with some differences. The authors used a version adapted from Mutsaarts, and colleagues (2006), which was modified for the use of children and adapted to children's hand size. A plastic disc was placed in front and sloping upwards in the direction away from the participants at an angle of 10 degrees. The disc was surrounded by six target pictures. Participants were seated in front of the apparatus. Then, a target picture was presented at the center of a computer screen, surrounded by moving arrows. Participants were instructed to turn the handle in the direction of the arrows so that the wooden stick pointed to the target picture. Children were given 5 familiarization trials prior to testing. Only 180 degree turns were analyzed in terms of grip selection. Altogether, 76 children with HCP (hemiparetic cerebral palsy) with a mean age of 8.72 years were tested. Results revealed that 61% of the children showed a sensitivity for ESC planning. The side of lesion had no influence on anticipatory planning skills.

Van Swieten et al. (2010) assessed motor planning skills in 27 children with DCD (6 to 13 years old) and in 20 children with autism (9 to 14 years old), as well as in 70 normally developing children (5 to 14 years old) and 40 adults (19 to 32 years old). A largely modified version of the handle-rotation-task was used. Specifically, they presented the disk lying flat on the table in front of the participants and explicitly asked them to always grasp the bar with their thumb pointing towards the marked end. The bar could be grasped in two ways: Either with a pronated or a supinated grip. Much different to the original version was that participants were sitting in front of a computer screen. On the screen, a white arrow indicated the direction in which the bar needed to be rotated, until the thumb was aligned with a red dot indicating the end position. Each rotation movement covered 180 degrees and could be performed clockwise or counterclockwise. Participants were given eight practice trials in which the experimenter made sure that they followed the instructions (e.g. grasp the object with the thumb at the red end and turn it following the white arrow). They were further told that there were always two ways in which they could grasp the bar and were asked to think about which of the two ways they were going to use. Then, participants performed 8 trials for each of the 4 conditions, resulting in a total of 32 test trials.

Results for the normally developing children showed that 20% of 5- to 8-year-olds and 50% of the 9- to 14-year-olds demonstrated the ESC effect. In the DCD group, only 10% of the 5- to 8-year-olds and 25% of the 9- to 13-year-olds showed the ESC effect in at least one of the conditions. Further statistical analyses confirmed that the difference in grip selection between younger children with DCD and younger normally developing children, as well as between older children with DCD and older normally developing children was statistically significant. Interestingly, 9- to 14-year-old children with autism showed the same grip selection pattern as normally developing children in this age group (50% ESC grips) and thus, performed much better than the DCD population in this respect.

Crajé, Aarts, et al. (2010) tested the ESC effect in 24 children (3 to 6 years old) with cerebral palsy (CP) and 24 normally developing children (3 to 6 years old). These children were equally distributed into four age groups. Crajé, Aarts, et al. (2010) introduced a new task version, similar to the one used by Jongbloed-Pereboom et al. (2013), as described above. In their study, the bar was replaced by a wooden sword, which was presented on the table in front of the participants in one of six possible orientations. According to the authors, two orientations represented critical condition in which only an uncomfortable initial grip resulted in ESC. The remaining four orientations resembled uncritical condition in which a comfortable initial grip also resulted in ESC. Participants had to grasp the handle of the sword and to stick it into a tight hole in a wooden block that was positioned behind the sword on the table. Thus, this task additionally incorporated a transport phase and an insertion action. To familiarize themselves with the task, each child was asked to demonstrate the insertion of the sword once from the 12 o'clock position. Then, 18 test trials (3 trials for each of the 6 initial positions) were performed in random order.

Almost all children in the normally developing group (90% of the 3-year-olds, 95% of the 4-year-olds, and 100% of the 5- and 6-year-olds) inserted the sword with a comfortable posture in the uncritical trials. In the critical trials, however, the ESC effect increased from 10% in 3-year-old, to 30% in 4-year-old, to 65% in 5-year-old, and to 75% in 6-year-old normally developing children. The differences between critical and uncritical trials were significant for 3- and 4-year-old children, but not for the 5- and 6-year-olds. Children with CP used comfortable grip postures in 75% of the 3- and 4-year-olds, in 90% of the 5-year-olds, and in 95% of the 6-year-olds in the uncritical trials. In the critical trials, however, only 10% of the 3-year-olds, 20% of the 4-year-olds, 30% of the 5-year-olds, and 25% of the 6-year-olds showed the ESC effect. Thus, different from the control group, there was no evidence for an increase of motor planning skills with age in the CP group.

Together, the studies on children with developmental disorders provide mixed results and must be further examined for the specific impairment. In children with developmental coordination disorder (DCD), it was shown that they demonstrated the ESC effect in the bar-transport-task (Smyth & Mason, 1997). But, in the handle-rotation-task, results were inconclusive. Whereas Smyth and Mason (1997) and van Swieten et al. (2010) were not able to find any sensitivity for ESC planning in their samples, Wilmut and Byrne (2014a) were able to detect ESC planning in children with DCD at the age of 9 years. Children with cerebral palsy (CP) did not show the

ESC effect in the study of Crajé, Aarts, et al. (2010), but Kirpatrick et al. (2013) were able to find ESC sensitivity in children with HCP at the age of 9 years. Only about half of the children with motor learning deficits (MLD) and a high nonverbal mental age (of 7 years) showed ESC planning in the bar-transport-task, whereas numbers were lower for children of a low nonverbal mental age (Hughes, 1996). Finally, in both studies including children with autism, the majority of children did not show the ESC effect, neither in the bar-transport-task (Hughes, 1996), nor in the handle-rotation-task (van Swieten et al., 2010). For all studies, it should be also noticed that normally developing children, who served as control groups, did not always outperform those children with developmental disorders. For an overview of all studies and their results, please refer to Table 2.

2.4. Discussion

The aim of the present work was to give a systematic overview of research on the development of the ESC effect (as an indication of the presence of motor planning skills) in children. Three databases *Medline*, *PubMed*, and *Scopus* were scrutinized, using a predetermined set of keywords and an 8-step search procedure. A total of 18 published studies were identified, 12 of which assessed ESC planning in normally developing children (Adalbjornsson et al., 2008; Jongbloed-Pereboom et al., 2013; Jovanovic & Schwarzer, 2011; Knudsen et al., 2012; Manoel & Moreira, 2005; Robinson & Fischman, 2013; Scharoun & Bryden, 2013; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Toussaint et al., 2013; Weigelt & Schack, 2010; Wilmut & Byrne, 2014b). The remaining six investigations focused on ESC in atypically developing children, including children with autism (Hughes, 1996; van Swieten et al., 2010), developmental coordination disorder (Smyth & Mason, 1997; van Swieten et al., 2010; Wilmut & Byrne, 2014a), mild learning deficits (Hughes, 1996), and/or cerebral palsy (Crajé, Aarts, et al., 2010; Kirpatrick et al., 2013). Across all of these studies, three different ESC tasks were used: the bar-transport-task (Hughes, 1996; Jovanovic

& Schwarzer, 2011; Knudsen et al., 2012; Manoel & Moreira, 2005; Smyth & Mason, 1997; Thibaut & Toussaint, 2010; Toussaint et al., 2013; Weigelt & Schack, 2010), the handle-rotation-task (Crajé, Aarts, et al., 2010; Jongbloed-Pereboom et al., 2013; Kirpatrick et al., 2013; Smyth & Mason, 1997; van Swieten et al., 2010; Wilmut & Byrne, 2014a; Wilmut & Byrne, 2014b), and the overturned-glass-task (Adalbjornsson et al., 2008; Knudsen et al., 2012; Robinson & Fischman, 2013; Scharoun & Bryden, 2013). Except for Smyth and Mason (1997) and Knudsen and colleagues (2012), who employed both the bar-transport-task and the handle-rotation-task or the bar-transport-task and the overturned-glass-task, respectively, all other studies tested for the ESC effect using only a single task.

2.4.1. Age effects of ESC planning in different tasks

Across the studies reviewed here, children's age groups ranged from 1½ years to 14 years of age. The 14 studies that found ESC planning abilities in early childhood observed children ranging between 1½ years to 12 years of age. Given that adults do show ESC planning, it is still an open question why in some studies younger children showed ESC planning (Jovanovic & Schwarzer, 2011; Knudsen et al., 2012), whereas in other studies older children up to 14 years of age did not (van Swieten et al., 2010). These results also contrast with findings of those studies reporting the ESC effect in childhood suggesting a further development in motor planning abilities with increasing age. It is possible that this absence of the ESC effect in older school-aged children is due to the choice of task. These children were assessed with the handle-rotation-task (van Swieten et al., 2010), in which results are inconclusive for younger children, as they showed ESC planning in the more child-oriented sword version (Crajé, Aarts, et al., 2010; Jongbloed-Pereboom et al., 2013), but not in the more adult-oriented version (Smyth & Mason, 1997). In another variation of this task, Wilmut and Byrne (2014a) found typically developing children as soon as they reached nine years of age to behave in terms of ESC, but on a very low level. In another study, however, they found children as young as 4 years of age to behave in terms of ESC in the same task (Wilmut & Byrne, 2014b).

Most importantly, the observation of Jovanovic and Schwarzer (2011), suggesting that the ESC effect is not present in children of 1½ years and in children aged 2 years, as well as those of Weigelt and Schack (2010) and Scharoun and Bryden (2013), with the ESC effect absent in children of 3 and 4 years, confirms that such anticipatory planning skills are not an inborn trait, but rather develop over the course of sensory-motor maturation. The span of development ranges from 3 to 12 years of age, with the most noticeable growth spurt around 5 to 8 years in the majority of children. Thus, the development of ESC planning is not reflected by a linear increase of the planning skill, but rather by a positively accelerated function, which exhibits a fast developmental spurt around 6 years of age and then approaches an asymptote somewhere beyond 10 years of age.

Deviations from this function may arise from motor reorganization. It is likely that different sensory-motor maturation processes, which support the development of cognitive control during early childhood (Piaget & Cook, 1952), also enable the development of ESC planning (Fischer, 1980). Interestingly, 8-year-old children provided less evidence for anticipatory planning than 6-year-old children in the study of Thibaut and Toussaint (2010), 7-year-old less than 6-year-old children in the study of Jongbloed-Pereboom et al. (2013), and 6-year-old less than 5-year-old in the bar-transport-task and 7-year-old less than 6-year-old children in the overturned-glass-task by Knudsen et al. (2012), even if not statistically significant in the latter study. Thibaut and Toussaint (2010) refer to the motor reorganization hypothesis (Bard, Hay, & Fleury, 1990) to explain these contra-intuitive results. According to this hypothesis, motor structures reorganize in children around the age of 8, resulting in a momentary instability of previously acquired abilities. However, motor reorganization did not seem to affect the developmental pattern revealed by Stöckel and colleagues

(2012). Hence, more studies with children of this age group are needed to shed light on the role that motor reorganization plays on the development of anticipatory planning skills.

To sum up, the findings of the studies reviewed here differed with regard to the age at which most of the normally developing children show ESC planning. In studies employing various versions of the bar-transport-task, at least half of the children showed the ESC effect at the age of 3½ years (Jovanovic & Schwarzer, 2011), 4 years (Hughes, 1996; Smyth & Mason, 1997), 5 years (Knudsen et al., 2012; Weigelt & Schack, 2010), 6 years (Thibaut & Toussaint, 2010; Toussaint et al., 2013) and/or 7 years (Stöckel et al., 2012). In contrast to these findings, in Manoel and Moreira (2005) only 39% of the oldest age group tested at 6 years of age showed ESC planning. In the three studies using the overturned-glass-task, at least half of the children showed the ESC effect at the age of 3 years (Knudsen et al., 2012), 5 to 6 years for bimanual manipulation or 7 to 8 years for unimanual manipulation (Scharoun & Bryden, 2013). Contrary to these findings, less than half of the children in the oldest age group with 5- to 6 years in the study conducted by Adalbjornsson et al. (2008) showed the ESC effect. Finally, in studies using various versions of the handle-rotation-task, Crajé, Aarts, et al. (2010) reported that the majority of 5-year-olds showed evidence for ESC planning, Jongbloed-Pereboom et al. (2013) found 6-year-old children to behave at a rate of 50% in terms of ESC, with the 7-year-olds showing less, the 8-year-olds again more ESC sensitivity, whereas Wilmut and Byrne (2014b) found normally developing children in a modified version of this task to behave to 62% in terms of ESC at the age of 4 years already. In contrast, Smyth and Mason (1997) and van Swieten et al. (2010) did not find evidence for the ESC effect in the majority of their children at 8 years (Smyth & Mason, 1997) and between 9 and 14 years (van Swieten et al., 2010).

In clinical populations, there is evidence for ESC planning in the bar-transport-task in children with MLD at a nonverbal mental age of about 7 years (Hughes, 1996). For children with DCD, the majority showed ESC planning in the bar-transport-task already at 4 years of age (Smyth & Mason, 1997). Whereas Wilmut and Byrne (2014a) found 9-year old children with DCD to behave in terms of ESC to an amount of 55%, the majority of children with DCD did not show the ESC effect in the handle-rotation-task by 8 years (Smyth & Mason, 1997) or 9 to 14 years of age (van Swieten et al., 2010). Similarly, the majority of preschool children with CP did not show ESC planning in the handle-rotation-task by the age of 6 or 7 years (Crajé, Aarts, et al., 2010; Kirpatrick et al., 2013). Also, the majority of children with autism did not show ESC planning, neither in the bar-transport-task by a nonverbal mental age of 10 years (Hughes, 1996), nor in the handle-rotation-task by 14 years of age (van Swieten et al., 2010).

Overall, the findings of those studies that observed the ESC effect to be present in preschool children suggest a systematic increase in the number of normally developing children across the preschool years.

2.4.2. Other factors constraining the ESC effect in children

Given the inconsistencies in findings between the studies reviewed here, both for normally developing children and children with developmental disorders, the potential factors influencing the presence of the ESC effect will be discussed in the remainder of the discussion section. One possible explanation for the different results may relate to differences in task demands between the three tasks employed. More specifically, differences in the number of action steps, in the object rotations, in the precision requirements, the familiarity with the task, the procedures, and in motivation might explain the ambiguous findings, as well as differences in sample characteristics. Finally, developmental factors will be discussed in relation to the different child populations assessed in the studies reviewed.

2.4.2.1. Number of action steps

A possible explanation for the different results concerning the ESC effect relates to the issue of task complexity, which relates to how many actions steps had to be performed to solve a particular action. It may be that more complex tasks reduce children’s cognitive resources for ESC planning. With regard to the number of action steps to-be-performed, the bar-transport-task and the handle-rotation-task only require two action steps (grasp and place onto/into target; grasp and turn/insert), as compared to three steps in the overturned-glass-task (grasp, turn, pour). For the task requiring two action steps, the ESC effect was reported to be present in (at least) 5-year-old children in a number of studies (Hughes, 1996; Jovanovic & Schwarzer, 2011; Knudsen et al., 2012; Robinson & Fischman, 2013; Smyth & Mason, 1997; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Weigelt & Schack, 2010; Wilmut & Byrne, 2014b). Unfortunately, findings are inconclusive with regard to the more complex three-step overturned-glass-task. Adalbjornsson et al. (2008) were not able to find any sensitivity for ESC planning in the overturned-glass-task. However, Scharoun and Bryden (2013) found the effect to be present in 5-6-year-olds and 7-8-year-olds, respectively; Knudsen and colleagues (2012) as soon as 3 years of age, and Robinson and Fischman (2013) with 4 years of age. Given these inconsistent findings, it is still an open question whether any differences in the amount of actions steps needed to solve the object manipulation may explain overall inconsistencies in the reviewed findings. In this regard, it is most interesting that two recent studies conducted by Wilmut and Byrne (2014a, 2014b) were able to show that the ability to plan for ESC decreased with increasing number of actions steps required to complete the task.

2.4.2.2. Required degree of object rotation

The tasks used differed with regard to the required degree of object rotation: (1) The bar-transport-task typically involved a manual rotation over 90 degrees (e.g. Hughes, 1996; Smyth & Mason, 1997; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Toussaint et a., 2013; Weigelt & Schack, 2010), but some task versions were also performed with a rotation of 180 degrees (Jovanovic & Schwarzer, 2011; Knudsen et al., 2012); (2) the handle-rotation-task, or versions thereof, included manual rotations of up to 180 degrees (e.g. Crajé, Aarts, et al., 2010; Jongbloed-Pereboom et al., 2013; Wilmut & Byrne, 2014a, 2014b); and (3) the overturned-glass-task required manual rotations of 180 degrees (Adalbjornsson et al., 2008; Knudsen et al., 2012; Robinson & Fischman, 2013; Scharoun & Bryden, 2013). In this regard, results of studies on adults suggest that the ESC effect found for tasks employing a 90 degree object rotation (e.g., Rosenbaum et al., 1990; Weigelt et al., 2006) is reduced when the task requires an higher amount of object rotation, both for unimanual (Rosenbaum et al., 1993; Hughes, Seegelke, & Schack, 2012) and bimanual object manipulation (e.g., Hughes & Franz, 2008; Hughes et al., 2011; Janssen et al. 2010). Thus, the task demands relative to the degree of manual rotation appear to influence the presence of the ESC effect.

The required degree of object rotation may have also affected the performance of children in a number of studies reviewed here. For example, it may explain the absence of the ESC effect for the overturned-glass task in the study conducted by Adalbjornsson et al. (2008), although other studies found the effect to be present in older children (Knudsen et al., 2012; Robinson & Fischman, 2013; Scharoun & Bryden, 2013). Also, the majority of children in the study by Jovanovic and Schwarzer (2011) did not show the effect when the bar had to be rotated over 180 degrees. However, in their study, the absence of the effect can also be explained with the young age of the children (i.e., the effect was not present in children below the age of 3 years). Using a similar apparatus, Knudsen et al. (2012) were able to find ESC planning in children of 5 years. In the largely modified version of the handle-rotation-task used by Crajé, Aarts, et al. (2010), Jongbloed-Pereboom et al. (2013), and Kirpatrick et al. (2013) the ESC effect seemed to develop with age and was only present for older, normally developing children, whereas children as young as 4 years showed anticipatory planning skills in the version used by Wilmut and Byrne (2014b). Together, the degree of manual rotation required to solve a particular task may influence the children`s motor performance.

2.4.2.3. Precision requirements

Another constraint to the ESC effect may relate to the precision requirements of the task (*precision hypothesis*, Rosenbaum et al., 1993). The assumption is that people`s anticipatory planning strategies are related to the amount of precision required to end the task (Rosenbaum et al., 2006). Here, precision refers to how accurate a certain movement (e.g. an object placing action) must be completed in the final part. For example, inserting a particular object into a small target hole may require more precision than simply placing the object on a target circle of similar size. In fact, when the task does not require much precision, ESC is significantly reduced (Rosenbaum et al., 1996). Similar to this latter finding, it has been shown that children need less planning when throwing a ball into a bucket (low precision), as compared to fitting the ball into a small tube (high precision) (Claxton, Keen, & McCarthy, 2003). Nevertheless, these authors demonstrated differences in the kinematic profile of the grasping action, depending on future task demands (high or low precision demands), and revealed that even 10-month old infants show some anticipatory planning skills when considering systematic patterns in these reach-to-grasp profiles.

Also, it has been assumed, that finishing manipulations at or near the middle of the pronation/supination range should be easier than at or near the extremes

(Rosenbaum et al., 1996). In essence, people`s precision increases while performing in comfortable postures and movements can be made more quickly within that range of comfort near the neutral-zero point of motion (Rosenbaum et al., 1996; Short & Cauraugh, 1997). In addition, movements are executed more quickly within a comfortable range of motion, known as the *middle-is-faster effect* (Rosenbaum et al., 1996).

For the studies on children reviewed in the current work, the precision requirements varied (especially) for the bar-transport-task. While four studies showed an increase in the ESC effect with age when the task required inserting the bar (high precision) into a target hole at the end of the action (Jovanovic & Schwarzer, 2011; Knudsen et al., 2012; Stöckel et al., 2012; Weigelt & Schack, 2010), Manoel and Moreira (2005) did not find an influence of this factor (i.e. inserting action). However, Hughes (1996) and Smyth and Mason (1997) found the effect to be present in the majority of their 4-year-old normally developing children and Toussaint et al. (2013) in 6-year old children, even though the object only had to be placed on a target (low precision). Also, when precision requirements were higher in the pencil alley task in Thibaut and Toussaint (2010, Experiment 2), older children showed an increase in the ESC effect. Together, findings are inconsistent with regard to the role of precision requirements and more research is needed to examine the influence of this factor on the planning skills of children.

2.4.2.4. Familiarity with the task

Previous studies differed also with regard to whether children were allowed to practice the task in familiarization trials before the actual testing began. Whereas Crajé, Aarts, et al. (2010), Hughes (1996), Knudsen et al., (2012), Jovanovic and Schwarzer (2011), Smyth and Mason (1997), van Swieten et al. (2010), and Wilmut and Byrne (2014b) gave the children the opportunity to get familiar with the task, Adalbjornsson et al. (2008), Jongbloed-Pereboom et al. (2013), Kirpatrick et al., 2013; Manoel and Moreira (2005), Robinson & Fischman, 2013; Scharoun and Bryden (2013), Stöckel et al. (2012), Thibaut and Toussaint (2010), Toussaint et al., 2013; Weigelt and Schack (2010), and Wilmut and Byrne (2014b) did not give any familiarization trials. In the 11 studies without any familiarization trials 9 studies found the ESC effect to be present. In the 7 studies, where children were allowed to get familiar with the task, 6 studies were able to provide evidence for ESC planning in children. Therefore, children's prior experience with a particular task (i.e. their familiarity) cannot fully explain the differences in the findings between studies.

Also, older children may show ESC planning only because of a higher level of expertise in similar tasks. As many toys for infants include actions, such as inserting objects into holes, but not pouring real liquids into real containers, it may be that young children are not as familiar with pouring water into a glass as older children and adults. Older children are even more familiar with different task requirements the more they are accustomed to different kinds of toys and to how to deal with them. However, though this may hold true for the youngest children in the study of Adalbjornsson et al. (2008), the oldest children in this study should have gained a fair amount of experience with pouring liquids into glasses.

In the study by Knudsen et al. (2012), children were not forced to pour any liquids, but just to turn over the cup. Besides the action effect, which appeared when the cup was placed on the coaster (i.e. a light switching on), there was no further maneuver (i.e. a filling action) intended. This may explain the finding, that even 3-year-olds showed the ESC effect in their study. These results by Knudsen et al. (2012) are in contrast to those of Scharoun and Bryden (2013), however. They observed significantly more children of 3 to 8 years demonstrating the ESC effect in the bimanual pick-up and pour task than in the unimanual pick-up and pass task. The results of the unimanual condition thus suggest that younger children may not adopt awkward grips to end an action comfortably, if the task does not require it. Robinson and Fischman (2013) examined only 4-year olds, who showed the ESC effect to an amount of 65%.

In any case, it may be that preschool children are more used to be handed a glass in the right orientation (especially if glasses are kept in places children cannot reach for them on their own), than to have to turn it first, such that specifically the turning action may have been less familiar to them. Realizing a pouring action may further influence the presence of ESC. In addition, offering familiarization trials in the beginning of the experiment may enhance the execution of ESC planning strategies, at least when children are younger.

2.4.2.5. Test procedure

Whether participants were seated or standing during the testing appears to influence the results. In 13 out of the 18 studies (Adalbjornsson et al., 2008, Crajé, Aarts, et al., 2010; Jongbloed-Pereboom, 2013; Jovanovic & Schwarzer, 2011; Kirpatrick et al., 2013; Manoel & Moreira, 2005; Robinson & Fischman, 2013; Scharoun & Bryden, 2013; Thibaut & Toussaint, 2010; Toussaint et al., 2013; van Swieten et al., 2010; Wilmut & Byrne, 2014a, 2014b) participants were seated. Only four tested them while standing (Knudsen et al., 2012; Smyth & Mason, 1997; Stöckel et al., 2012; Weigelt & Schack, 2010). It is not clear if participants in the study of Hughes (1996) were sitting or standing. ESC was found in all four studies in which children were standing, whereas ESC was observed in 11 of the studies in which children were sitting. It seems reasonable to assume that participants' grasping behavior is less constrained as long as they start from a neutral-zero-position (standing upright, with their arms hanging straight down their body, palms touching the legs). However, when they are sitting on a chair in front of the table, the range of arm motion is restricted by the table's surface, which serves as a barrier within the reach. It is possible that younger children try to avoid bumping with their elbows into the table. This may prevent children to use the underhand grip more often.

2.4.2.6. Motivation

In relation to the issue of familiarity mentioned above, any differences in the findings may be explained with reference to overall attractiveness of the task. A study conducted by Gollwitzer and Brandstätter (1997) revealed, that those implementation intensions, which are backed up by strong goal intentions, are more effective than implementation intentions without such motivational support. On the other hand, strong goal intentions do not necessarily lead to effective goal pursuit *per se*, but goal intentions (of the same motivational strength) followed by implementation intentions are more often realized than those without implementation intentions. This means, that choosing an action plan (i.e. acting in terms of ESC or not) seems to be modulated by intentional goals. Therefore, it could be that children have higher implementation intensions and choose an ESC grip to finish comfortably, when an action effect occurs.

The actions in the manual tasks were likely less fun to perform than playing to be a pirate and sticking the wooden sword into the tight hole. Motivational factors may also explain why Jovanovic and Schwarzer (2011) found ESC planning in children as young as 3½ years, which is a remarkable finding, whereas other studies did not report ESC planning in much older children. In their modification of the bar-transport-task, a salient action effect was added at the end of the action sequence. Action effects, such as lights (Paulus, Hunnius, Vissers, & Bekkering, 2011), play an important role in how children control their actions. It has been shown that children plan and select their actions by anticipating these corresponding action effects (e.g., Elsner & Aschersleben, 2003). In the study by Jovanovic and Schwarzer (2011), children were only able to produce this presumably interesting light effect when they correctly inserted the bar into the cylinder (independent of initial grip). This issue was addressed in the study of Knudsen et al. (2012), who wanted to find out if this action effect was the source of children's enhanced performance in the bar-transport-task. Inserting bars into cylinders might be more interesting when the insertion is instrumental for producing an interesting effect. This might have affected the child's overall motivation to perform the task and thereby focusing her attention on the task. They tested different age groups in task versions with and without action effects and did not find any differences between these conditions, suggesting that the action effect may not be the primary source of enhanced performance in the bar-transport-task. It is still possible, however, that the absence of an action effect in other studies using different tasks may explain why children only showed ESC planning at a later age. Further research is needed to address this question.

2.4.2.7. Influence of habitual and goal directed factors.

To select actions to solve everyday tasks, a habitual, stimulus-driven and an intentional, goal-directed system are employed by the central nervous system (Herbort & Butz, 2011). The habitual system associates stimuli with responses that were rewarding in the past. The goal-directed system, on the other hand, selects actions dependent on the match of anticipated action outcomes and current needs. For the ESC effect, it has been assumed that grip selection for object manipulation is determined by the goal-directed action selection system, e.g. the posture-based motion planning account (Rosenbaum et al., 2007a). In contrast to this assumption, recent studies, using response-compatibility paradigms, have also provided support for an involvement of the habitual action selection system (e.g. Masson, Bub, & Breuer, 2011; Tucker & Ellis, 1998). Accordingly, the perception of an object automatically evokes actions that are habitually applied to grasp these objects. The presentation of everyday objects may therefore automatically activate those actions that are habitually used to grasp them, independent of the current intention of the participant. A recent study by Herbort and Butz (2011) demonstrated that the ESC effect may be compromised for such habitual grasping behavior, when participants were presented with objects of everyday live. It may be that such habitual grasping effects also influenced the planning strategies in some of the children, especially, when the objects used were everyday life objects or objects that children are familiar with (Adalbjornsson et al., 2008; Crajé, Aarts, et al., 2010; Jongbloed-Pereboom et al., 2013; Knudsen et al., 2012; Robinson & Fischman, 2013; Scharoun & Bryden, 2013). Interestingly, five of these six studies using everyday life objects found ESC planning in children. The interaction of the habitual vs. goal-directed grasping systems and its influence of the ESC effect in the development of children`s planning abilities is another interesting field for future studies.

2.4.2.8. Sample size

The number of children assessed in the reviewed studies ranged from 17 to 351 children. However, in a number of studies, the sample size of each group tested was quite small (e.g. five to six children in each age group; Crajé, Aarts, et al., 2010; Manoel & Moreira, 2005), such that potentially present age effects were less likely to be detected by most standard statistical procedures. Another constraint could be the different sample sizes for the age groups tested within the studies. For example, van Swieten et al. (2010) tested 27 children with DCD in two age groups, 20 children with autism in only one age group, 70 normally developing children in two age groups, as well as 40 adults in another group. Analyzing the performance of participants in groups of different sample sizes may be problematic as comparisons can be inconclusive. Thus, sample size can be seen as a critical factor in some of the studies reviewed here.

2.4.3. Parallels of cognitive and motor development

Despite these inconsistencies, the studies reviewed above point to a pattern of a gradual improvement for motor planning skills across preschool and school children. It is likely that this developmental pattern is linked to a major growth spurt in the development of more general cognitive functions, occurring in children at about 5 to 6 years of age. This would point to the interdependency between the development of higher cognitive control processes and the maturation of sensory-motor functions (as indicated by advanced motor planning abilities).

A number of cognitive abilities are impaired in children with various developmental disorders. Therefore, a comparison between the performance of normally developing children and children with developmental disorders may inform us more about the influence of cognitive planning skills on the ESC effect. The findings of the studies reviewed above, however, provide only mixed evidence. Although prior research demonstrated deficits in children with autism for tasks drawing on executive functions (Geurts, Verté, Oosterlan, Roeyers, & Sergeant, 2004) and complex planning skills (Prior & Hoffmann, 1990). Van Swieten and colleagues (2010) found autistic children to behave in the same manner as normally developing children in the handle-rotation-task. Also, Hughes (1996) showed an increase of the ESC effect from 5% in 3-year-old to 30% in 4-year-old autistic children (but this increase was not as large as in normally developing children). Compared to the controls, autistic children were of similar age or older in terms of their nonverbal mental age in this study (Hughes, 1996). In contrast, the children in van Swieten et al. (2010) had the same chronological age as controls, and thus, might have been even younger than the controls in terms of mental age, respectively. Finally, in contrast to the findings in normally developing children, children with autism were more likely to show the ESC effect in the handle-rotation-task compared to the bar-transport-task, thus showing a pattern opposite to normally developing children. Obviously, these considerations must be taken with caution due to a lack of studies on children with autism. Given a deficit in executive functioning in autism, it is still an open question whether cognitive planning skills play a crucial role in the development of the ESC effect.

Children with MLD (Hughes, 1996) showed an increase from 40% at 3 years to 50% at 4 years in the bar-transport-task. Though, these children showed less ESC planning than normal controls, the 4-year-olds’ performance (in terms of percentage of children showing ESC in the bar-transport-task) was comparable (if not even better) to the performance of normally developing children of the same age (Manoel & Moreira, 2005; Smyth & Mason, 1997; Thibaut & Toussaint, 2010; Weigelt & Schack, 2010). With regard to more specific motor deficits, three studies focused on children with DCD (Smyth & Mason, 1997; van Swieten et al., 2010; Wilmut & Byrne, 2014a) and two on children with CP (Crajé, Aarts, et al., 2010; Kirpatrick et al., 2013). Whereas children with autism are well known to have difficulties in cognitive planning, children with DCD may have specific difficulties in motor planning, due to their abnormal development of motor skills, such as poor eye-hand coordination and prehension difficulties. Interestingly, children with DCD did not show anticipatory planning skills in the handle-rotation-task (Smyth & Mason, 1997; van Swieten et al., 2010), but they were able to show this sensitivity in the bar-transport-task (Smyth & Mason, 1997), and in the handle-rotation-task (Kirpatrick et al., 2013). Also, there were no significant differences in performance between children with DCD and normally developing children in Smyth and Mason (Smyth & Mason, 1997). Though, children with DCD showed significantly less ESC planning than controls in van Swieten et al. (2010). But obviously, the percentage of children showing ESC increased in both groups in both studies with higher age. These findings suggest that children with DCD are delayed, but not impaired, in the development of ESC planning. In addition, these findings support the hypothesis that overall task demands are lowest in the bar-transport-task.

Different from DCD, motor disorders in CP are secondary to brain lesions and may therefore affect one side of the body more than the other (unilateral CP). Crajé, Aarts, et al. (2010) reported less ESC planning in the handle-rotation-task for children with CP compared to controls. However, there was an increase in both groups in percentage of children showing the ESC effect in the preschool years. Thus, similar to van Swieten et al.'s (2010) findings on DCD, ESC planning may be delayed in children with CP whereas performance of normal controls continued to increase after 5 years of age, there was a decrease or stagnation of ESC planning in children with CP between 5 and 6 years of age. Given that the development of ESC planning might not be linear (Thibaut & Toussaint, 2010) and given the findings for children with DCD, it is still an open question whether the majority of children with CP would show ESC planning at an older age. Unfortunately, the study conducted by Kirpatrick et al. (2013) did not include any control group.

Overall, the findings of the few studies on anticipatory planning in children with motor impairments are largely inconclusive. Both conditions assessed in the studies reviewed cover heterogeneous disorders and may show comorbidities also with cognitive deficits. The motor impairment in DCD may occur in isolation or with other cognitive deficits, such as learning disabilities or attention deficit disorders. Similarly, the motor disorders of CP are often accompanied by disturbances of sensation, cognition, and perception, among others (Rosenbaum, Paneth, Leviton, Goldstein, & Bax, 2007). Future research is therefore needed to investigate the relative roles of cognitive processes and motor skills in the development ESC planning.

2.5. Conclusion

Twelve out of the 18 studies reviewed found the ESC effect to be present in normally developing children across different ages (although to different extends). The emergence of such anticipatory planning skills is consistent with the findings of studies employing the same tasks with adults (Rosenbaum et al., 1990; Rosenbaum & Jorgensen, 1992). It is still an open question why evidence for anticipatory planning in childhood was found in some studies (Crajé, Aarts, et al., 2010; Jongbloed-Pereboom et al., 2013; Jovanovic & Schwarzer, 2011; Kirpatrick et al., 2013; Knudsen et al., 2012; Robinson & Fischman, 2013; Scharoun & Bryden, 2013; Smyth & Mason, 1997; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Toussaint et al., 2013; Weigelt & Schack, 2010; Wilmut & Byrne, 2014a, 2014b), but not by others (Adalbjornsson et al., 2008; Hughes, 1996; Manoel & Moreira, 2005; van Swieten et al., 2010). Possible reasons for inconsistencies in the findings may relate to differences in task demands, such as precision requirements, number of action steps to be performed, familiarity, and motivation. Despite the different findings regarding the age of emergence and the developmental trajectory, the studies reviewed suggest a marked increase in ESC planning around the end of the preschool years, as well as a further increase throughout childhood. Further research is needed to assess the development of ESC planning and to determine the relative influence of motor skills and cognitive factors on its developmental course.

2.6. Implementations

Based on the findings on the ESC development in the studies reviewed above, it becomes clear that the developmental trajectory of the ESC effect differs between the populations tested. This may be due to the tasks employed to test children's sensitivity for ESC. The tasks used were variants of the original version of the *bar-transport task* (Rosenbaum et al., 1990), the *handle-rotation task* (Rosenbaum, Vaughan, Jorgensen, Barnes and Stewart (1993), and the *overturned-glass task* (Fischman, 1997). Most relevant for the present project: Some studies found an early onset[7] of ESC development in normally children (as early as 3 years of age, e.g. Jovanovic & Schwarzer, 2011; Knudsen et al., 2012), other studies found the effect to be present at a later stadium of child development (as late as 10 years of age, e.g. Jongbloed-Pereboom et al., 2013; Thibaut & Toussaint, 2010; Scharoun & Bryden, 2013), or even were not able to find any sensitivity for ESC planning in the examined ages (e.g. until the age of 5 year, Manoel & Moreira, 2005; until the age of 7 years, Smith & Mason, 1997; or even until the age of 14 years, van Swieten et al., 2010). For children with developmental disorders, the onset may be even further delayed, e.g. in MLD (Hughes, 1996), autism (Hughes, 1996; van Swieten et al., 2010), in DCD (Smyth & Mason, 1997; van Swieten et al., 2010; Wilmut & Byrne, 2014a), and in CP (Crajé, Aarts, et al., 2010; Kirpatrick et al., 2013).

Above, many factors potentially modulating the development of the ESC effect, like age effects, the number of actions steps needed to accomplish the task, the required degree of object rotation, precision requirements, the familiarity with the task, task procedures, motivational aspects, and sample size were discussed. These factors may have influenced the time of onset of anticipatory planning skills. This concludes the literature review and thereby the first research aim has been fulfilled.

The second research aim is to examine the possible influence of executive functions (EF) on the developmental trajectory of the ESC effect. Both, EF and the ESC effect rely on planning abilities, which develop in children over the course of their cognitive and sensorimotor maturation. This raises the question whether the development of EF interacts with the development of motor planning abilities, as signified by the ESC effect. The existence of such a relationship has been proposed recently (Scharoun & Bryden, 2013; Stöckel et al., 2012; van Swieten, et al. 2010;

[7] ESC is assumed to be present, if more than 50% of the participants in one age-group showed the effect reliably, i.e. in more than 50% of the trials. If, for example, more than 50% of 5-year-olds showed the effect, but less than 50% of the 6-year-olds, planning for ESC is declared as being present from 7 years on, as the number of participants then stays consistently over 50%.

Wilmut & Byrne, 2014b), which is further supported by the similarity of the developmental trajectories of EF and the ESC effect (see Figure 4 for the projected developmental trajectory of the different EF, and the Table 2 for an overview of the developmental trajectories for the different ESC tasks).

Therefore, the second aim of the research project is to investigate the possible influence of EF on the developmental trajectory of the ESC effect. To this end, an experimental study examining the development of motor planning abilities and cognitive skills in children from 3- to 10-years of age was conducted. The experimental study will be reported in the following Chapter.

Chapter 3

Motor planning and executive functions across young ages

This chapter is based on the publication of Wunsch, K., Pfister, R., Henning, A., Aschersleben, G., & Weigelt, M. (under review). The development of motor planning skills and executive functions across young ages. *In prep.*

3.1. Introduction

Differences in grasp selection between adults and children have been construed as indicating a deficit in children's planning (see Hughes, 1996; Smyth & Mason, 1997), with the presence of ESC as an indicator for "thinking ahead", referring somewhat ambiguously to some kind of planning skills. This led to an important debate, initially raised by van Swieten et al. (2010), about whether performance in grasp selection tasks is driven by executive planning (i.e. actively planning ahead to solve actions correctly or to avoid mistakes, for example) or motor planning (i.e. planning motor actions in advance in order to solve them correctly or most economically), or both (Scharoun & Bryden, 2013; Stöckel et al., 2012). Van Swieten and colleagues (2010) argued that the ESC effect cannot fully rely on executive planning, because adults do not consistently select grasps, which end in comfortable positions. Thus, if executive planning was the driving force, executive functions would fail on some trials, but not on others, which is unlikely to be the case. Instead, van Swieten and colleagues (2010) proposed that grasp selection relies predominantly on pure motor planning processes and that the most efficient movement is selected for each grasp. On the other hand, it is commonly assumed that motor skills are very similar to intellectual skills in terms of acquisition and representation (Rosenbaum et al., 2001), which suggests the exact opposite of the aforementioned argument. In this regard, it has been assumed for a long time, that perceptual-motor skills and intellectual skills have closely related developmental origins, as already noted by Piaget and Cook (1952), who based the development of intelligence upon the emergence of skilled action.

Both, EF and the ESC effect are associated with planning. EF is an umbrella term that incorporates a collection of inter-related processes underlying purposeful, goal-directed behavior (Gioia et al., 2001). These executive processes are essential for the formation and maintenance of goals and strategies, preparation for action, and verification that plans and actions have been implemented appropriately (Luria, 1973). Processes associated with EF are numerous and commonly include anticipation, goal selection, planning, initiation of activity, self-regulation, mental flexibility, deployment of attention, and utilization of feedback (Anderson, 2002). Executive processes develop with the biological maturation of the frontal cortex throughout childhood and adolescence in a multi-stage process (Stuss, 1992), that is, with different developmental trajectories and rates for different functions (Passler et al., 1985). Therefore, EF play an important role in a child's cognitive functioning, behavior, emotional control, and social interaction, but develop at different rates and at different times, differently for children's individual development. This raises the question whether EF development may predict or influence the development of motor planning, as signified by the ESC effect (see also Scharoun & Bryden, 2013; Stöckel et al., 2012). The similarity of the developmental trajectories of EF and the ESC effect suggests a potential relationship in development (see Anderson, 2002, for the projected developmental trajectory of the different EF (depicted in Figure 4), and Chapter 2, for an overview of the developmental trajectories for the different ESC tasks (see Table 2)).

Therefore, the following study investigates the possible role of EF on the developmental trajectory of the ESC effect. To this end, eight groups of children and a group of adults were with examined within three ESC tasks, in order to assess their motor planning skills and in three EF tasks to measure their cognitive planning skills. The following predictions were made: (1) an increase of task performance in each subtest as children get older, (2) inter-correlations between the ESC tasks, as well as (3) positive correlations in each age group between participants' performance on ESC and EF tasks.

3.2. Method

3.2.1. Participants

Nine age groups with a total of 217 participants were recruited. For a detailed overview of participant's demographics please see Table 3. All children were recruited from local daycare centers, elementary schools or via announcements in a local newspaper in Paderborn; all adults were students at the University of Paderborn. Handedness was determined using a short test, detecting how they threw a ball, used a spoon, and wrote/drew with a pencil. For all groups of children, parents provided their informed consent for participation and for video recording their child during the experiment. Participation was voluntary, without any financial compensation. Children received a personal certificate of participation and some sweets.

3.2.2. Tasks and Procedures

A test-battery was designed to assess ESC planning and EF, consisting of three different tasks each: the bar-transport-task, the sword-rotation-task, and the grasp-height-task for ESC, and the Tower-of-Hanoi-task (TOH), the Mosaic-task, and the D2-attention-endurance-test for EF. For each task, the respective materials were placed on a table in front of the participant, except for the grasp-height-task, in which the shelf was placed next to the table. Participants stood in front of the table for the bar-transport-task and for the sword-rotation-task, and in front of the shelf for the grasp-height-task. In all EF tasks, they sat at the table, with seat height adjusted for each participant. Table height was 55 cm for kindergarten children and 75 cm for school children and adults. To adjust for differences in body height, preschoolers smaller than 110 cm stood on a 10 cm high podium, and school-aged children smaller than 120 cm or 130 cm stood on a 20 or 10 cm high podium. Dividing these heights (body height plus podium height) by table height revealed comparable height-coefficients between preschoolers, school-aged children, and adults (please

Table 3. Demographic overview of the sample.

Age	Mean age (years)	SD	*N*	% of children	Gender		Mean height (cm)	SD	Height coefficients	Type of School						Handedness	
					♂	♀				pre-school	1st grade	2nd grade	3rd grade	4th grade	5th grade	Right	Left
3-year-olds	3.5	0.3	21	11.1	10	11	101.8	4.9	2.0	21	0	0	0	0	0	20	1
4-year-olds	4.34	0.2	23	12.2	11	12	109.8	5.2	2.0	23	0	0	0	0	0	23	0
5-year-olds	5.4	0.3	26	13.8	13	13	115.8	6.7	2.0	24	2	0	0	0	0	22	4
6-year-olds	6.5	0.3	22	11.6	15	7	123.9	6.3	2.0	7	14	1	0	0	0	22	0
7-year-olds	7.5	0.3	26	13.8	11	15	130.7	6.5	2.1	0	11	15	0	0	0	24	2
8-year-olds	8.5	0.3	27	14.3	11	16	134.5	5.7	2.1	0	0	13	13	1	0	26	1
9-year-olds	9.4	0.3	23	12.2	10	13	141.1	5.0	2.1	0	0	0	13	10	0	22	1
10-year-olds	10.5	0.3	21	11.1	8	13	147.2	7.5	2.1	0	0	0	0	16	5	18	3
Adults	24.4	2.2	28	N/A	15	13	176.3	8.4	2.1	0	0	0	0	0	0	27	1

see Table 3). A camera was positioned 150 cm besides the participant, at a height of 160 cm, and recorded the whole experiment for later coding.

Participants were tested individually by one experimenter. For several pre-schoolers, also a teacher or a parent was present in order to make the child feel comfortable. Prior to testing, adult participants or children's parents completed a short questionnaire on handedness, on how they completed their way to kindergarten/school/university, and on leisure time activities, sport participation, and spoken languages. Afterwards, children completed a short test to determine handedness as the hand that was used in at least two out of the three tasks. This hand was marked with an ink stamp. In the ESC tasks, children were instructed to always use the "stamp-hand". The ESC tasks were run without familiarization trials. The order of all six tasks was randomized across participants to prevent effects of serial order. In the ESC tasks, participants stood in front of the table or the shelf, 10 cm away from the edges, respectively, or sat in front of the table with the respective apparatus on it for the EF tasks, with materials 10 cm away from the edge of the table. On average, the entire session lasted between 90 and 100 minutes. The duration differed according to participant's time needed to complete the different tasks and according to requests for breaks between the subtests. In general, most of the adults were able to complete the testing session in about 75 minutes, whereas some children needed up to 150 minutes to complete the whole session.

3.2.2.1. Motor tasks used to assess ESC

In all three motor tasks, participants stood in front of the table or the shelf, 10 cm away from the edge behind a starting line, the apparatus or the middle platform at body midline, with their arms hanging on each side of their body, the palm facing their upper legs (hereafter: starting position). Participants were instructed to always use their dominant hand ("stamp-hand", see above) for all grasps made in the ESC tasks.

Bar-transport-task: In this study, a modified version of the original bar-transport-task (Rosenbaum et al., 1990) was used, which was similar to the one employed by Weigelt and Schack (2010). Different to the original task version, there was only one target at midline in front of the apparatus (and not two targets on either side as in the original task). A wooden bar, 20 cm long, with one black and one white end rested horizontally on two cradles, 15 cm above the table. A 5 cm high, black cylindrical container served as the movement target and was placed 10 cm in front of the support. To keep precision requirements comparable across age groups, the bar's diameter measured 1.5, 2.0, or 2.5 cm for preschoolers, school-children and adults, respectively, and the target hole diameter measured 2.0, 2.5, or 3.0 cm for preschoolers, school-children and adults, respectively (see Figure 8).

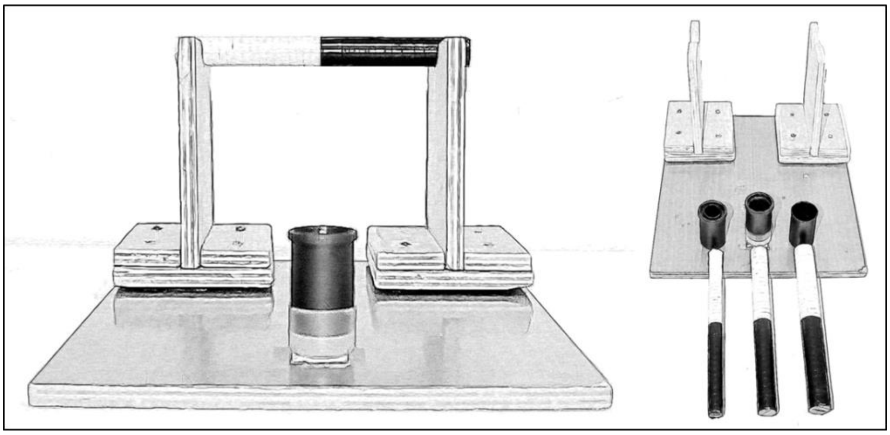

Figure 8. Apparatus used for the bar-transport-task. Left the standard start position (orientation of the bar was counterbalanced), right the different sizes of bars and target holes used for different ages.

The start orientation of the bar (i.e. black or white end on the right side) was counterbalanced across participants and remained the same throughout the experiment. Participants were instructed to take up the starting position, to then grasp the bar firmly with their "stamp-hand", and to insert the black or white end of the bar into the target hole, as indicated by the experimenter. After the insertion action was completed, they were instructed to get back to the starting position. To prevent observational learning, the experimenter used a pincer grip at one end of the bar to reposition the bar back on the two cradles. Participants completed six trials in randomized order, three trials for each end. They could use either an overhand or an underhand grip to grasp the bar. This resulted in either an upright (i.e. thumb-up) or an inverted (i.e., thumb-down) hand position at the end of the movement (see Figure 9), depending on the start-orientation of the bar.

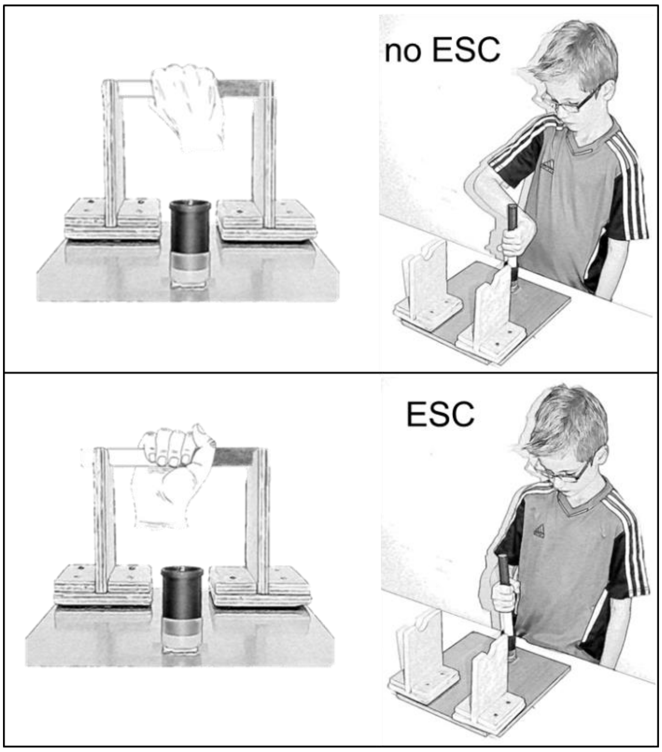

Figure 9. Both pictures show a critical trial, where the white end of the bar had to be inserted into the target hole, and the possible outcomes**.** Upper part: An initially comfortable overhand posture results in a finally uncomfortable thumb-down posture. The child therefore does not behave in a manner consistent with ESC. Lower part: An initial grip adaption to a more uncomfortable underhand position results in a finally comfortable end position with the thumb pointing upwards.

In the three uncritical trials, an overhand grip automatically resulted in a comfortable thumb-up position; in the three critical trials, however, an underhand grip was necessary to end in the comfortable thumb-up position and therefore, in ESC. Grasp choice was coded from the video. Following recent studies (Adalbjornsson et al., 2008; Stöckel et al., 2012; Weigelt & Schack, 2010), we considered the ESC effect to be present if in a given condition (critical and uncritical trials) at least two out of the three trials ended in the comfortable position.

Sword-rotation-task: A variation of the original rotation task (Rosenbaum et al., 1993) was used, which was similar to the task versions created by Crajé, Aarts, et al. (2010) and Jongbloed-Pereboom et al. (2013). A wooden sword (30 cm in length, 3.2 cm in width, and 0.8 cm in height; handle length = 10 cm) was horizontally placed on a platform (47 x 47 cm) in front of a target box in one of six start positions (Position 1 = 0° (12 o'clock position), Position 2 = 90°, Position 3 = 135°, Position 4 = 180°, Position 5 = 225°, and Position 6 = 270°). The sword's blade had to be inserted into a tight fitting hole in a wooden block (47 cm in length, 16 cm in width, and 16 cm in height; hole 3.5 x 1 cm) (see Figure 10). The same apparatus was used for all age groups.

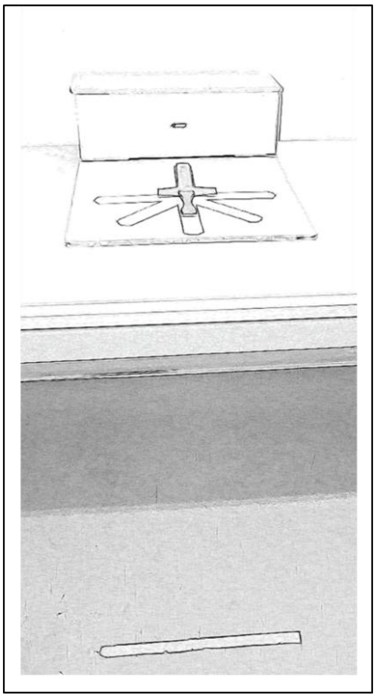

Figure 10. Apparatus for the sword-rotation-task. The sword is in the start position (Position 1). Positions are numbered clockwise.

Again, participants were instructed to take up the starting-position and were told that they were a pirate (to adults this task was explained without the cover story) and that they had to insert the sword into the box by firmly grasping the handle in exactly the position it laid on the table, that is, without turning the sword before grasping it. Each session started with Position 1 to make sure participants understood the task. The experimenter retrieved the sword from the box and repositioned it on the platform always by grasping it at the cross guard to avoid observational learning. The task consisted of three blocks of 6 trials (one for each position), resulting in a total of 18 trials. Trial positions were randomized in each block. Participants could choose grips that resulted in either a comfortable end position (ESC; with the thumb pointing towards the blade) or an uncomfortable end position (no ESC; with the thumb pointing away from the blade) (see Figure 11).

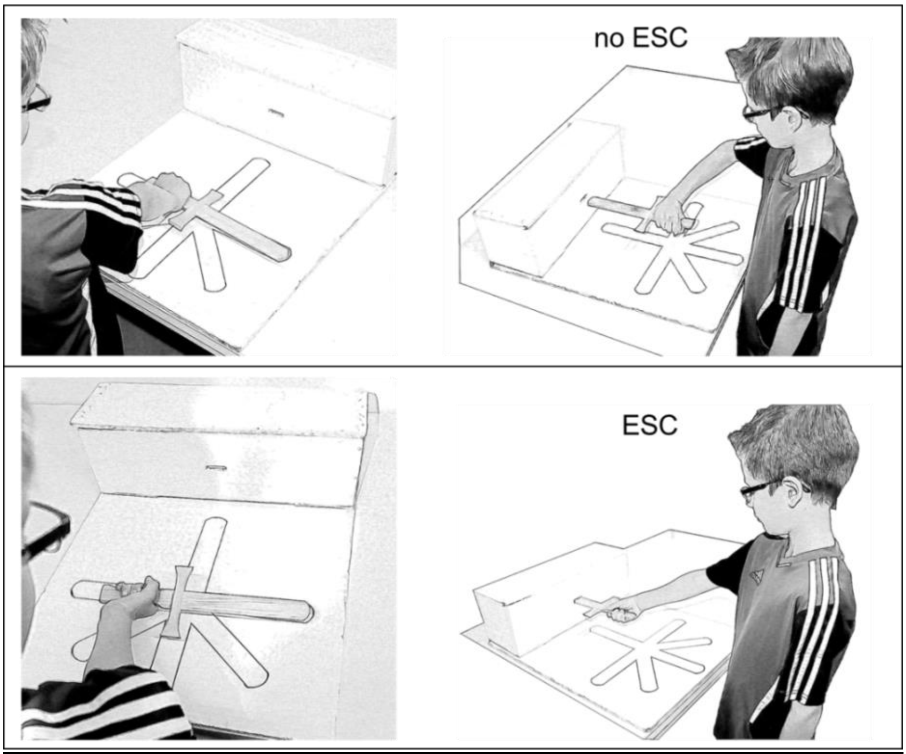

Figure 11. Both pictures show a critical trial (Position 2) and the possible outcomes**.** Upper part: An initially comfortable overhand posture results in a finally uncomfortable posture with the thumb pointing away from the blade. The child therefore does not behave in a manner consistent with ESC. Lower part: An initial grip adaption into a more uncomfortable underhand position results in a comfortable end position with the thumb pointing towards the blade.

Within each block, two trials were critical. Here, grasping the sword in a more uncomfortable hand position (at Positions 2 and 3) resulted in a comfortable end position. Grasp choice was coded from the video. We considered the ESC effect to be present if at least 4 out of the 6 critical trials ended in a comfortable position.

Grasp-height-task: An adaptation of the original grasp-height-task (Cohen & Rosenbaum, 2004) was used, which was similar to the version employed by Weigelt and colleagues (2007). Participants had to transport a standard toilet plunger from a home platform to a lower or higher target platform, and back to the home platform. Board heights were individually adjusted to participants' body height by taking the board heights and average height of adult participants reported in Rosenbaum and colleagues (2006) as reference. For example, for an 87 cm tall child, shelf heights were 25.4, 43.2, and 61.0 cm for the low, middle and high shelf, respectively. On each shelf board, a wooden platform was attached in such a way that it protruded 15 cm from the shelf. The home platform was attached to the horizontal center of the middle shelf board. The two target platforms were attached to the participant's side of handedness, one on the low and the other on the high shelf board. The toilet plunger stood on the home platform: a circular rubber base (10 cm in diameter and 5 cm high) supported the cylindrical wooden shaft (2.5 cm in diameter and 33 cm or 44 cm in length for child or adult participants, respectively, see Figure 12).

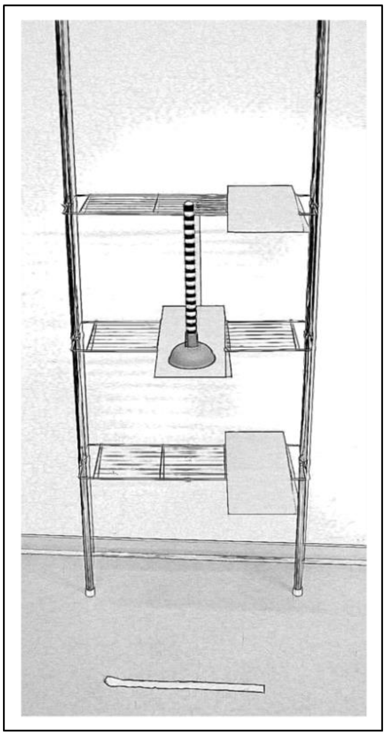

Figure 12. Apparatus used for the grasp-height-task. The plunger is in the start position. Shelf heights were scaled to participants body height.

Participants were told to take up the starting position. Child participants were told that their performance was videotaped in this task in order to program a robot afterwards that could then perform the same actions as they did and children therefore needed to closely follow the instructions. Participants' task was to stand in the start position, to grasp the plunger firmly on the shaft and to transport it to the platform indicated by the experimenter (home-to-target moves). Afterwards, they had to resume the starting position and then bring the plunger back to the home platform (target-to-home moves). Participants were told that home and target platform could differ across trials. Participants completed a total of six trials: the plunger was transported from the home platform to the high target platform and back to the home platform in three trials, and from the home platform to the low target platform and back to the home platform in another three trials. Conditions were always blocked, with the start platform for the first three trials counterbalanced across participants. Grasp height was coded from the video. Participants showed planning for ESC if they grasped the plunger lower for the home-to-target moves than for the target-to-home moves for the high platform, and higher for the home-to-target moves than for the target-to-home moves for the low platform (see Figure 13).

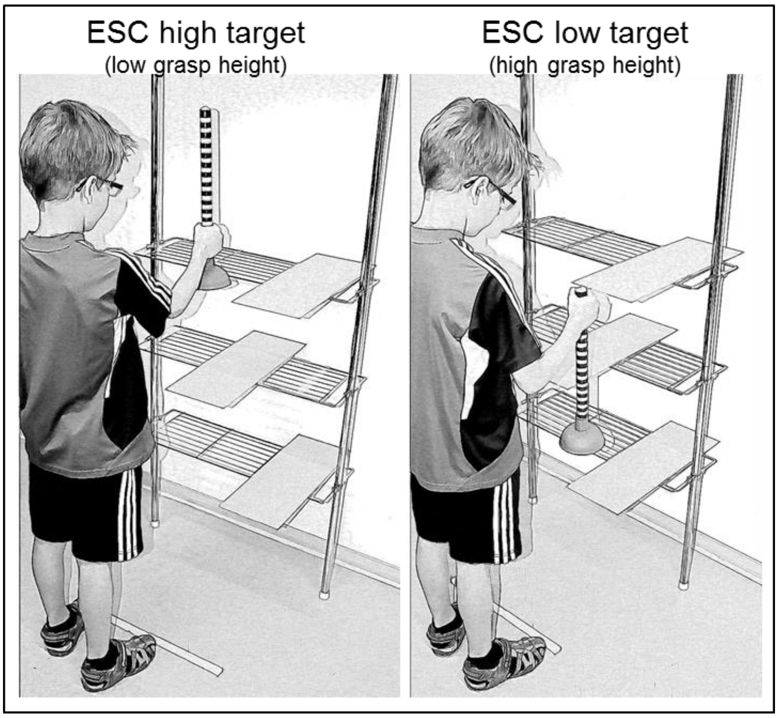

Figure 13. End-State Comfort in the grasp-height-task.

ESC was considered to be present if participants showed this pattern in at least two out of the three trials for each platform. Also, mean differences in grasp heights were computed for later analyses.

3.2.2.2. Cognitive tasks used to assess EF

In all three cognitive tasks, participants sat at a table, on a height-adjustable chair. Materials were placed in front of them, according to the particular test manual.

Tower-of-Hanoi-task: We used a slightly modified version of the original task (Simon, 1975), which was similar to Welsh (1991), but used only one apparatus as in the original version. It consisted of 3 pegs in a row (height: 23 cm, diameter: 4 cm, distance between pegs: 15 cm) that were attached on a bottom plate. On these pegs, up to five discs of varying size and color could be located: black (diameter: 13 cm), blue (diameter: 11 cm), green (diameter: 9 cm), red (diameter: 7 cm), and yellow (diameter: 5 cm). The target position was indicated by a picture, displayed at a 75 degree angle on a music stand, 20 cm behind the apparatus (see Figure 14). The peg on the very right was the target peg, and was marked with a black duct tape at the top.

Participants were instructed to build a tower of discs as shown by the target position on the picture, starting from the arrangement presented. Each participant was to solve up to ten different tower problems, with increasing degree of difficulty. Depending on the number of discs and on the starting arrangement, trials differed in the minimal number of moves necessary to complete the tower. Three test versions were created with difficulty adjusted to age: a version for 3- and 4-year-olds, for 5- and 6-year-olds, and for 7-year-olds and older children and adults. Every test started with a familiarization trial with three discs (2, 3 or 6 moves according to the test version), in which rules were explained and questions could be clarified. Participants had to follow three rules: (1) move only one disc at a time, (2) a disc may only be in your hand or on a peg, but not on the table or somewhere else, and (3) a smaller disc can be placed on top of a bigger disc, but a bigger disc cannot be placed on top of a smaller disc. In test trials, each starting position was initially covered by placing a cardboard in front of the apparatus to assess latency. The task was terminated whenever participants were not able to solve a tower problem in up to twice the minimal number of moves necessary to solve the problem, or if participants did not move any disc within 90 seconds. The single tower problems included 3 or 4 discs in the two easier test versions, and 4 or 5 discs in the most difficult version. Minimal number of moves necessary ranged between 2 and 15 for 3- and 4-year-olds, between 4 and 15 for 5- and 6-year-olds, and between 7 and 31 for children aged 7 and older, and adults[8].

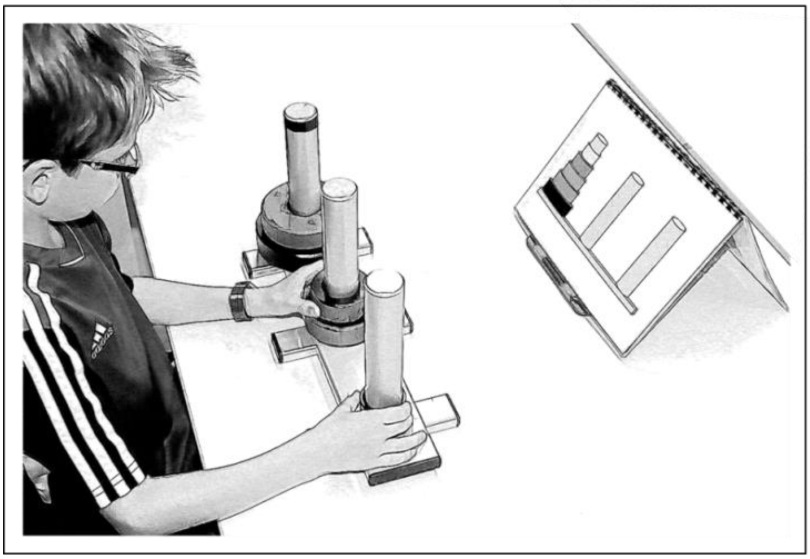

Figure 14. Apparatus used for the Tower-of-Hanoi-task. The Tower shown on the picture needed to be re-built on the peg marked with the black tape.

Start- and end-positions of the discs were checked from the video and the number of steps to complete the tower was counted. Number of tower problems completed correctly served as dependent measure.

Mosaic-task: This task is a subtest of the Wechsler Scale of Intelligence[9]. In the Mosaic-task, a given mosaic pattern has to be re-created with a set of building

[8] For each age group, problem difficulties were as follows, whereby the first number always indicates the number of discs used, the second number always indicates the number of moves for optimally solving the problem: 3-2, 3-3, 3-4, 3-5, 3-6, 4-7, 4-8, 4-9, 4-10, 4-11, and 4-15 for 3- and 4-year olds; 3-4, 3-5, 3-6, 4-7, 4-8, 4-9, 4-10, 4-11, 4-13, 4-15 for 5- and 6-year olds; and 4-7, 4-9, 4-10, 4-11, 4-13, 4-15, 5-20, 5-24, 5-27, and 5-31 for children older than 7 years and adults.

[9] The Mosaic-task is a subtest of the HAWIVA®-III (Hannover Wechsler Intelligenztest für das Vorschulalter; German translation and adaption of the WPPSI®-III (Wechsler Primary and Preschool Scale of Intelligence) of David Wechsler (2002); Ricken, Fritz, Schuck, & Preuß, 2007; for preschool children), the HAWIK®-IV (Hamburg Wechsler Intelligenztest für Kinder; German translation and adaption of the WISC®-IV (Wechsler Intelligence Scale for Children) of David Wechsler (2003); Petermann & Petermann, 2008; for school children) and the WIE® (Hamburg Wechsler Intelligenztest für Erwachsene; German translation and adaption of the WAIS®-III (Wechsler Adult Intelligence Scale) of David Wechsler (1997); von Aster, Neubauer, & Horn, 2006; for adults) to assess visuospatial and motor skills.

blocks. The target picture or the 3D model was positioned 18 cm away from the edge of the table, 10 cm to the side of participants' body midline on the opposite side of handedness. Participants had to arrange up to nine cubes (side length: 2.5 cm) of different colors (all red sides, all white sides or red and white sides; see Figure 15).

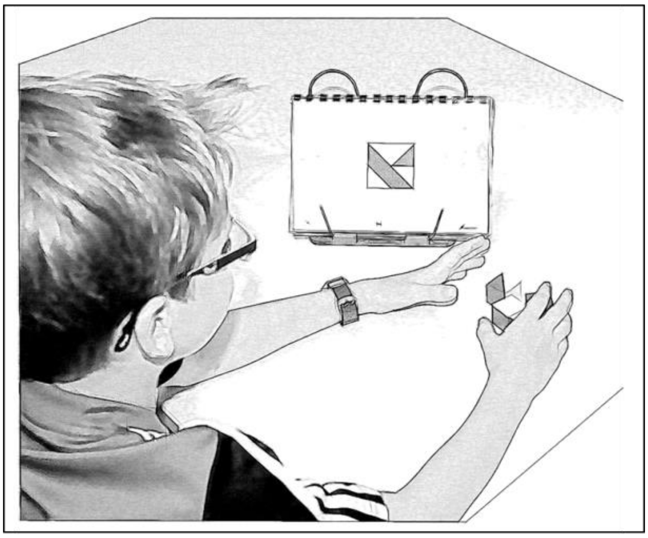

Figure 15. Apparatus used for the Mosaic-task. The pattern displayed on the picture should be re-build with the several cubes.

The test was administered in accordance with the respective test manual and age group. Completion time was coded from the video and performance was checked for accuracy. The percentage of scored points was calculated as indicated in the respective test manual, and served as dependent measure for this task.

D2-attention-endurance-task: Three versions of this speeded test of selective attention (Brickenkamp, 1962) were used: the analogous subtests in the Intelligence and Development Scales for preschool children (IDS-P; Grob, Reimann, Gut, & Frischknecht, 2013) and for school children (IDS, Grob, Meyer, & Hagmann-von Arx, 2009), and the D2-R for adults (Brickenkamp, Schmidt-Atzert, & Liepmann, 2010). Preschool children`s task was to sort cardboard cards (6 x 6 cm) showing a duck, according to the presence or absence of a distinct characteristic. A pencil, lying 25 cm away from the child at the side of their handedness indicated where to stack the cards with the given characteristic (see Figure 16).

Figure 16. Set-up of the D2-task according to the IDS-P for children aged 3 to 5 years. Cards had to be sorted due to a specific pattern.

In the paper-pencil version for school children, participants were presented with a DIN A3 sheet of paper showing rows of ducks with or without distinct characteristics. Children had to mark the ducks with the target characteristics (see Figure 17).

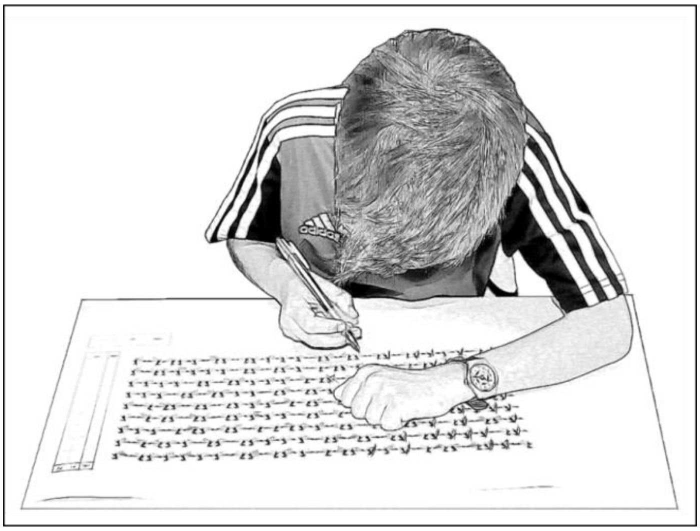

Figure 17. Set-up of the D2-task according to the IDS for children aged 5 to 10 years. Ducks had to be sketched out due to a specific pattern.

In the paper-pencil version for adults, rows of the letters *p* and *d* were presented on a DIN A4 sheet of paper, and letters with distinct characteristics had to be marked (see Figure 18). Videos of preschool children were checked to verify the number of properly sorted cards. Performance was scored in accordance with the respective test manual. According to the test manual, the total number of scored points served as dependent measure.

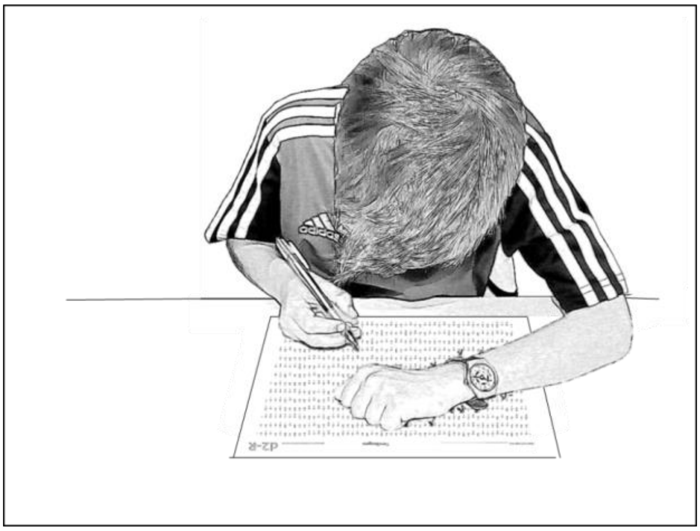

Figure 18. Set-up of the D2-task according to the D2-R adults. All "*p*'s" had to be sketched out due to a specific pattern.

3.2.3. Data Analysis / Scoring

Chi-Square tests were used to examine group differences in the ESC tasks due to the dichotomous nature of the dependent variables. For the EF tasks[10], one-way ANOVAS were used to examine these differences. To test for age effects, regression analyses were applied. Bivariate Pearson's correlations were computed in order to find possible relationships within the ESC tasks and the EF tasks, and between these motor and cognitive tasks.

3.3. Results

This section will be divided into three major parts, according to the specific research goals: (1) the development of ESC, (2) the relationship within the tasks measuring ESC, and (3) the correlation between ESC and EF.

3.3.1. The development of ESC

In the following section, the results of the three tasks used to measure anticipatory planning are depicted.

3.3.1.1. Bar-transport-task

Figure 19 illustrates the mean percentage of participants in each group who showed ESC planning in at least two out of three trials in each condition. In the uncritical trials (e.g. trials where the right side of the bar had to be inserted into the tar-

[10] We measured different dependent variables for the Mosaic and the Tower of Hanoi tasks, e.g. the total amount of correctly solved items, the total score and the score with bonus-points for fastest resolve in the Mosaic task, and the amount of incorrect moves, the number of correctly solved items or the number of the item where the first mistake was made before doing the first move in the Tower of Hanoi task. Due to their correlations (Mosaic-task: r = .229 for correctly solved items and total score; r = .194 for correctly solved items and bonus-score, and r = .950 for total score and bonus-score; all $p < .01$; Tower-of-Hanoi-task: r =.261 for the amount of incorrect moves and the item with the first mistake, r = .149 for the amount of incorrect moves and the number of correctly solved items, and r = .218 for the item with the first mistake and the number of correctly solved items; all $p < .05$), however, we chose the most superordinate variable for further analysis.

get hole for right-handers), all participants in all age groups adopted an overhand grasp in at least two out of the three uncritical trials and therefore ended in a comfortable end position. In the critical trials, only 24% of the 3-year old children showed sensitivity for ESC planning, this amount increased to 48% in the 4-year-olds, to 62% of the 5-year-olds. Here, a stagnation of the developmental trajectory can be seen in 5-to-8-year old children: 64% of the 6-year-olds, 62% of the 7-year-olds, and 63% of the 8-year-olds showed ESC behavior. Then, the amount of participants showing ESC increased again from 78% in the 9-year-olds, to 95% in the 10-year-olds, up to 96% in adults. A chi-square analysis showed these differences in the proportion of children showing ESC in the critical trials to be significant, $\chi^2(7) = 34.93$, $p < .001$.

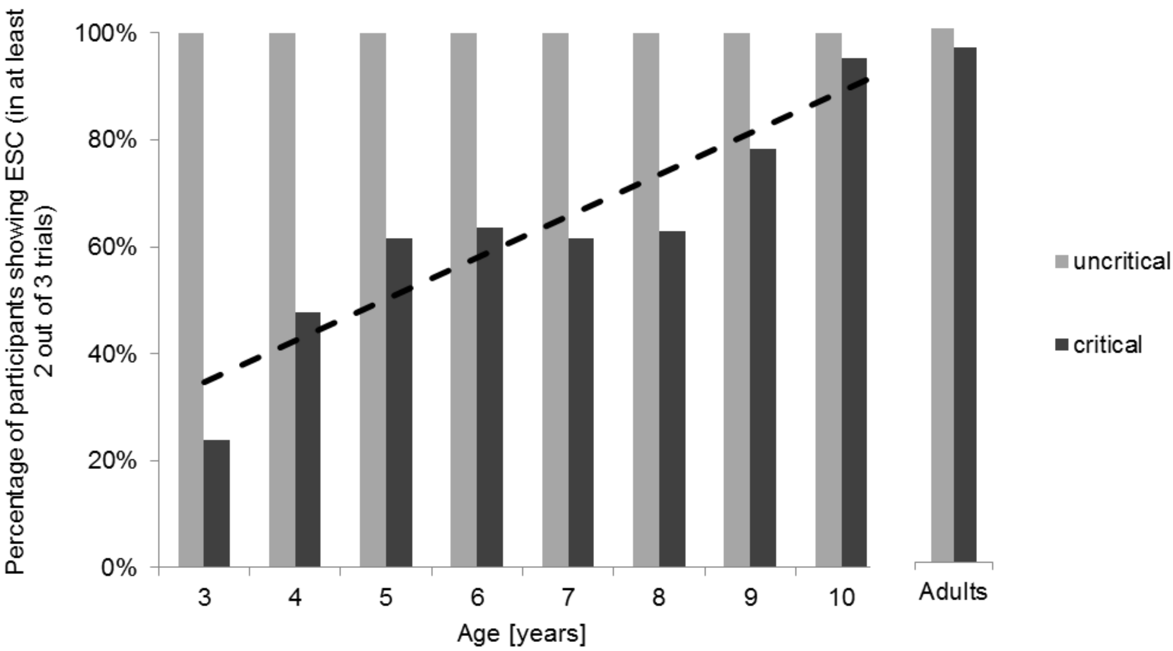

Figure 19. Percentage of the participants in each group showing end-state comfort in at least two out of three trials in the uncritical (initial overhand grip) and critical (initial underhand grip) conditions in the bar-transport-task.

A regression analysis of the percentage of participants showing ESC in at least two out of three critical trials across the child groups revealed the developmental trajectory to be statistically significant with a slope of 7.8% per year, $t(6) = 5.622$, p

= .001. The entire regression model including the intercept yielded an adjusted R^2 = .814, $F(1,7) = 31.608$, $p < .001$. Single chi-square four-field tests revealed that all children groups up to the age of 9 years behaved significantly less often in terms of ESC than adults did; $\chi^2(1) = 27.93$, $p < .001$ for the 3-year-olds; $\chi^2(1) = 15.71$, $p < .001$ for the 4-year-olds; $\chi^2(1) = 10.12$, $p < .01$ for the 5-year-olds; $\chi^2(1) = 8.98$, $p < .01$ for the 6-year-olds; $\chi^2(1) = 10.12$, $p < .01$ for the 7-year-olds; $\chi^2(1) = 9.62$, $p < .01$ for the 8-year-olds; $\chi^2(1) = 4.02$, $p < .05$ for the 9-year-olds). There was no difference in behavior between 10-year-olds and adults ($\chi^2(1) = 0.04$, $p > .05$).

Considering all children, a Kruskal-Wallis Test revealed the differences between the age groups to be statistically significant across all three trials (Trial 1 $\chi^2(7) = 28.62$, $p < .01$; Trial 2 $\chi^2(7) = 27.71$, $p < .001$; Trial 3 $\chi^2(7) = 26.76$, $p < .001$). This shows the distinct developmental trajectory for ESC planning. We also investigated whether children change their grip behavior across the trial repetitions and thus, exhibit short-term learning effects over the course of the three critical trials. Figure 20 depicts the percentage of children in each age group performing in a manner consistent with ESC in each of the three critical trials.

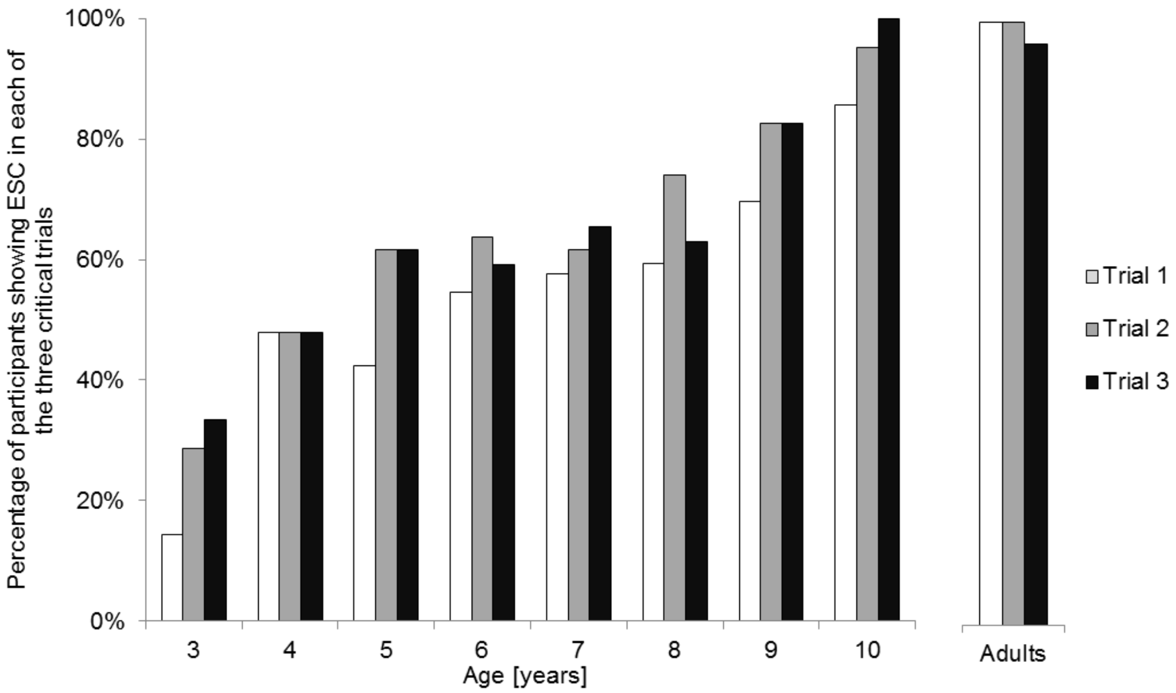

Figure 20. Percentage of participants showing end-state comfort in each of the three critical trials in the bar-transport-task.

Whereas 3-year-olds, 7-year-olds, and 10-year-olds showed an increase in ESC grasps with increasing trial number (from 14% to 29% to 33% in 3-year-olds; from 58% to 62% to 65% in 7-year-olds; and from 86% to 95% to 100% in 10-year-olds), 4-year-olds showed the same amount of ESC grasps in all trials (48%). Five-year-olds increased in ESC grasp performance from Trial 1 to Trial 2 and Trial 3 (from 42% to 62%, respectively), in the same way as 9-year-olds did (from 70% to 83%, respectively). Six-year-olds and 8-year-olds showed ESC planning more often in Trial 2 than in Trial 1, but then the percentage of ESC conform grasps decreased again in Trial 3 (from 55% to 64% to 59% in the 6-year-olds, and from 59% to 74% to 63% in the 8-year-olds). Thus, there is no systematic pattern detectable, so that short-term learning effects may not have occurred across these three trials.

3.3.1.2. Sword-rotation-task

Figure 21 illustrates the mean percentage of participants in each group who showed ESC planning in the uncritical conditions (i.e. Positions 1, 4, 5, and 6) and in the critical conditions (i.e. Positions 2 and 3). In the uncritical trials, all participants adopted a grip with the thumb being oriented towards the blade, and thus, ended in a comfortable position when inserting the sword into the box. In the critical trials, however, only 43% of the 3- and 4-year old children showed sensitivity for ESC planning, this amount increased to 58% of the 5-year-olds, to 64% in the 6-year-olds. Again, similar to the bar-transport-task, even if more delayed, a stagnation of the developmental trajectory can be detected in 7-to-10-year old children. Here, 73% of the 7-year-olds, 74% of the 8-year-olds, 78% of the 9-year-olds, and 76% of the 10-year-olds showed ESC behavior. All adults used an ESC conform grasp in at least four out of the six critical trials. A chi-square analysis showed these effects in the proportion of children showing ESC in the critical trials to be marginally significant, $\chi^2(7) = 12.89$, $p = .075$.

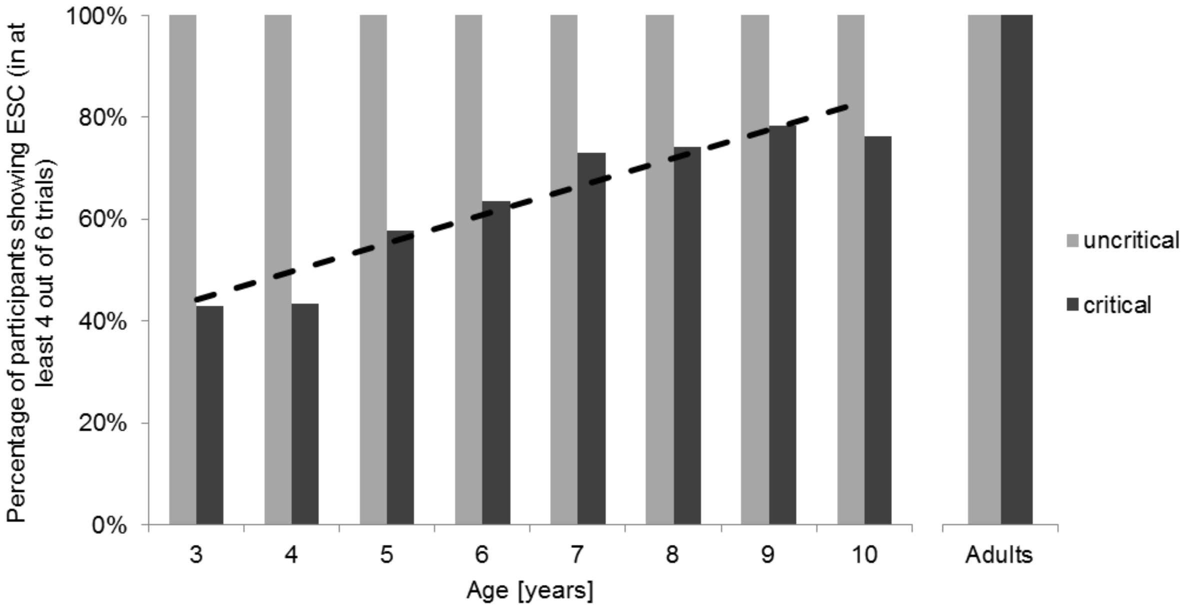

Figure 21. Percentage of participants in each group showing end-state comfort in the sword-rotation task in at least seven out of the twelve uncritical trials and in at least four out of the six critical trials.

A regression analysis of the percentage of participants showing ESC in at least four out of six critical trials across the child groups revealed the developmental trajectory to be statistically significant with a slope of 5.5% per year, $t(6) = 7.156$, $p < .001$, adjusted $R^2 = .878$, $F(1,7) = 51.209$, $p < .001$. Single chi-square four-field tests revealed that all children groups behaved significantly less often in terms of ESC than adults did; $\chi^2(1) = 21.19$, $p < .001$ for the 3-year-olds; $\chi^2(1) = 21.24$, $p < .001$ for the 4-year-olds; $\chi^2(1) = 14.88$, $p < .001$ for the 5-year-olds; $\chi^2(1) = 12.12$, $p < .001$ for the 6-year-olds; $\chi^2(1) = 8.66$, $p < .01$ for the 7-year-olds; $\chi^2(1) = 4.24$, $p < .05$ for the 8-year-olds; $\chi^2(1) = 6.75$, $p < .01$ for the 9-year-olds; and $\chi^2(1) = 7.42$, $p < .01$ for the 10-year-olds).

Considering all children, a Kruskal-Wallis Test did not consistently reveal the differences between the age groups to be statistically significant across all three trials in Position 2 (Trial 1 $\chi^2(7) = 7.22$, $p > .05$; Trial 2 $\chi^2(7) = 10.47$, $p > .05$; Trial 3 $\chi^2(7) = 15.58$, $p < .05$) and in Position 3 (Trial 1 $\chi^2(7) = 29.97$, $p < .001$; Trial 2 $\chi^2(7) = 11.44$, $p > .05$; Trial 3 $\chi^2(7) = 16.95$, $p < .05$). We also investigated whether children change their grip behavior across the trial repetitions and thus, exhibit short-term learning effects over the course of the six critical trials. Figure 22 depicts the percentage of children in each age group performing in a manner consistent with second-order motor planning in each of the three critical trials, in the upper graph for Position 2, in the lower graph for Position 3.

A closer examination of the data did not reveal a systematic pattern. It is not the case that children started to plan for ESC with increasing trial number. Therefore, like in the bar-transport-task, short-term learning effects may not have improved participants performance in terms of ESC.

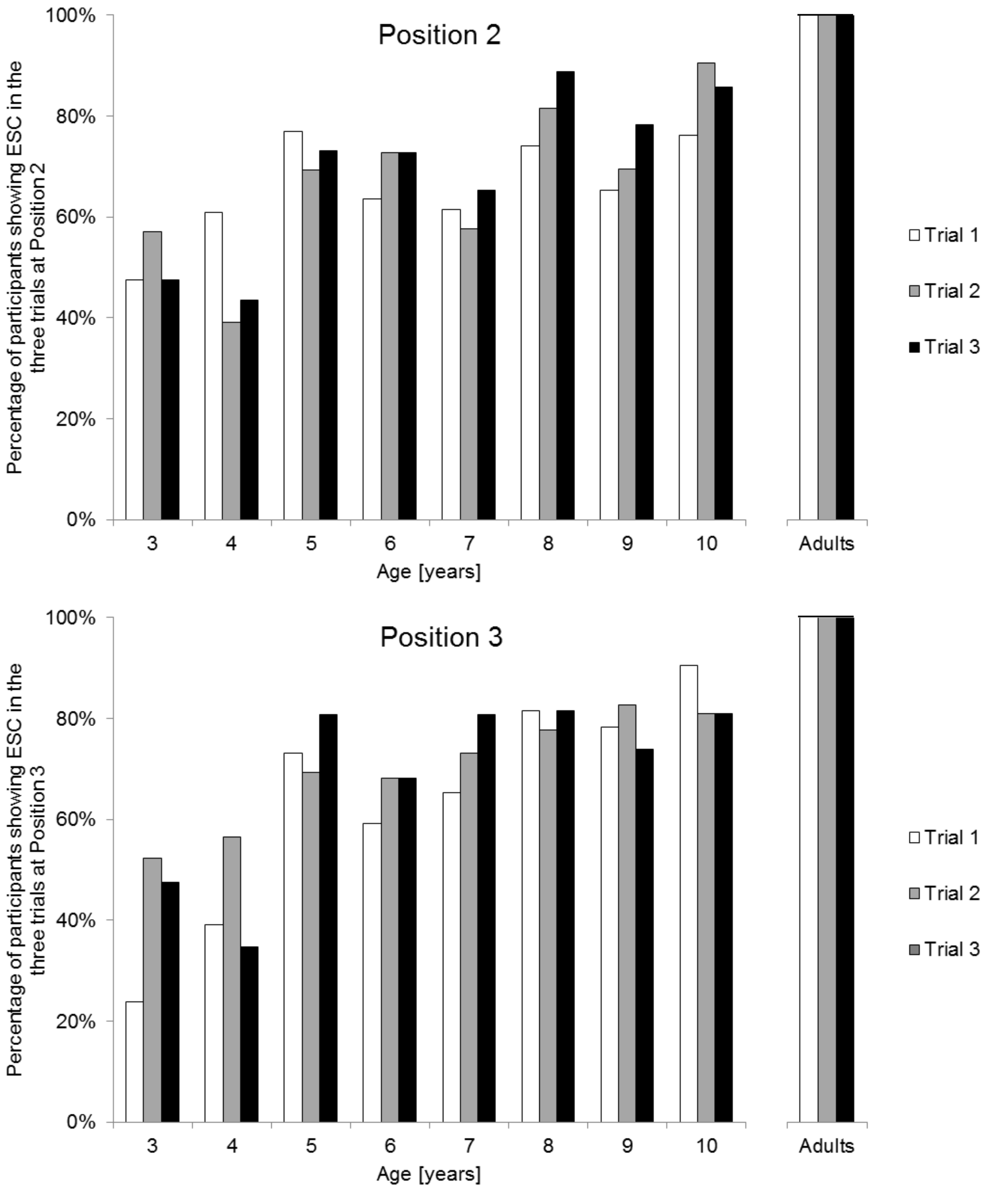

Figure 22. Percentage of the participants showing end-state comfort in each of the three critical trials for Position 2 (upper picture) and Position 3 (lower picture), respectively.

3.3.1.3. Grasp-height-task

Figure 23 depicts the percentage of participants who demonstrated ESC in the grasp-height-task. Results showed, that 19% of the 3-year-olds, 35% of the 4-year-olds, 19% of the 5-year-olds, 32% of the 6-year-olds, 38% of the 7-year-olds, 33% of the 8-year-olds, 39% of the 9-year-olds, 45% of the 10-year-olds, and 93% of the adults showed ESC planning for the high target moves. In the low target moves, however, 5% of the 3-year-olds, 4% of the 4-year-olds, 8% of the 5-year-olds, none of the 6-year-olds, 4% of the 7-year-olds, 22% of the 8-year-olds, 26% of the 9-year-olds, 14% of the 10-year-olds, and 50% of the adults showed ESC planning. Thus, ESC planning seems to be more frequent when bringing the object to high positions than to low positions. But, even 10-year-old children showed only half as many grasp behaviors in terms of ESC as adults do. This hints to a rather protracted development of ESC planning for tasks exploiting a continuous task space.

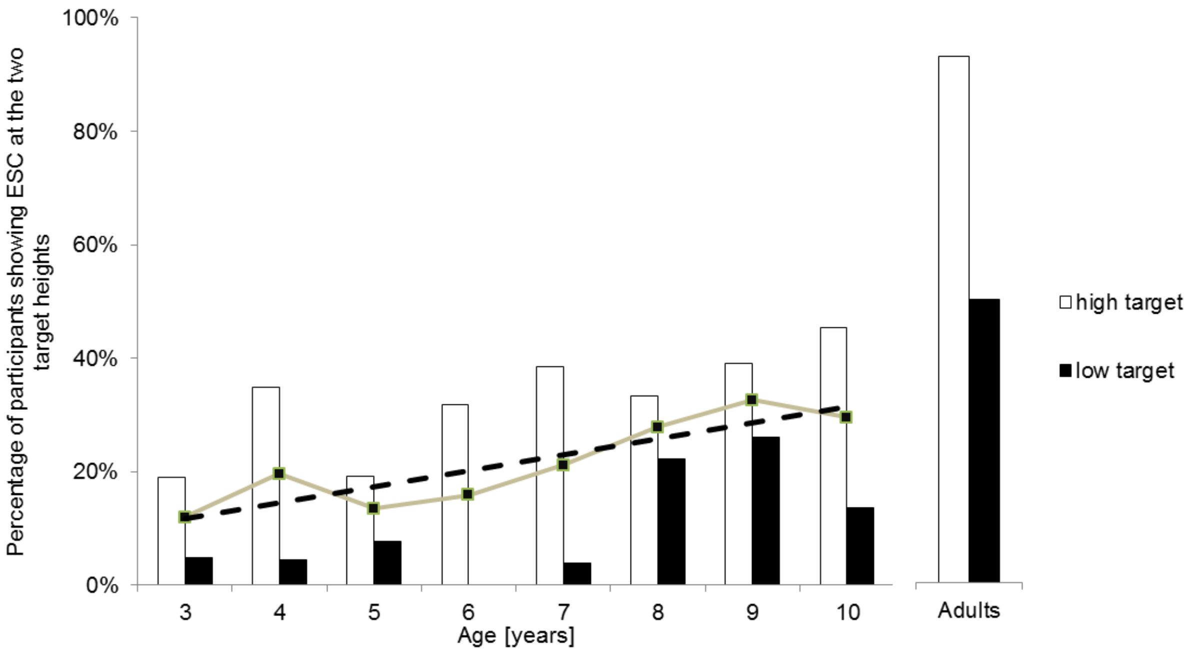

Figure 23. Percentage of the participants showing end-state comfort in the grasp-height-task for the high target position (light grey bars) and the low target position (dark grey bars). The light grey line indicates means of grasp height in both conditions; the dashed line shows the regression line.

A chi-square analysis revealed that there are significant differences between the groups in the amount of participants showing ESC averaged across both positions ($\chi^2(7) = 120.59$, $p < .001$). A regression analysis of the mean differences in grasp height across the child groups revealed the developmental trajectory to be statistically significant with a slope of 1.81 cm per year, $t(6) = 12.986$, $p < .001$, adjusted $R^2 = .878$, $F(1,7) = 166.011$, $p < .001$. Single chi-square four-field tests revealed that all children groups behaved significantly less often in terms of ESC than adults did ($\chi^2(1) = 34.24$ for the 3-year-olds; $\chi^2(1) = 27.21$ for the 4-year-olds; $\chi^2(1) = 36.86$ for the 5-year-olds; $\chi^2(1) = 30.49$ for the 6-year-olds; $\chi^2(1) = 27.34$ for the 7-year-olds; $\chi^2(1) = 20.95$ for the 8-year-olds; $\chi^2(1) = 15.32$ for the 9-year-olds; and $\chi^2(1) = 17.70$ for the 10-year-olds, all $p < .001$).

For further analysis, a score was computed for the mean differences in grasp height across both target positions (see Figure 24). The mean grasp heights for home-to-target and for target-to-home moves were computed for both, high target and low target trials. For both, the differences of the mean grasp heights were computed. The means from these two differences were multiplied by (-1). This resulted in the following distribution: Mean grasp-height difference for 3-year-olds was -14.55, for 4-year-olds -14.71, for 5-year-olds -12.92, for 6-year-olds -10.77, for 7-year-olds -8.61, for 8-year-olds -5.35, for 9-year-olds -4.66, for 10-year-olds -3.51, and 4.68 for adults. These values are the dependent variable for all further correlational analyses.

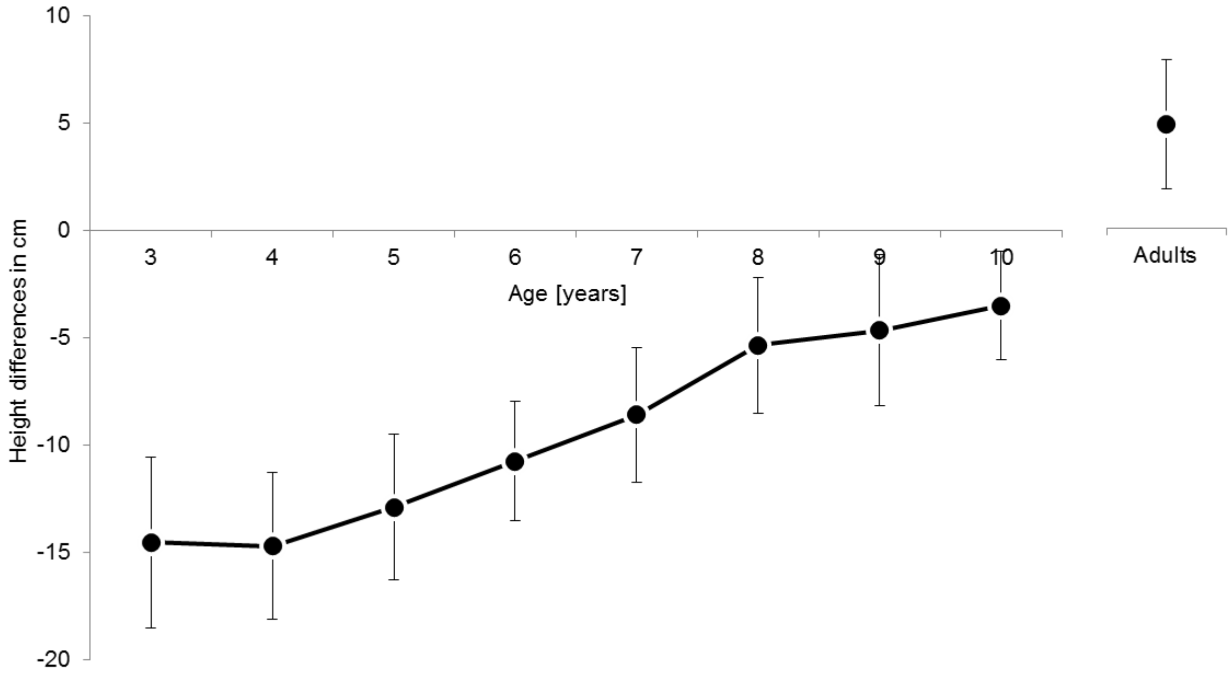

Figure 24. Mean differences in grasp height averaged for the high-target-moves and the low-target-moves. Error bars represent confidence intervals for the distribution of grasp height.

Considering all children, a Kruskal-Wallis Test revealed the differences between the age groups to be statistically significant in trials one and three for the high target platform (Trial 1 $\chi^2(7) = 17.07$, $p < .05$; Trial 2 $\chi(7)^2 = 11.37$, $p > .05$; Trial 3 $\chi^2(7) = 22.09$, $p < .01$) and in all trials for the low target platform (Trial 1 $\chi^2(7) = 21.78$, $p < .01$; Trial 2 $\chi^2(7) = 25.48$, $p < .001$; Trial 3 $\chi^2(7) = 28.98$, $p < .001$). Again, it was investigated whether participants change their grip behavior across the trial repetitions and thus, exhibit short-term learning effects over the course of the six trials. Figure 25 depicts the percentage of children in each age group performing in a manner consistent with second-order motor planning in each of the three trials, in the upper graph for the high target platform, in the lower graph for the low target platform.

The results show a similar pattern as observed in the above mentioned tests. There can be no systematic pattern in grasp choice found. Therefore, like in the bar-transport-task and in the sword-rotation task, short-term learning effects may not have improved participants performance in terms of ESC.

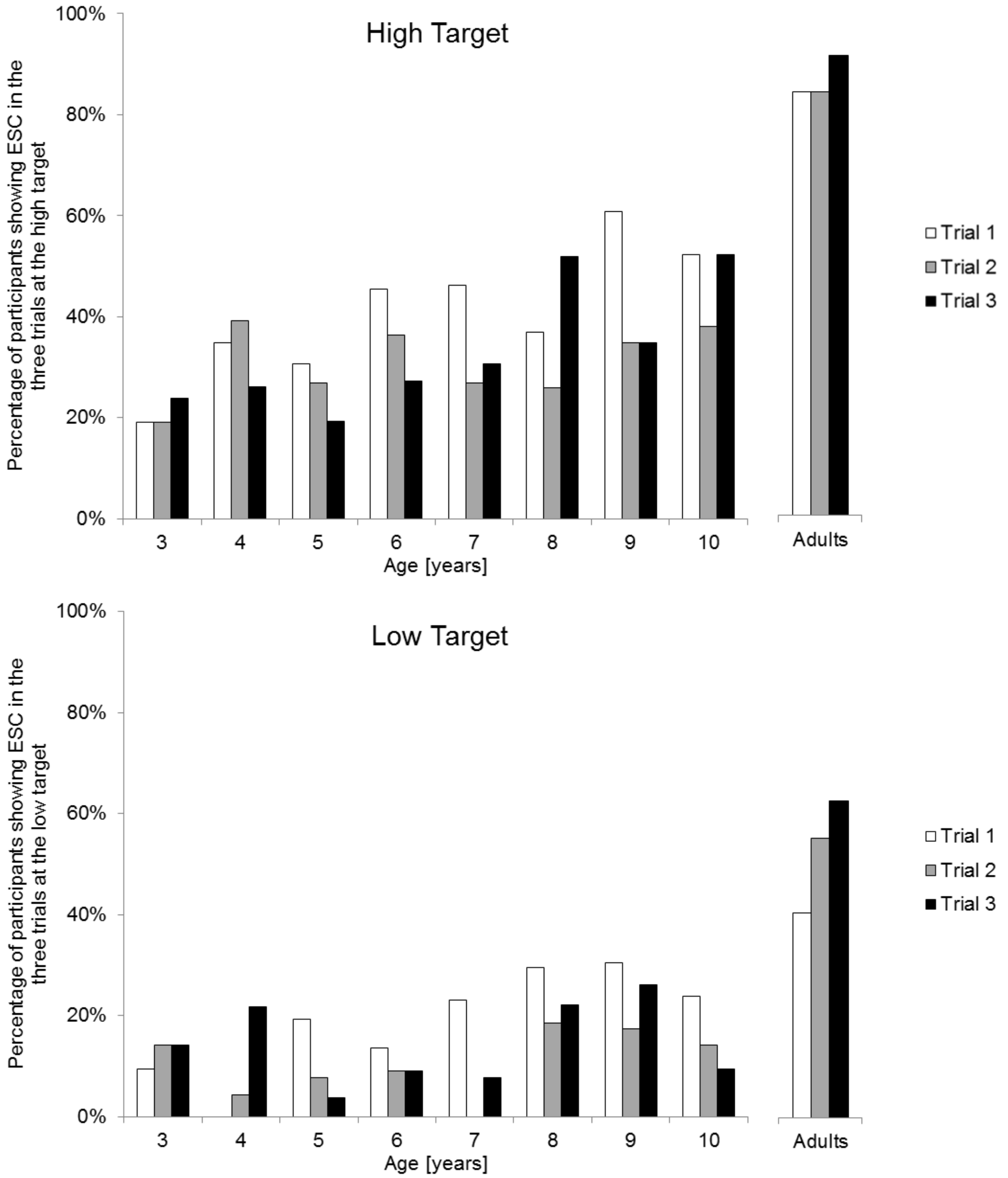

Figure 25. Percentage of participants showing end-state comfort in each of the three trials for the high (upper picture) and the low target platform (lower picture).

3.3.1.4. Intercorrelations of the ESC tasks

The results above show that there are similar developmental trends for ESC performance within each single motor task. When plotting the results of the three ESC tasks similar as is done in Figure 7 in the systematic review (Chapter 2.3.2.1.), it is clearly observable that the development of ESC planning is delayed for the grasp-height-task. Whereas ESC seems to be fully present in children of ten years in the bar-transport-task, the development of ESC planning in the sword-rotation-task seems to be protracted into adolescence, as ten year old children show ESC only to an amount of about 80%.

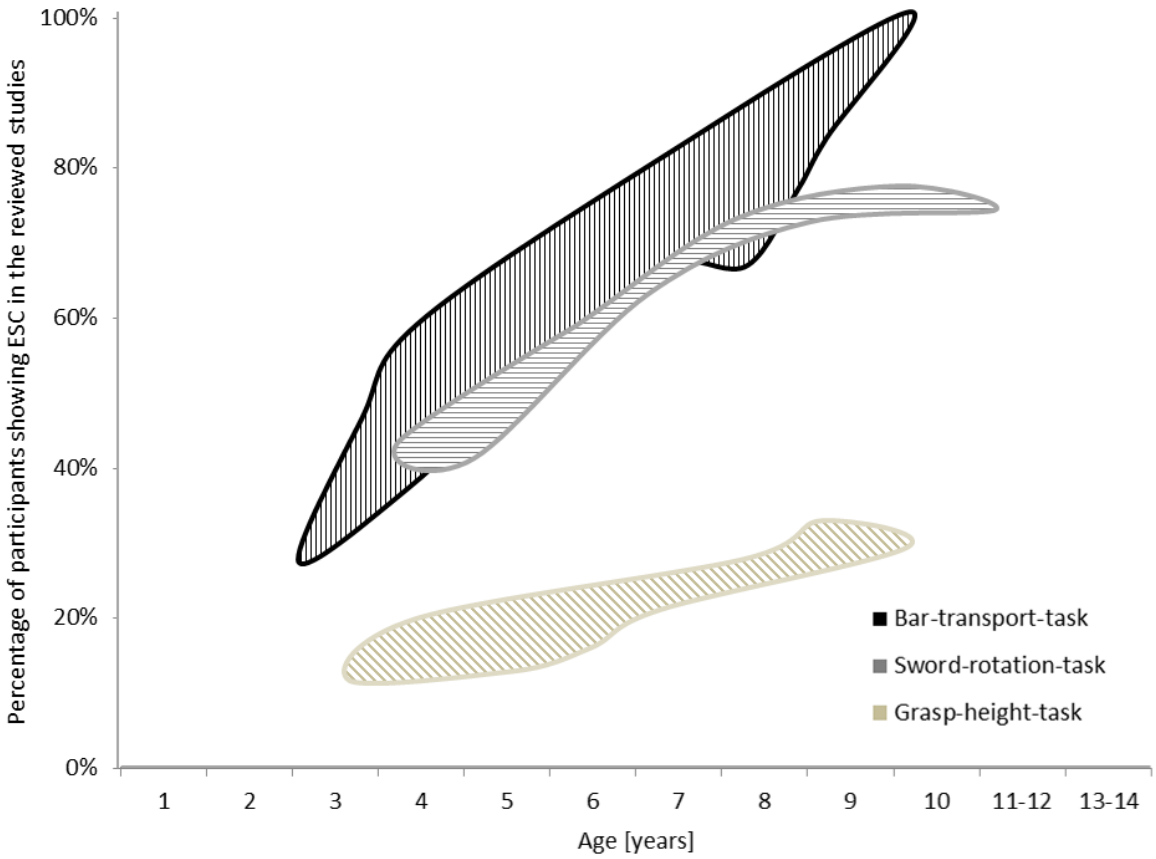

Figure 26. Scatter diagram of the results of the three tasks used to assess ESC planning in normally developing children in the experimental study.

Consequently, the question arises whether the different measure of ESC performance are interrelated. For this reason, we computed Pearson's pairwise bivariate correlations between the three motor tasks (see Table 4).

Table 4. Pairwise Pearson's correlations between the three motor tasks. Note that two correlations for the adult sample could not be computed due to ceiling effects in the sword-rotation-task.

	Correlations between the motor tasks		
Age	Bar-transport task & sword-rotation task	Bar-transport task & grasp-height task	Sword-rotation task & grasp-height task
3 years	-.258	-.144	-.155
4 years	.565**	.263	-.113
5 years	.283	.210	.126
6 years	.214	.247	.261
7 years	.055	.079	.236
8 years	.071	.071	.020
9 years	.233	-.115	-.326
10 years	-.125	-.058	.386
Adults	N/A	.367	N/A
Overall	.276**	.305**	.245**

*: $p < .05$; **: $p < .01$

Small to medium correlations emerged when considering the entire sample (last row of Table 4), even though these correlations are mostly driven by the between-group differences described above. By contrast, there was no sign of intercorrelations of the different ESC measures within the groups (except for the correlation of the bar-transport-task and the sword-rotation-task for the 4-year-olds). To further assess these within-group differences, we Z-transformed each correlation coefficient for each of the non-adult groups, averaged these transformed values and re-transformed the resulting values to correlation coefficients. This procedure yielded mean correlations of r = .14 for the bar-transport-task and the sword-rotation-task, r = .07 for the bar-transport-task and the grasp-height-task, and r = .06 for the sword-rotation-task and the grasp-height-task. Testing the corresponding mean Z-values against zero did not yield any significant differences, *p*s > .193.

3.3.1.5. Summary

The results in the motor task support previous findings indicating that children's ability for anticipatory planning increases with age. Whereas only 24 % of the youngest children showed ESC in the bar-transport-task, this amount increased up to adult-like level of 95% in 10-year old children. In the sword-rotation-task, a similar pattern emerged. Here, as many as 43% of the youngest children showed ESC, whereas the development until an adult-like amount progresses more slowly, as only 76% of the 10-year-olds showed ESC planning. Therefore, the development seems to have an earlier onset in this task, but may be delayed somewhat further into adolescence. In the grasp-height-task, anticipatory planning seems not to be seen as an efficiency constraint, as children as well as adults did not show the grasp-height-effect reliably.

3.3.2. The development of EF

In the following section, the results of the three EF tasks are reported. As the comparison across age groups is difficult due to different variable outcomes (see Chapter 3.3.3.), only descriptive data will be presented.

3.3.2.1. The Tower-of-Hanoi-task

Figure 27 illustrates the mean percentage of correctly solved items in each group in the Tower-of-Hanoi-task. Results showed that 3-year-olds solved 13% of all items correctly, 4-year-olds solved 24%, 5-year-olds solved 46%, 6-year-olds solved 54%, 7-year-olds solved 42%, 8-year-olds solved 48%, 9-year-olds solved 49%, 10-year-olds solved 57%, and adults solved 66% out of the ten items. Please note that task difficulty increased with increasing item number, and that 3- to 4-year-olds (light grey bars), 5- to 6-year-olds (dark grey bars), and participants 7 years and older (black bars) received different test protocols.

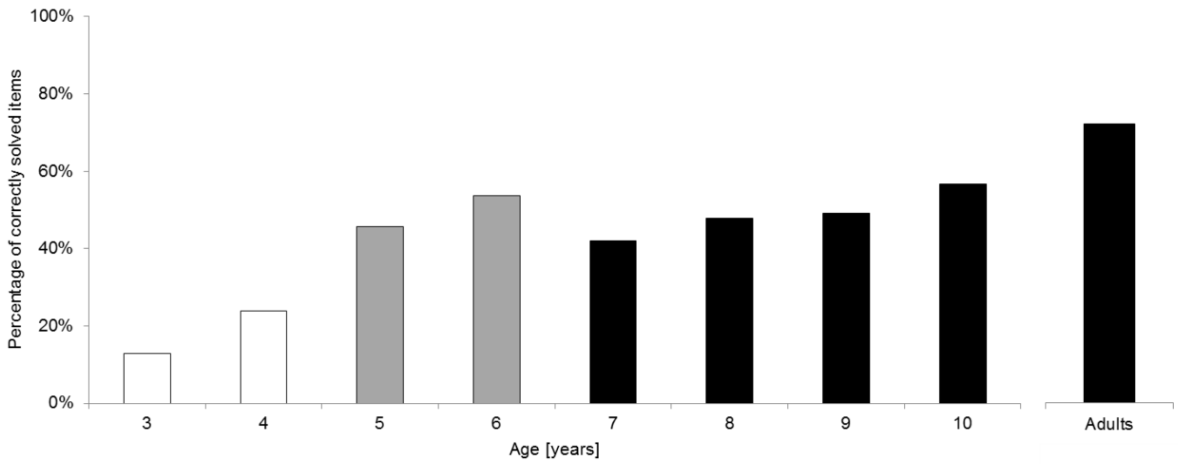

Figure 27. Percentage of correctly solved items in the Tower-of-Hanoi-task. The shading of the bars indicates different versions of the test protocol used according to the age of participants.

3.3.2.2. The Mosaic-task

Figure 28 shows the mean percentage of points (relative to the respective total score) in the Mosaic-task for each group. Results showed that 3-year-olds reached 38% of the possibly total score, 4-year-olds reached 49%, 5-year-olds reached 71%, and 6-year-olds reached 80%. These groups accomplished the easier version of the task (see light grey bars in Figure 28). In the school children's version, 7-year-olds reached 51%, 8-year-olds reached 69%, 9-year-olds reached 75%, and 10-year-olds reached 86% (see dark grey bars in Figure 28). In the adult version, participants reached 68% of obtainable points. Even if preschool children aged between 3 and 6 years and 11 months had used the same protocol, the total reachable score would have differed, as children aged 3 to 4 years started with Item 1, whereas 4-year-olds started with Item 7, and 6 year-olds started with Item 10. Test protocol changed at age 6, depending on whether children were still in kindergarten or already in school. Preschool children used the same protocol as younger children, whereas 6-year old school children received the more difficult version, in which they started with Item 1, whereas children aged 8 years and older started with Item 3. The two different bars in Figure 28 for 6-year-olds correspond to whether children were attending kindergarten or school.

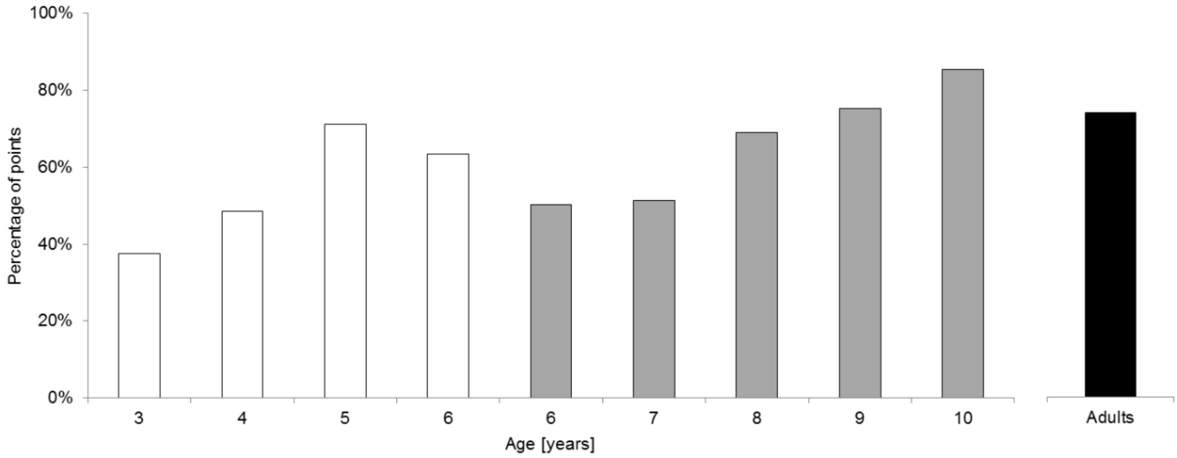

Figure 28. Percentage of points reached depending on the total score in the Mosaic-task. The shading of the bars indicates different versions of the test protocol used according to the age of participants.

3.3.2.3. The D2-attention-endurance-task

For the D2-attention-endurance-task, Figure 29 illustrates the mean percentage of points reached depending on the total score in each group. Results showed that 3-year-olds reached 36% and 4-year-olds reached 48% of the possibly total score in the card-sort D2 from the IDS-P (see light grey bars in Figure 29). Five-year-olds reached 28%, 6-year-olds reached 37%, 7-year-olds reached 45%, 8-year-olds reached 53%, 9-year-olds reached 64%, and 10-year-olds reached 71% (see dark grey bars in Figure 29) in the D2-task from the IDS. In the adult version, participants reached 43% of obtainable points.

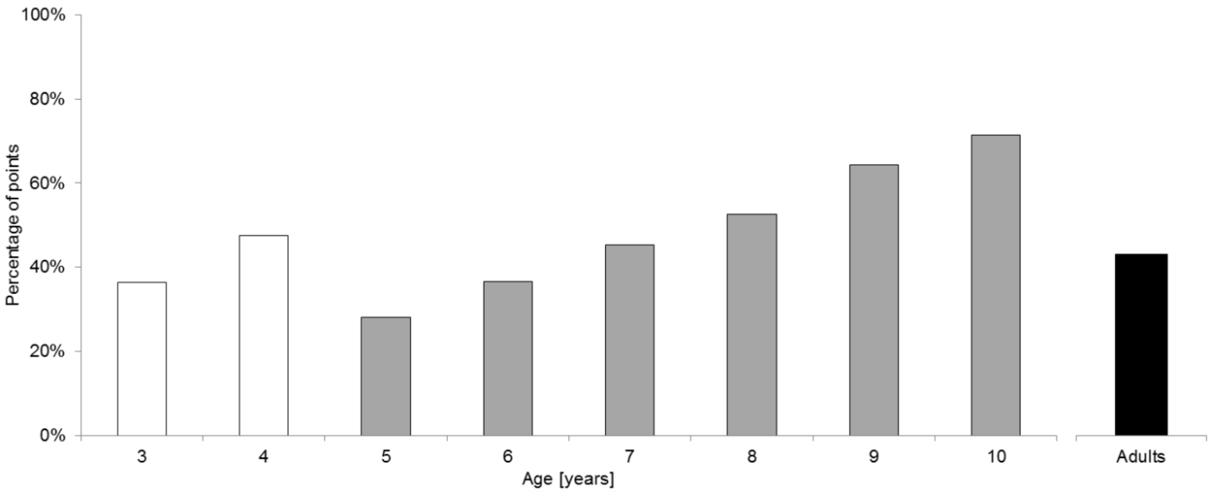

Figure 29. Percentage of points reached depending on the total score in the D2-task. The shading of the bars indicates different versions of the test protocol used according to the age of participants.

3.3.2.4. Intercorrelations of the EF tasks

As for the ESC tasks we executed Pearson's pairwise bivariate correlations in order to assess intercorrelations between EF tasks (see Table 5).

Table 5. Pairwise Pearsons's correlations between the three cognitive tasks. *Note*: Overall correlations could not be computed as different test protocols were used for age groups.

	Correlations between the cognitive tasks		
Age	D2 & Mosaic-task	D2 & Tower-of-Hanoi-task	Mosaic-task & Tower-of-Hanoi-task
3 years	.388	.436*	.379
4 years	.022	-.013	.234
5 years	.284	.153	.098
6 years	.640**	.244	.127
7 years	.333	.353	.185
8 years	.460*	-.277	-.002
9 years	.061	-.108	-.058
10 years	.039	-.266	.192
Adults	.382*	-.006	.124

*: $p < .05$; **: $p < .01$

There were only a few significant correlations within the age groups, specifically for the D2- and the Tower-of-Hanoi-task in 3-year-olds and the D2- and the Mosaic-task in 6- and 8-year-olds and adults. The large majority of the correlations, however, was not significant.

3.3.2.5. Summary

The results in the cognitive task support previous, findings indicating that children tend to increase their performance with increasing age (Anderson, 2002). Between-group comparisons were impeded by the different measures obtained in the different test versions used for the different age groups. In the Tower-of-Hanoi-task only 10-year-olds consistently solved more than half out of the ten items correctly. These results are in line with previous work (Welsh, 1991), showing an increasing ability in solving more difficult problems with increasing age.

In the Mosaic-task, children as young as 5 years were able to gain more than half of the total points. Therefore, visual perception seems to develop at a similar stage as ESC did in the bar-transport-task and in the sword-rotation-task. Unfortunately, there are no standard-values given in the manuals of the three different test batteries for the Mosaic-task. To the best of our knowledge, previous studies used the entire test batteries to assess IQ, and therefore did not provide any data of the mosaic-test per se.

In the D2-attention-endurance-test children from the age of 8 years reached 53% (43%) of obtainable points (please find the standard-values from the test-manuals in parentheses behind the result). Compared to the standard-values, participants' attention levels were above average in the current study.

3.3.3. The relationship between ESC and EF

Prior to the examination of possible relationship between motor planning and executive functioning, Table 6 provides an overview over the results from the different motor and cognitive tests, separated by age groups.

Table 6. Detailed results of all age groups in the six different tasks.

	Bar-transport-task		Handle-rotation-task		Grasp-height-task			Tower-of-Hanoi-task	Mosaic-task	D2-task
	(percentage of participants showing ESC in at least 2 out of 3 trials)		(percentage of participants showing ESC in at least 4 out of 6 trials)		(percentage of participants showing ESC in at least 2 out of 3 moves to either platform)		Mean diff. in grasp height (cm)	(percentage of solved items)	(percentage of points)	(percentage of points)
	uncritical	critical	uncritical	critical	HtT-moves	TtH-moves				
3-year-olds	100	23.8	100	42.7	19.1	4.8	-14.6	12.9	37.6	36,3
4-year-olds	100	47.8	100	43.5	34.8	4.4	-14.7	23.9	48.5	47,5
5-year-olds	100	61.5	100	57.7	19.2	7.7	-12.9	45.8	71.2	28,1
6-year-olds	100	63.6	100	63.6	31.8	0	-10.8	53.6	55.1	36,6
7-year-olds	100	61.6	100	73.1	38.5	3.9	-8.6	41.9	51.4	45,4
8-year-olds	100	63.0	100	74.1	33.3	22.2	-5.4	47.8	69.0	52,5
9-year-olds	100	78.3	100	78.3	39.1	26.1	-4.7	49.1	75.2	64,4
10-year-olds	100	95.2	100	76.2	45.5	13.6	-3.5	56.7	85.5	71,4
Adults	100	96.4	100	100	92.7	50.0	4.7	66.1	67.7	43,1

Note. HtT = Home-to-Target-moves; TtH = Target-to-Home-moves.

The main purpose of this examination was to assess a possible relationship between motor planning and executive functions. Therefore, Pearson's correlations were computed between all motor and cognitive tasks (see Table 7).

Table 5. Pairwise Pearson's correlations between the cognitive and the motor tasks.

	D2			Mosaic-task			Tower-of-Hanoi-task		
Age	**BTT**	**SRT**	**GHT**	**BTT**	**SRT**	**GHT**	**BTT**	**SRT**	**GHT**
3-year-olds	-0,02	0,078	0,334	0,239	0,075	0,257	-0,039	0,033	-0,126
4-year-olds	-0,032	0,207	0,071	0,068	-0,344	0,272	0,414*	0,004	0,356
5-year-olds	0,358	0,19	0,492*	0,279	0,278	0,406*	0,112	-0,201	-0,06
6-year-olds	0,064	0,129	-0,046	0,059	0,165	-0,112	0,072	0,072	0,053
7-year-olds	0,049	-0,104	-0,263	0,261	-0,084	-0,011	0,053	-0,325	-0,184
8-year-olds	0,137	-0,043	-0,078	0,16	0,418*	-0,101	-0,156	0,179	-0,159
9-year-olds	0,173	-0,133	0,427*	0,04	0,04	-0,206	-0,018	0,231	0,064
10-year-olds	0,018	-0,048	0,384	0,57*	0,11	0,046	0,059	0,103	-0,061
Adults	0,003	N/A	-0,181	0,11	N/A	0,124	0,038	N/A	0,065

Note. BTT =Bar-transport-task; SRT = Sword-rotation-task; GHT = Grasp-height-task.

The analyses yielded mostly small and non-significant correlations across the participants of each individual group, except for the following: performance in the D2-attention-endurance-task correlated significantly with the grasp-height-task in the 5-year-olds and 9-year-olds, the Mosaic-task correlated with the bar-transport-task in 10-year-olds, with the sword-rotation-task in the 8-year-olds, and with the grasp-height-task in 5-year-olds, whereas the Tower-of-Hanoi-task was only correlated with the bar-transport-task in 4-year-olds.

In contrast to the ESC tasks, overall correlations across the participants of different groups are not possible for the EF tasks, because we opted to use different versions of the tasks for different age groups. In other words: As cognitive functions develop during childhood, it was not possible to use only one test for every single cognitive function. In all tasks, two or three different versions of each test were used to examine executive functions as described in the methods section. As for the inter-correlations of the ESC tasks, however, we computed mean correlations across all non-adult groups and tested the resulting mean Z-score against zero. This procedure yielded a significant correlation between the mosaic task and the bar-transport-task, $r = .218$, $p = .018$, whereas the remaining correlations were not significant *p*s > .082.

3.4. Discussion

The goal of the present study was three-fold: to examine (1) the developmental trajectories of the different tasks, (2) possible relationships between all motor tasks used, and (3) potential relations between the performance in both, the motor and the cognitive task, specifically whether EF predict ESC planning. To this end, a specific test battery examined the development of motor planning skills and EF in children and adults. To examine motor planning skills, the bar-transport-task, the sword-rotation-task, and the grasp-height-task were conducted. To test EF, different, age-related versions of the Tower-of-Hanoi-task, of the Mosaic-task, and of the D2-attention-endurance-test were used. This test battery was employed to assess the performance of eight groups of children, aged 3 to 10 years, and one group of adults.

With regard to the developmental trajectories observed for the presence of motor planning skills (as indicated by the ESC effect), the results support previous studies using the bar-transport-task (Hughes, 1996; Jovanovic & Schwarzer, 2011; Knudsen et al., 2012; Smyth & Mason, 1997; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Toussaint et al., 2013; Weigelt & Schack, 2010) and the sword-rotation-task (Crajé, Aarts et al., 2010; Jongbloed-Pereboom et al., 2013). Specifically, the propensity to perform a certain motor action in a manner consistent with the ESC effect (steadily) increased from young kindergarten children to school children, and adults. Thus, children’s motor planning skills develop as they get older. For the bar-transport task, adult-like performance was reached around the age of ten years (see also Knudsen et al., 2012; Stöckel et al., 2012; Thibaut & Toussaint, 2010). For the sword-rotation task, this development seems to be somewhat delayed, as even 10-year old children showed the ESC effect less often than adults (see also Jongbloed-Pereboom et al., 2013). In addition, the results of the grasp-height-task suggest that this basic developmental trend across young ages generalizes from a rather dichotomous grip selection (underhand vs. overhand) to grasp choices in a continuous task space (here, along the vertical axis of the object). However, the age at which participants display adult-like performance in these kinds of tasks appears to be much further protracted, as only about half of the 10-year old children showed the ESC effect in the grasp-height task.

Participants' performance in the cognitive tasks is also in line with previous findings (Anderson, 2002). In general, EF matured with age, as indicated by the increase of children's task performance as they get older. For the Tower-of-Hanoi task, only the oldest children of the test-protocols for 5-6-year-olds, and participants aged 10 and older in the most difficult task version were able to solve more than half of the disc-transfer problems correctly in the given difficulty (6-year-olds solved 54%, 10-year-olds solved 57%). For the Mosaic-task, 5- and 6-year-olds reached more than half of the attainable total points for the easier task version (71% for the 5-year-olds, 80% for the 6-year-olds), and all of the older children were able to accomplish more than half of the test as well (51% of the 7-year-olds, 69% of the 8-year-olds, 75% of the 9-year-olds, and 86% of the 10-year-olds). Moreover, in the D2-task younger children aged 3 and 4 years were not able to reach more than half of all total points as in the Tower-of-Hanoi task mentioned above. Here, children as old as 8 years solved more than 50% of the items correctly (8-year-olds reached 53%, 9-year-olds reached 64%, and 10-year-olds reached 71%).

As for the second goal of the study, the correlation analyses did not provide much support for intercorrelations between motor tasks. Although, correlations emerged when analyzing the data across the entire sample, no such relationship was found within any of the different age groups (except for the correlation between the bar-transport-task and the sword-rotation-task in 4-year-olds). This pattern of results is similar to that found in two previous studies[11] (Knudsen et al., 2012; Smyth & Mason, 1997), which tested the same children in two different motor tasks within one single experiment. In all other studies conducted so far, only a single ESC task was used. The current work therefore extends this previous line of research and is the first to investigate the development of motor planning skills by using three different tasks in a within-subjects design.

There are several possible reasons why performance in the motor tasks was not correlated. This outcome may be due to differences in the number of required action steps, in the precision requirements, in children's perception of comfort, the required degree of object rotation, in children's familiarity with the task, and/or in motivational aspects (for a more detailed discussion of these influencing factors see Chapter 2.4.).

To examine possible interdependencies between the development of motor planning and EF was the third goal of the present study. Mean correlations in child participants were between r = -.013 and r = .218 and therefore, motor performance

[11] As the first author of this paper was a co-author in the study by Knudsen and colleagues (2012), data was checked post-hoc for relations between the two ESC tasks used in either study (the grasp-height-task was excluded due to the continuous nature of the dependent variable). Phi-coefficient analyses revealed similar results: In the study by Knudsen and colleagues (2012), the bar-transport-tasks and the overturned-glass-task was only correlated in 4-year-old children (ϕ = .522, p < .05), In our study, however, we found both tests to be correlated in the 4- and 5-year-olds (ϕ = .476, p < .01 and ϕ = .440, p < .01), but not in the other participant groups. This means, that the two tasks used in our study and the two tasks used in the study by Knudsen and colleagues (2012) possibly measure different aspects of motor planning. Hence, the developmental trajectories of ESC planning may not be related between these different tasks, possibly due to different task constraints, as already discussed in Chapter 2.

and EF were not related for this set of tasks. The notion that motor skill development may not be as closely related to the maturation of EF has been previously assumed and put forward by van Swieten et al. (2010). These authors argued that if adults do not always perform in a manner consistent with ESC, then EF must fail in these cases. However, it is also plausible that EF may sometimes fail under certain circumstances, even in adults, as has been shown, for example, by Blakemore and Choudhury (2006), de Luca and colleagues (2003) or Salthouse, Atkinson and Berish (2003).

An alternative explanation for the null-findings in the present correlational analyses may relate to the specific EF and motor tasks used. It may be that the cognitive processes necessary to succeed in the Tower-of-Hanoi task, the Mosaic task, and the D2-attention-endurance-task are not or only in part required in the bar-transport-task, the sword-rotation-task, and the grasp-height-task. It is still an open question whether the performance in other EF tasks may be stronger related to the ESC task used here, and whether performance in other motor tasks may be predicted by the EF tasks used here. In fact, a recent study by Gonzalez and colleagues (2014) reported a correlation of performance between hand and space use (in a grasp-and-place and in a grasp-and-built-task) and EF for 5- to 10-year old children. A more elaborated research program across a larger number of cognitive and motor tasks is certainly warranted to further exploit the links between the cognitive and the motor development of young children.

3.5. Conclusion

In summary, the present study examined children's performance in three object manipulation tasks and compared their performance with three cognitive tasks that measured EF. There was a clear developmental trajectory for all abilities examined here (motor planning skills, as well as problem solving skills, visuo-spatial abilities, and attention). Contrary to the predictions made, findings showed only weak and unreliable intercorrelations between the different motor tasks. In addition, the performance in the cognitive tasks used to test EF did not reliably predict participant's performance in the different ESC tasks. Future research is needed to further assess potential interdependencies between motor skill development and the maturation of cognitive abilities. Specifically, the findings of the current work suggest to carefully constructing test batteries with respect to the abilities underlying different cognitive and motor tasks.

Chapter 4

General Discussion

In the foregoing chapters, an introduction was given to motor behavior, cognitive control, and the development of both. Then, in the review study (Chapter 2) and in the experimental study (Chapter 3), the two aims of the research project were considered. The first aim was addressed in the review study in Chapter 2. The literature overview provided detailed insights into the existing studies on the ESC effect in children. The various tasks and procedures employed were compared to highlight differences and similarities between these studies and the different developmental patterns of ESC planning in normally developing children and in children with developmental disorders. Moreover, possible factors influencing the development of ESC planning were discussed and new directions for future research were provided.

Altogether, 18 studies investigating the presence of the ESC effect in children have been identified. Twelve of these studies assessed ESC planning in normally developing children (Adalbjornsson et al., 2008; Jongbloed-Pereboom et al., 2013; Jovanovic & Schwarzer, 2011; Knudsen et al., 2012; Manoel & Moreira, 2005; Robinson & Fischman, 2013; Scharoun & Bryden, 2013; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Toussaint et al., 2013; Weigelt & Schack, 2010; Wilmut & Byrne, 2014b). The remaining six studies focused on the ESC effect in children with different developmental disorders, including children with autism (Hughes, 1996; van Swieten et al., 2010), children with developmental coordination disorder (Smyth & Mason, 1997; van Swieten et al., 2010; Wilmut & Byrne, 2014a), with mild learning deficits (Hughes, 1996), and with cerebral palsy (Crajé, Aarts, et al, 2010; Kirpatrick et al., 2013). Across these studies, three different kinds of basic tasks (or versions thereof) were employed: the bar-transport-task, the handle-rotation-task, and the overturned-glass-task.

Results were inconsistent. Some studies found ESC planning in children as young as 3 years (Jovanovic & Schwarzer, 2011), others did not find ESC planning to be present until the age of 10 (Thibaut & Toussaint, 2010), while some studies were not able to find the effect at all in the children tested (e.g. Manoel & Moreira, 2005). The findings were independent of developmental consistency (i.e. if children were normally developing or with developmental disorders). Possible reasons for the differences in the findings may relate to the particular task demands, such as precision requirements, the number of action steps to be performed, familiarity, and motivation. Despite the different findings regarding the age at which the effect emerged and the developmental trajectory, the studies presented in the review study in Chapter 2 suggest a marked increase in ESC planning around the end of the preschool years, as well as a further increase throughout childhood.

The experimental study reported in Chapter 3 was conducted to shed more light on this topic. It was examined how the ability for ESC planning develops during childhood and how this development relies on the development of EF. A test battery consisting of six sub-tests, three of which tested motor planning and three tested executive functions in children aged 3 to 10 years, was employed. A total sample of 217 participants was examined. Results revealed that the majority of 5-year-olds showed ESC planning in the bar-transport-task and in the sword-rotation-task (more than 50% of all children showed ESC in more than 50% of the trials). In the grasp-height-task, only the majority of adults showed anticipatory planning skills. Here, the developmental trajectory seems to be distinctly protracted in children, compared to the two other motor tasks. At the same time, only small to medium correlations were found between the three motor tasks, considering the whole sample, but there was no sign of intercorrelations of the different ESC measures within the age groups. The correlational analyses between the behavior in the ESC tasks and in the EF tasks yielded mostly small and non-significant correlations across the participants of each individual group, with few exceptions: Performance in the D2-attention-endurance-task correlated significantly with the grasp-height-task in the 5-year-olds and 9-year-olds, the Mosaic-task correlated with the bar-transport-task in 10-year-olds, with the sword-rotation-task in the 8-year-olds, and with the grasp-height-task in 5-year-olds, and the Tower-of-Hanoi-task was only correlated with the bar-transport-task in 4-year-olds. Therefore, on a first sight, this study did not find any relationship of between the development of motor and executive planning abilities in children.

Taken together, results showed (1) a positive developmental trajectory for each of the sub-tests, with better task performance as children get older, (2) that the performance in the separate tasks was not correlated across participants, and (3) that there was no relationship between performance in the motor tasks and in the cognitive tasks used in the present study.

It is obvious, that the ability to plan for ESC develops fastest in the bar-transport-task, followed by the sword-rotation-task (see Figure 26). These results are in line with what was observed in the review study (Chapter 2). In the grasp-height-task, which was never examined in children before, a very protracted development of ESC planning is observable. In the following section, possible reasons for the different developmental trajectories and the lack of a relationship between the tasks will be discussed.

4.1. Constraints on the development of anticipatory planning abilities

In the experimental study, the results of the systematic review can be confirmed, concerning the age effects in the examined ESC tasks. A positive developmental trajectory was examined in all three tasks, although with different slopes. In the following paragraphs, possible constraints will be discussed, which may have influenced the developmental trajectories in the different tasks.

4.1.1. Motor reorganization

The argument of motor reorganization was confirmed, as children aged 7 and 8 years showed a stagnation (or even a decrease in the grasp-height-task) of ESC planning development in these ages. These findings are supported by other studies on ESC (e.g. Thibaut & Toussaint, 2010), who found 6-year-olds to perform better in the bar-transport-task than 8-year-olds, and studies on other tasks measuring goal-directed movements, like in visual aiming (e.g. Bard et al., 1990). These authors found that 8-year-olds moved a lever more slowly and with less accuracy than 6-year-olds. They assumed, that this demonstrates, that 8-year-olds need more feed-back control than other age groups. In another study, Meulenbroek and van Galen (1988) described reorganization processes in writing, as they observed a decrease in writing speed and an increase in writing dysfluency between 8 and 9 years of age. They suggest that older children try to improve writing quality using visual feedback. Other reorganization processes take place at this age in drawing (e.g. Lange-Küttner, 2009). However, the assumption that this stagnation may be due to cognitive maturation processes can be denied, as there is no major spurt in the development of EF measured in the developmental study.

The review study suggested to find ESC planning in the majority of children in the bar-transport-task first at ages between 3 ½ and 7 years, which was confirmed by the data of the experimental study for children of 5 years of age (in line with the findings of Knudsen et al., 2012 and Weigelt & Schack, 2010). The handle-rotation-task seemed to have a protracted development based on the review study, which can partly be confirmed in our study. We found the majority of children showing the ESC effect at the same age as in the bar-transport-task, but with a shallower slope. Whereas planning strategies seem to be almost fully present in 10-year-olds, only 76% of the children in this age group showed the effect in the sword-rotation-task. Therefore, the development of ESC planning seems to be protracted into adolescence, or at least after the age of 10 years in the sword-rotation-task. For the grasp-height-task, one cannot compare the present results to another study, because anticipatory planning skills in a continuous task with object translation have not been investigated in children before. The only study, which examined grasp height in children so far, was conducted by Jovanovic and Schwarzer (2011). In their version of the bar-transport-task, with the bar standing in an upright position at the beginning of each trials, they measured grasp heights for baseline (translation) and reverse (rotation) trials. They found, that children grasped the bar at a higher point in the baseline condition than in the reverse condition. The results of the experimental study in Chapter 3 suggest, however, that ESC planning in a continuous task space seems not to be that predictable as it is in the other tasks, where the presence of ESC continuously increased with age. Even adults did not show the effect reliably.

4.1.2. Degree of object rotation

Results of studies on adults suggest that the ESC effect found for tasks employing a 90 degree object rotation (e.g. Rosenbaum et al., 1990; Weigelt et al., 2006) is reduced, when the task requires an higher amount of object rotation, both for unimanual (e.g. Rosenbaum et al., 1993; Hughes et al., 2012) and bimanual object manipulations (e.g. Hughes & Franz, 2008; Hughes et al., 2011; Janssen, Crajé, Weigelt, & Steenbergen, 2010). The motor tasks used in the experimental study (Chapter 3) differed regarding the required degree of object rotation: there was no rotation needed in the grasp-height-task, a 90 degree rotation in the bar-transport-task, and up to 180 degree rotations in the sword-rotation-task. The aforementioned assumption can be confirmed for the two tasks which required rotation, as the regression slope for the bar-transport-task is steeper than for the sword-rotation-task (see Figure 19 and 21 in Chapter 3.3.1.).

The developmental trajectories of the bar-transport-task and the sword-rotation-task are in line with previous research (e.g. Crajé, Aarts, et al., 2010; Weigelt & Schack, 2010). It is still an open question, however, why the behavior in both tasks is not related in participants of the different age groups. One possible explanation is that the underlying mechanisms for 90 degree rotations and higher degree rotations are different. It may be, that planning for bigger rotations may need more cognitive capacity, which may not be available in all children younger than 10 years of age. Cognitive development occurs in spurts, as suggested by cognitive development theorists like Piaget (1936) for example. The possible underlying abilities develop at different times, at different rates, and interindividually different. If the underlying mechanisms for both, low rotation tasks and higher rotation tasks are not the same, it may be that they develop at different times in maturation. In some children, one skill develops before the other, and vice versa in other children.

4.1.3. Precision requirements

Another constraint for the ESC effect to show up may relate to the precision requirements of the task (*precision hypothesis*, Rosenbaum et al., 1993). The assumption is that people`s anticipatory planning strategies are related to the amount of precision required to end the task (Rosenbaum et al., 2006; Rosenbaum et al., 1996; Short & Cauraugh, 1999). Rosenbaum and colleagues (1996) confirmed the prediction that the ESC effect relies on precision requirements, whereas other studies were not able to support this assumption (e.g. Hughes et al., 2012). In their study, Hughes and colleagues (2012) examined this assumption in a version of the bar-transport-task, requiring 180 degrees of object rotation by adding precision requirements to the start and end of the object manipulation. According to the precision hypothesis, they hypothesized that people plan their movements to afford comfortable start postures if precision requirements are high at the start of the movement, and that they should plan their movement to afford comfortable end postures, if precision requirements are high at the end of the action. Unfortunately, they found half of the participants follow their hypothesis, the other half planned for ESC, independent of precision requirements at the start and/or end of the action. Therefore, the influence of precision requirements still remains to be clarified. Nevertheless, our results gained in the experimental study provided partial support for the precision hypothesis. The bar-transport-task and the sword-rotation-task required precision when inserting the bar/sword into the target hole, whereas the grasp-height-task did not require that much precision, as the platforms were big enough to easily place the plunger onto them. This may be another reason why ESC is only little observed in this task. Therefore, it can be reasoned that if precision requirements were higher, then more children would have shown ESC in the grasp-height-task.

4.1.4. Perceived comfort

It can be assumed, that children do not perceive an underhand grip or a thumb-down grasp as awkward as adults do and therefore, do not see the necessity of adjusting their grasp strategy in terms of ESC. This may be due to another view of comfort in children, compared to adults. Adults rate a rather supinated position of 90 degrees of their hand as quite awkward. As childrens' joint flexibility is rather higher than in adults, it may be that they do not feel uncomfortable in this end position. Until today, only one study examined perceived comfort in children (Wilmut & Byrne, 2014b). Unfortunately, these authors did not provide the data to analyze the difference in children and adults on the different grasp orientations. In any case, comfort ratings of children at different ages and in different ESC tasks should be examined in future studies.

4.1.5. Different kinds of learning effects

The studies reviewed in Chapter 2 as well as the tasks used to asses anticipatory planning skills also differed regarding constraints, which may have provoked any learning effects. These can be originated through differences in the experience with the task (i.e. if children were already familiar with the kind of task through toys or deliberate play), differences in the exposure to the task (i.e. if children were given any familiarization trials, and how many trials were comprised in the testing session), and differences in test procedures regarding observational learning (i.e. if children were shown the correct solution of the task by the experimenter prior to testing).

One assumption regarding experience with the task is that children may have a higher level of expertise in some tasks than in others. As many toys for infants include actions, such as inserting objects into holes, but not putting objects into shelves, it may be that children are not as familiar with these kinds of actions and thus, did not show the grasp-height-effect until the age of 10 years. This may be due to the existence of two independent systems, which are required to solve goal-directed tasks: a habitual, stimulus-driven and an intentional, goal-directed system, which are employed by the CNS (Herbort & Butz, 2011, see Chapter 2.4.1.7.). The perception of an object automatically evokes actions that are habitually applied to grasp these objects. The presentation of everyday objects may therefore automatically activate those actions that are habitually used to grasp them, independent of the current intention of the participant. It may be that such habitual grasping effects also influenced the planning strategies in some of the children, especially, when the objects used were everyday life objects. This might be the case for the grasp-height-task, because children are familiar with wooden blocks or sticks of trees, but they use these objects rather for playing than for simply placing them. Therefore, they may have stored a habitual grasp posture somewhere in the middle of the bar, making it easier for them to use it for deliberate play.

Also, the exposure to the task differed across the studies reviewed in Chapter 2. The first difference in test procedure was whether or not participants were given the opportunity to practice the task before the actual testing began. Some studies gave children an opportunity to practice prior to testing (e.g. Crajé, Aarts, et al., 2010; Knudsen et al., 2012; Jovanovic & Schwarzer , 2011), whereas others did not (e.g. Adalbjornsson et al., 2008; Jongbloed-Pereboom et al., 2013; Weigelt & Schack, 2010). Results showed, that the presence of ESC does not seem to depend on the chance to get familiar with the task, as some of the studies found evidence for ESC planning in children, others did not. These differences in findings were independent of the presence of familiarization trials.

The second constraint regarding exposure relies on the amount of trials participants were given during the testing session. Whereas children had to complete only six trials in the bar-transport-task (three critical trials) and in the grasp-height-task, but 18 trials (six critical trials) in the sword-rotation-task, one might think (based on learning theories), that more trials could lead to better performance. Upon today, there is hardly any empirical evidence for this notion. On exception is provided by McCarthy and Keen (2005), who presented infants a spoon, lying in different orientations, for 12 consecutive trials. Results revealed, that 12-month old infants used the appropriate radial grip more often when the spoon was presented in the same orientation all 12 times, than when the orientation of the spoon was alternated. But, even when the spoon was presented in a blocked fashion (i.e. six times with the bowl pointing to the left, six times with the bowl pointing to the right), there were no learning effects observable.

These observations are in line with the results provided in Chapter 3 (see Figure 20 for the performance in the three trial repetitions in the bar-transport-task, Figure 22 for the six trials repetitions in the sword-rotation-task, and Figure 25 for the six trials in the grasp-height-task). Results showed that experiencing nonefficient grips in earlier trials had no influence on grasp choice in the following trials. However, it is still an open question, whether the developmental onset of ESC would have been found earlier in the present tasks if children were provided with much more trials to practice

Besides the findings, that children improved their strategies after repeated trials of spoon use (McCarthy & Keen, 2005), there is also much other evidence that many aspects of motor development involves learning by experience (for a review see Berger & Adolph, 2007). Also, learning theories assume that observational learning and instructions play an important role in cognitive (and motor) development (e.g. Vygotski, 1977). Hence, children might optimize their grasp strategies through observational learning. Only one of the studies reviewed in Chapter 2 did explicitly examine the role of these effects in children (Jovanovic & Schwarzer, 2011). In their study, Jovanovic and Schwarzer (2011) showed that demonstrating the task by the experimenter led to a significant improvement in grasp strategies applied by the children, suggesting that children indeed benefited from observation. One quite plausible interpretation of this result is that the acquisition of efficient motor patterns is the result of learning, which would be in line with other findings (Berger & Adolph, 2007; Boncoddo, Dixon, & Kelly, 2010; Oztop, Bradley, & Arbib, 2004). As the tasks were not demonstrated in the experimental study, no assertion can be made about observational learning effects in general, but a possible influence can be denied for the tasks used in the experimental study (Chapter 3). However, it is still an open question, whether observational learning or verbal instructions can modify children's behavior, so that ESC behavior emerges much earlier in the course of motor (and cognitive) development.

4.1.6. Directedness of the tasks

In a study on toddlers, Claxton and colleagues (2009) found that self-directed actions led to an earlier onset of ESC planning, which is in line with Vygotski's theory (1977). The child learns best from interaction with the environment and from the interaction with other social agents. The results of the review study (Chapter 2) suggest, that self-directed actions lead to an earlier onset of development of ESC planning. Therefore, self-directed tasks should be taken into account in future investigations on the development of ESC planning.

4.2. Theory-driven assumptions

Regarding the DOF problem mentioned in Chapter 1.1 (Bernstein, 1967), it can be assumed from the data of ESC planning in adults that people tend to choose their grasp strategy due to the most economic behavior (Rosenbaum et al., 2012). When grasping the cup, which is standing upside down in the cabinet, adults will choose an uncomfortable thumb-down posture when initially grasping the cup in order to end the action comfortably, with their thumb pointing upwards, in a manner consistent with ESC. The DOF are limited to those outcomes, which enable the most economical behavior and therefore results in an almost automatical response to the stimulus, enabling the person to drink from the cup after its rotation. Children, however, have a greater variability in selecting their grasping posture; the control of the DOF is lower than in adults. With regard, Bernstein (1967) postulated three learning stages. In the first stage, the control problem is accounted for by reducing the number of degrees of freedom by simply freezing them (Vereijken, van Emmerik, Whiting, & Newell, 1992). Whether or not a learner freezes the DOF is influenced by the need for control. Children's initial lack of control over the great number of DOF leads to high variability in performance (Haehl, Vardaxis, & Ulrich, 2000). When DOF are eliminated, the variability of performance is reduced. Therefore, children younger than five years (according to the results of the experimental study) are not able to vary their grasping posture, i.e. to adapt an uncomfortable thumb-down posture at the beginning of the action of turning the cup over. They basically reduce the DOF as they freeze them, meaning that always the same default grip is used.

In the second stage, as learning progresses, children can explore additional degrees of freedom and increasingly incorporate them into task solution, thereby adding flexibility to the performance (Vereijken, van Emmerik, Bongaardt, Beek, & Newell, 1997). The exploration of DOF leads to an increase in performance variability, whereas successful exploitation leads to increased flexibility in action outcomes. This means, that children aged five years and older start not to freeze the DOF, but rather explore different outcomes when using a higher amount of DOF. Therefore, they try out how the inclusion of other DOF affects their behavior. They begin to use thumb-down grasps for grasping the cup, taking more DOF into account. Then, in the third stage, expertise has progressed to a level where reactive forces are no longer fought or resisted, but actively exploited

Considering the results of the ESC tasks in the experimental study, this stage model can be confirmed. Younger children seem to freeze the DOF, resulting in default grasps across the different tasks. As they grew older, children start to explore more and more DOF, enabling them to adapt grip choice prior to grasping. Based on spatial features of DOF, it can be assumed, that the amount of DOF in the grasp-height-task (i.e. grasp height) is higher in continuous tasks compared to tasks, where only two different grips are possible, like in the bar-transport task.

Concerning grip choice, one can chose only an overhand- or an underhand grip in the bar-transport-task. Moreover, in the continuous grasp-height-task, no joint flexibility is necessary in a way as in other tasks, which need rotation of the object. This may be another concern of not finding ESC in the grasp-height-task in children as old as 10 years of age. As there is no need to explore new DOF as suggested in Stage 2 of Bernstein's model, the possible outcomes were not much different depending on grasp height, children tend to retain their default grip without any adjustment. Even in adults, the amount of ESC is comparably low, which may be due to the same constraints. Our results, however, are in line with the suggestion of a most recent study (Hermens, Kral, & Rosenbaum, 2014), in which the authors argued that ESC may be restricted to relatively simple grasping movements.

According to the ideomotor approach (as outlined in Chapter 1.2.1.), it can be assumed that people experience their motor abilities only indirectly through the perception of achievable sensory effects. This is the case in ESC planning. Referring again to the example of the Introduction: When a person wants to take out a cup from the kitchen shelf in the morning, which is oriented upside-down, he/she will anticipate the sensory consequences when grasping the cup either with a thumb-up or with a thumb-down gasp. As ESC is about control (e.g. Rosenbaum et al., 2012), the person will chose the initially uncomfortable thumb-down grasp, in order to achieve the posture, which allows for the most movement control at the end of the action, when pouring coffee into the cup. As children younger than five years did not show evidence for ESC planning in the tasks included in the experimental study, it can be assumed that they are not as sufficient to anticipate, evaluate, and correct sensory consequences (and to correct mistakes). Only by the time they are able to do so, the motor action could be adjusted in terms of ESC.

Imagine a young child going to the kitchen shelf to get a cup out of it for a hot chocolate in the morning, he/she will grasp it with a default grip (i.e. with the thumb pointing upwards), resulting in an uncomfortable posture at the end of the movement. Under the age of (minimal) 5 years, this consequence does not get evaluated with regard to control, and therefore, no grip adaption (error correction) is implemented. This may be because people first have to learn about the sensory effects, which can be produced through motor actions (Elsner & Hommel, 2001). Not until then, sensorimotor units are built, which are necessary for the anticipation of movements (or showing the ESC effect). These functional units, which are built with the integration of motor programs and action effects, represent actions and provide a person cognitive access to voluntary actions: the motor program can be activated through the anticipation of the desired consequences (Elsner & Hommel, 2001).

Relying on the ABC theory (Chapter 1.3.2.), which takes the primacy of action-effect learning, as well as the conditionalization of action-effect relations into account (Hoffmann 1993, 2003; Hoffmann et al., 2004, 2007), it can be assumed, that behavioral competence (in the introduction example: grasp the cup, pour coffee into it, and to drink coffee from the cup) emerges by the acquisition of action-effects. Thereby, one needs to distinguish between body-intern and body-extern action effects. The latter are any effects, which appear as a result of an action somewhere in the environment. When thinking about making coffee in the morning, a person goes into the kitchen and presses the button on the coffee machine. The subsequent effect of that action (i.e. pressing the button), is that the machine starts brewing coffee. It might be, that these kind of body-external action-effects have an influence on the presence on ESC in children. This assumption was examined in a study by Jovanovic and Schwarzer (2011), who found children as young as three years to show the ESC effect, when the task provided a body-extern action effect (i.e. a light turned on when the child inserted the bar into the target hole). Knudsen and colleagues (2012) investigated their role more profoundly. They used a similar version of the bar-transport-task as Jovanovic and Schwarzer (2011), as well as the overturned-glass-task. Action-effects were added to both tasks, meaning that the correct execution of the action resulted in a shed-on of lights. However, in this study body-external action-effects did not seem to influence children's behavior in both tasks.

A body-internal action effect is the subsequently perceived posture at the end of a movement. In the cup example, with the cup standing upside down in the cabinet, there are two possible ways to grasp it: with a thumb-up or with a thumb-down grasp. Both versions result in different outcomes after the rotation of the cup. Whereas grasping with a thumb-down grasp will result in a comfortable end state, an initial thumb-up grasp will result in a very uncomfortable end position, with the arm pronated or supinated by 180 degrees. This perceived outcome can be denoted as a body-internal action effect, which can either be positive (comfortable) or negative (uncomfortable).

Next, the ABC theory by Hoffmann (1993, 2003) and the conceptualization about the DOF by Bernstein (1967) will be blended to provide a new look at anticipatory behavioral control in children.

4.3. A new look at anticipatory behavioral control in children

Even young children can anticipate action effects (for review see Daum & Aschersleben, 2014; Elsner, 2007). However, based on the results of Chapter 2, young children do not show the ESC effect. This is surprising, because the literature suggests that even infants are able to anticipate action effects, but most of these anticipated effects were body-external effects. For example, a seminal study conducted by Rovee and Rovee (1969) showed 2- to 5-month old infants to learn the relation between leg kicks and the following contingent movements of a mobile above their head. Such body-external effects were also examined in studies using ESC tasks by Jovanovic and Schwarzer (2011), as well as by Knudsen et al. (2012), in which motor actions were aided by visual effects (i.e. switching on lights). Jovanovic and Schwarzer (2011) found the ESC effect to be present in 3-year old children in a version of the bar-transport-task, after children produced light effects at the end of the actions. However, as Knudsen and colleagues (2012) demonstrated, such visual effects may not be critical for the acquisition of anticipatory planning abilities in the bar-transport-task and the overturned-glass-task.

Hence, the ability to anticipate body-external effects may not be (fully) decisive for the ESC effect to be present in children. Rather, it is most plausible to assume, that instead of body-external action effects, the ability to anticipate body-internal action effects (i.e. ending an action in a comfortable versus in an uncomfortable end position) may be critical for the development of ESC planning. This assumption will be further grounded within a three-stage model based on Bernstein's conceptualization of the DOF problem (1967, see Chapter 4.3.) and Hoffmann's ABC theory (2009, see Chapter 1.3.2. and 4.3.).

The model depicted in Figure 30 shows a three-phase learning model of anticipatory behavioral control, using the coffee-cup example from the beginning of this thesis (Chapter 1). Phase 1 of the model refers to children younger than (approximately) 4-5 years, the age, at which children habitually use a default thumb-up grasp. Phase 2 represents the behavior of children roughly between 5-10 years, when the majority starts to show the ESC effect for the first time. Phase 3 resembles the manifestation of the ESC effect in children (typically) older than 10 years, and in adults.

In the example of the child going into the kitchen to have a cup of milk, the cup standing upside down in the cabinet serves as the *situational condition*. The grasping action to be performed, namely to take the cup out of the cabinet in order to have a cup of milk, is the *voluntary action*. The (body-internal) *effect anticipation* is the intended end-posture and the *real effect* is the reafferent perception of the actual end-posture, which is attained when the manual rotation action is completed. This defines the major components of the three-phase model.

In Phase 1 of the model, younger children will always (automatically) select a default grasp to reach for the cup, as has been suggested by Weigelt and Schack (2010). Thus, they may not be able to anticipate an action outcome other than ending the movement in a thumb-up posture (as a default posture). This may be due to the "freezing" of additional DOF for better task control, as was already explained in Chapter 4.3. (Bernstein, 1967). As a consequence, they will finish the manipulation in an uncomfortable thumb-down posture. Because task experience does not seem to influence grasp selection in children of this age (as was observed in the experimental study, Chapter 3), the comparison of the real effects (i.e. uncomfortable thumb-down posture) with the effect anticipation (default thumb-up posture) in order to form action effect associations may be incomplete, delayed, or may not take place at all. Therefore, neither the primary formation of action-effect associations nor the secondary contextualization of action-effect associations is realized.

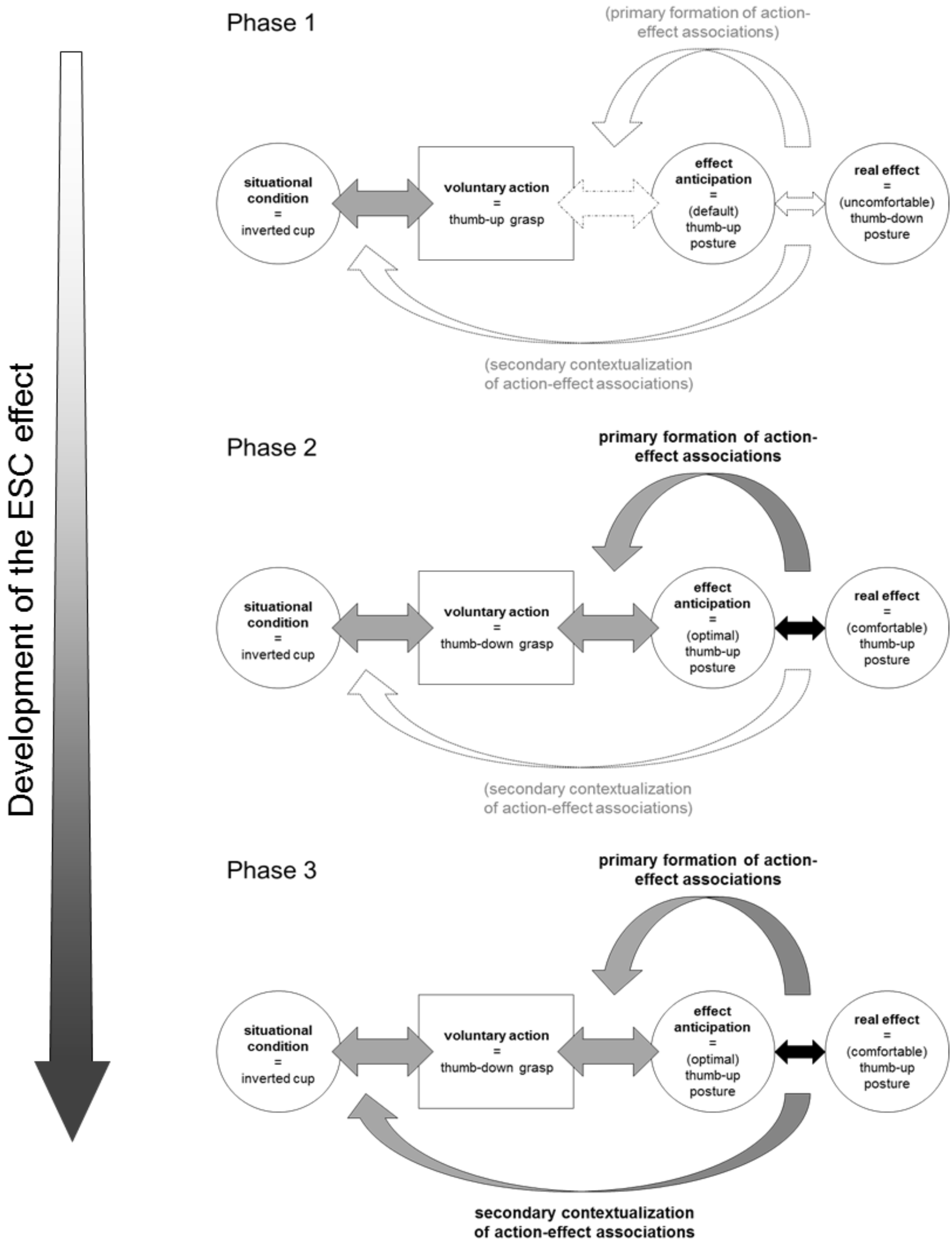

Figure 30. Three-phase adaptation of the ABC theory by Hoffmann (2009), adjusted to account for children's performance in ESC tasks. In Phase 1, children automatically select a default grasp (thumb-up grasp), as they are not able to anticipate other effects. As the real effect does not match the effect anticipation, no action-effect associations are formed and no contextualization to the situational condition takes place. In Phase 2, children are able to anticipate different action outcomes. Now, the real effect matches the effect anticipation and action-effect anticipations are formed (i.e. initial thumb-down grasp results in final thumb-up posture after rotation), but these are not yet contextualized to the situational condition. In Phase 3, children (and adults) are able to precisely anticipate desired action effects, based on strong action-effect associations. As the real effect reliably matches the effect anticipation, the action-effect association is now contextualized to the situational condition (i.e. inverted cup).

In Phase 2, children begin to “free” additional DOF as their motor actions become more variable, resulting in new task solutions. This is accompanied by eminent processes of motor reorganization (e.g. Bard et al., 1990; Thibaut & Toussaint, 2010; see Chapter 4.1.1.). Thus, from various experiences with different task solution, they are now able to anticipate different action outcomes, such as a thumb-up posture (as the optimal posture to finish the action). Now, the real effect matches the effect anticipation and action-effect associations are formed (i.e. initial thumb-down grasp results in final thumb-up posture after rotation). The situational condition (i.e. inverted cup), however, is not yet contextualized to this new action-effect association.

In Phase 3, an optimal space of DOF is exploited (Bernstein, 1967) and actions are flexibly selected to achieve intended goal-states. Older children and adults are able to precisely anticipate desired (body-internal) action effects (i.e. to end comfortably with a thumb-up grasp) based on strong action-effect associations. Again, the real effect matches the effect anticipation. As the flexible selection of grasping actions demonstrates, these action-effect associations are contextualized to the situational condition, enabling the actors to choose optimal body postures (Rosenbaum et al., 1996).

4.4. Criticism on the experimental study

First, there is one point to criticize about the review study provided in Chapter 2. In this study, a search procedure was applied, based on previous systematic reviews like the one of Blauw-Hospers & Hadders-Algra (2005) or Greaves et al. (2010), containing eight distinct steps for literature search. Quite recently, another, standardized system for systematic literature search was discovered by the author of this thesis. This schema is named “PRISMA – Transparent reporting of systematic reviews and meta-analyses” (Moher, Liberati, Tetzlaff, & Altman, 2009). The PRISMA Statement consists of a 27 item checklist. If this schema would have been applied to the systematic review in Chapter 2, this might have made the review more comparable to other reviews and improved in its structure.

Second, the tasks to measure ESC planning abilities might have been too different to exhibit relationships between their developmental patterns. They differed regarding many details, like the degree of object rotation vs. object translation, their motivational character, or the precision requirements (see Chapter 2.4.2.). Maybe, these are too many factors that prevented the finding of any correlations between them. Moreover, all tasks were external-directed, what has been shown elsewhere to gather rather small effects than when tasks are self-directed (like the spoon-handling-task, for example, which showed even toddlers to plan their actions in advance; Claxton et al., 2009; McCarthy et al., 1999). Therefore, the use of more self-directed tasks, and of tasks, that were more similar regarding their task constraints, may reveal more similar developmental trajectories than the tasks used in the experimental study (Chapter 3).

The third concern reading the EF tasks is, that task selection may have been appropriate, but not for the big range of considered ages. As different test protocols were needed for different age groups, results of the tests were difficult to compare. The developmental trajectories in the different tasks must be seen critical. For example: A 5-year old child solved 40% of the TOH task, a 6-year-old solved 60%. One would expect a 7-year-old to solve more than 60%, maybe 70% of the items, but as the test protocol changed and the items became more difficult, a 7-year old child might perform even worse. This may have sophisticated the results on EF in children. One solution would be to examine children of a smaller age-range, while using tests with the same protocol within the age range (i.e. 3- to 5-year-olds, as the test protocols stay the same in all three EF tasks for that age range). Another possibility is to find tasks, that are able to measure EF over a larger age range, but with the same protocol. However, the author is not aware of any test to fulfil this criterion. Either, the cognitive development requires an increase in difficulty, or there are ceiling effects at a certain age (e.g. in the famous Stanford marshmallow task to measure inhibitory control, where the test procedure stays the same, but children as old as 7-years do show ceiling effects; Mischel, Ebbesen, & Raskoff Zeiss, 1972).

Fourth, it might be that the selection of EF tasks may not have been appropriate to examine a relationship to ESC planning. Maybe, the EF tasks chosen in the experimental study (i.e. problem solving, visual perception, and attention) are no underlying mechanisms of ESC planning abilities. Therefore, other tests to assess EF may be used. However, it needs to be assumed, that a study on correlations between motor and intellectual functions in children between 7 and 18 years, which uses different measures of intelligence as well as several motor tasks, is not able to find a relationship between motor and cognitive functions. Such cognitive measures should be applied in combination with ESC tasks to examine a possible relationship of more superior cognitive skills and the more subordinate motor ability of ESC planning. One possible measure could be inhibitory control. Results of a study conducted by Eigsti et al. (2006) revealed, that the proportion of time preschoolers directed their attention away from a rewarding stimulus was positively associated with efficiency (here: greater speed without reduced accuracy at responding targets in a go-/no-go task). As the ESC effect can also be seen as an efficiency constraint of motor planning, the influence of inhibitory control on the ESC effect may be another possible mediating factor on ESC planning. Another possible underlying cognitive function could be memory performance. In a study conducted by Weigelt et al. (2009), a close relationship was revealed for perceptual-motor control (ESC) and cognitive processing (i.e. to memorize letters). Logan and Fischman (2011) conducted an experiment, in which participants had to view a series of letters and then perform an ESC task. Results revealed that independent of task complexity, the commonly found recency effect in memory recall was absent. This suggests a reciprocal influence of physical action and cognitive processes, which were interpreted as a basic concurrence cost. In another recent study, Spiegel and colleagues (2014) investigated the influence of available attentional resources on task-costs. Results revealed complex interactions, in that the processes involved in movement planning, spatial attention, and visuospatial working memory are functionally associated, but not linked in a mandatory fashion. Therefore, these cognitive skills could provide more insight into the functional linkage of cognition and action planning. It may be, that this and other measures of cognitive functions are more related to the development of ESC than the EF tasks chosen in our study.

4.5. Directions of future studies

Even if a number of important questions regarding the development of cognitive and motor planning skills could have been answered here, some open questions remain, which should be the focus of future research. A selection of open topics based on what was discussed above will be listed in the following.

In the review study, several task constraints were identified, which may have an influence on the presence of ESC in the different tasks. However, still not much is known about the role of these constraints in children, including the influence of the number of action steps, the required degree of object rotation, precision requirements, and so on (see Chapter 2.4.2). In future studies, the influence of each of these constraints should be further examined in children (and adults).

Moreover, it is possible that children’s perception of comfort is different from the perception of comfort in adults. There have been several studies investigating perceived comfort ratings for ESC tasks (e.g., Johnson, 2000; Rosenbaum et al., 1993; Seegelke, Hughes, & Schack, 2011). In these studies, participants perceived grasps at both ends of their supination or pronation range as considerably more awkward than those in the middle of their comfortable ranges of motion. By contrast, only one study has investigated perceived comfort levels in children and compared these to adults (Wilmut & Byrne, 2014b). Here, only the ratings of 10- to 12-year old children were similar to those of adults, suggesting that younger children perceive postures at both ends of their supination or pronation range as less awkward. It must be noted, however, that children may not conceptualize a given rating scale (and thus may not provide their comfort ratings) in the same way as adults do. In any case, the findings from these studies, as well as those reported here, suggest that future research should give greater consideration to the comfort ratings provided by children.

As mentioned above, the influence of internally- versus externally-oriented tasks in children should be examined. In toddlers, it has been demonstrated that self-directed motor planning tasks may elicit more effective motor planning than externally-oriented tasks, as the consequences of the actions are more obvious to the participants (Claxton et al., 2009). As nothing is known about the developmental trajectories of internally- versus externally-oriented tasks in children, it should be the aim of future research to examine this relationship.

Furthermore, nothing is known about the influence of habitual vs. goal-directed stimuli (Herbort & Butz, 2011). A recent study by Herbort and Butz (2011) demonstrated that the ESC effect may be compromised for such habitual grasping behavior, when participants were presented with objects of everyday live. It may be that such habitual grasping effects also influenced the planning strategies in some of the children, especially, when the objects used were everyday life objects or objects, children are familiar with. This assumption should be examined in future studies with children and adults.

Another cognitive function possibly linked to ESC is mental rotation. To anticipate the future state of an object, and the grasp posture which is attained with a dedicated starting position, the to-be-manipulated object needs to be mentally rotated into the desired end position in order to anticipate grasp outcomes. Marmor (1975) was the first to study mental rotation in children and found out, that 5-year old children were able to solve mental rotation tasks. Comparing this outcome with the results of the bar-transport-task and the sword-rotation-task of the experimental study, it is obvious, that this is exactly the age where the majority of children is sensitive for ESC. A study conducted by Frick, Daum, Walser, and Mast (2005) investigated the relationship of mental and manual rotation. They found, that mainly in children younger than 11 years mental and motor processes are coupled more closely than in older children and adults. Therefore, the ability to mentally rotate objects may be a premise for the anticipation of end postures in object manipulation tasks.

Despite the fact, that no relationship between ESC and EF was found in the experimental study in Chapter 3, it might be that other EF tasks could be more appropriate for future investigations, such as the Wisconsin Card Sort task (Grant & Berg, 1948) or a Go-/ no Go task (Nosek & Banaji, 2001). Alternative to EF tasks, more general tests of cognitive functions could be applied, especially those, that test for intelligence in children (e.g. the Wechsler Intelligence Scale for Children, Wechsler, 2003). Also, the influence of memory performance on the ESC effect should be within the focus of future research, as can be derived from other studies (Weigelt et al., 2009; Logan & Fischman, 2011). The main restriction will be to find appropriate measures for the majority of age groups tested in the experimental study.

The search for new cognitive tasks, however, may not be easy, as a most recent study on correlations between motor and intellectual functions in normally developing children between 7 and 18 years showed that motor and intellectual domains in normally developing children are largely independent and should be, for the most part, considered separately (Jenni et al., 2013). Hence, the question remains, whether cognitive and motor development is in other ways related, and if so, which measures (of cognitive and executive functions) could be used to examine this relationship appropriately. Therefore, future studies should take other cognitive functions into account, which might be more correlated with the performance in ESC tasks than the tasks in the experimental study used here.

Given the positive developmental trajectory for ESC planning in children, it still remains an open question how the ability for anticipatory planning develops at old ages. If cognitive (or executive) factors are really an determining mechanism for the development of ESC, does the effect decline in higher age, as cognitive functions do? Many studies have demonstrated that cognitive decline takes place with increasing age, even with different intraindividual extends (Salthouse, 1991). The course of the developmental curve for ESC planning over the lifespan still needs to be clarified. A first step into this direction was already taken by the author (Wunsch, Weigelt, & Stöckel, in prep): Older adults between 60 and 80 years were tested in the bar-transport-task. Results showed that there is a decline in ESC sensitivity in higher ages, which is similar in unimanual and bimanual grasping tasks. Older participants tended not to select ESC as consistent as their younger counterparts. Based on these results, it was suggested, that the ability for motor planning may rely on cognitive planning skills, which are known to decline in higher ages. Hence, the ability for anticipatory planning at the end of the lifespan should be examined in future studies, using different tasks and cognitive measures.

4.6. Conclusion

The review study (Chapter 2) provided insights into the *status quo* of research on the developmental pattern of the ESC effect as a signification of anticipatory planning abilities in children. As the results showed, the ESC effect develops from early childhood until adolescence, with different trajectories for different ESC tasks. The experimental study (Chapter 3) supported the pattern of results from previous studies across different ESC tasks, as has been revealed in the review study (Chapter 2). In addition, no relationship between performance in the EF tasks and the developmental trajectory of the ESC effect was observed. Thus, contrary to what one would assume from the most prominent cognitive developmental theories (e.g. Piaget, 1936; Vygostki, 1977), there may not be such a tight link between cognitive and motor development in children. This lack of evidence, however, should be addressed again in future studies, as well as the influence of other factors on the development of the anticipatory planning abilities and motor skills during childhood.

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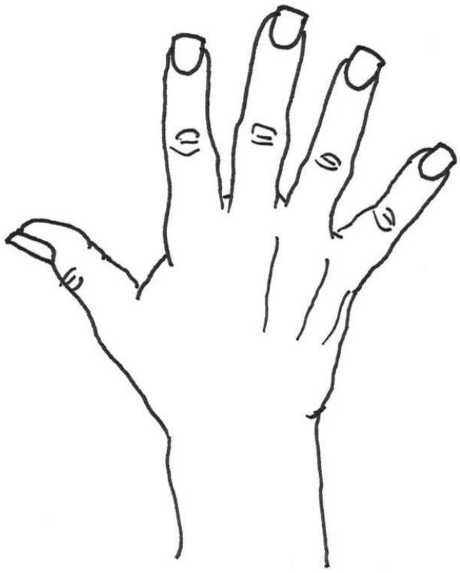

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Supplements

Supplements

Supplement A – Means for the tasks of the experimental study

A1. Mean percentage of ESC grasps in the bar-transport-task divided by age groups.

	Uncritical trials			Critical trials			ESC in > 50% of trials	
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Uncritical	Critical
3-year-olds	100	100	90,5	14,3	28,6	33,3	100	23,8
4-year-olds	100	100	95,7	47,8	47,8	47,8	100	47,8
5-year-olds	100	100	96,2	42,3	61,5	61,5	100	61,5
6-year-olds	95,5	95,5	100	54,5	63,6	59,1	100	63,6
7-year-olds	100	100	88,5	57,7	61,5	65,4	100	61,5
8-year-olds	100	100	100	59,3	74,1	63,0	100	63,0
9-year-olds	100	91,3	96,3	69,6	82,6	82,6	100	78,3
10-year-olds	95,2	95,2	100	85,7	95,2	100	100	95,2
Adults	100	100	100	96,4	96,4	92,9	100	96,4

Note. All values describe percentages of participants. Trials 1,2 and 3 were not assigned in the demonstrated order, but were presented randomly. The mean percentages demonstrated in the last two rows were applied to statistical analyses.

A2. Mean percentage of ESC grasps in the sword-rotation-task divided by age groups.

	Uncritical trials												Critical trials						ESC in > 50% of	
	Position1			Position 4			Position 5			Position 6			Position 2			Position 3				
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Uncritical	Critical
3-year-olds	100	100	100	85,7	90,5	95,2	95,2	95,2	100	100	100	100	47,6	57,1	47,6	23,8	52,4	47,6	100	42,9
4-year-olds	100	95,7	100	87,0	91,3	87,0	100	100	100	100	100	100	60,9	39,1	43,5	39,1	56,5	34,8	100	43,5
5-year-olds	100	92,3	92,3	100	100	100	96,2	100	96,2	100	96,2	100	76,9	69,2	73,1	73,1	69,2	80,8	100	57,7
6-year-olds	100	95,5	90,9	81,8	86,4	77,3	95,5	95,5	95,5	100	95,5	95,5	63,6	72,7	72,7	59,1	68,2	68,2	100	63,6
7-year-olds	100	96,2	96,2	96,2	96,2	96,2	100	96,2	96,2	100	100	100	61,5	57,7	65,4	65,4	73,1	80,8	100	73,1
8-year-olds	96,3	100	96,3	96,3	96,3	92,6	100	96,3	92,6	100	100	100	74,1	81,5	88,9	81,5	77,8	81,5	100	74,1
9-year-olds	100	100	87,0	100	100	95,7	100	91,3	95,7	95,7	100	95,7	65,2	69,6	78,3	78,3	82,6	73,9	100	78,3
10-year-olds	100	100	95,2	90,5	100	100	100	100	100	100	95,2	100	76,2	90,5	85,7	90,5	81,0	81,0	100	76,2
Adults	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Note. All values describe percentages of participants. Positions 1 to 6 and Trials 1,2 and 3 were not assigned in the demonstrated order, but were presented randomly. The mean percentages demonstrated in the last two rows were applied to statistical analyses.

A3. Mean grasp heights in the grasp-height-task divided by age groups.

	Grasp height [cm]				ESC [% of participants]		
	High target (HT)		Low target (LT)				
	HtT	TtH	HtT	TtH	HT	LT	Mean
3-year-olds	48,7	37,2	53,1	70,6	19,0	4,8	11,9
4-year-olds	48,2	40,6	54,4	76,2	34,8	4,3	19,6
5-year-olds	54,0	47,0	56,1	74,9	19,2	7,7	13,5
6-year-olds	53,5	49,8	52,9	70,8	31,8	0,0	15,9
7-year-olds	51,1	50,8	55,2	72,1	38,5	3,8	21,2
8-year-olds	59,0	59,8	64,3	75,8	33,3	22,2	27,8
9-year-olds	58,7	59,7	60,2	70,5	39,1	26,1	32,6
10-year-olds	58,4	60,6	60,7	69,8	45,5	13,6	29,5
Adults	41,4	50,1	56,6	56,0	92,9	50,0	71,4

Legend. HtT = Home-to-Target moves; TtH = Target-to-home moves

Note. Presented values for HtT and TtH moves reflect mean grasp height collapsed over all three HtT and TtH trials, respectively. The last three rows show the percentage of participants, who showed ESC. ESC was declared as being present, if grasp height was lower in TtT than in TtH moves in moves to the high target platform, and if grasp height was higher in HtT than in TtH moves in moves to the low target platform.

A4. Mean performance on the Tower-of-Hanoi-task divided by age groups.

	Accomplished items	First mistake		Latency	Time per item	Superflous moves	Rule violations	Correctly solved	Solved items
	[# of items]	[# of item]	[# of moves]	[in s]	[in s]	[# of moves]	[amount]	[% of accomplished items]	[% of total items]
3-year-olds	1,3	1,4	1,1	16,5	55,5	1,5	2,2	38,9	12,9
4-year-olds	2,4	2,2	1,1	8,8	38,9	1,8	2,0	73,9	23,9
5-year-olds	4,6	3,1	1,2	7,4	52,7	3,4	1,2	63,5	45,8
6-year-olds	5,4	2,2	1,3	7,2	43,5	3,5	2,3	42,2	53,6
7-year-olds	4,2	1,4	1,8	11,5	61,2	4,8	1,0	31,1	41,9
8-year-olds	4,8	1,7	1,7	6,1	45,0	5,0	1,1	28,3	47,8
9-year-olds	4,9	1,7	2,0	5,2	40,5	5,0	1,3	42,8	49,1
10-year-olds	5,7	2,0	1,7	5,4	40,8	5,8	0,5	35,0	56,7
Adults	6,6	2,8	2,6	7,3	48,6	5,3	0,1	44,3	66,1

Note. The table shows the values for performance in the TOH-task. Every participant had the chance to complete 10 items. The task was terminated if 1) the total amount of 2xn moves was exceeded, or if 2) the participant did not make any move within 30 seconds. Correctly solved items indicate those items, which were solved in the optimal amount of moves without any superfluous moves or mistakes. Solved items, however, include all items until termination, no matter if they were completed correctly, or just within 2xn moves. For statistical analyses, the amount of solved items was used.

A5. Mean performance on the Mosaic-task divided by age groups.

	Accomp-lished items	First mistake	Time per item	Incorrect pattern	Time exceedance	Correctly solved	No time bonus	Time bonus	Possible points	Points
	[# of items]	[# of item]	[in s]	[# of items]	[# of items]	[% of accomp-lished items]	[# of points]	[# of points]	[# of points]	[% of total points]
3-year-olds	11,6	8,7	12,9	4,6	1,1	50,5	17,3	17,3	46	37,6
4-year-olds	15,2	14,8	23,2	4,3	2,1	66,0	16,5	16,5	34	48,5
5-year-olds	19,2	16,8	25,6	2,7	2,8	83,3	24,2	24,2	34	71,2
6-year-olds	12,2	11,7	30,7	2,4	2,5	53,2	22,5	22,5	28	55,1
7-year-olds	9,3	9,1	26,9	3,1	2,8	66,5	25,7	26,7	50	51,4
8-year-olds	11,5	9,3	30,9	1,9	1,9	82,0	31,7	34,9	46	69,0
9-year-olds	11,7	10,6	33,5	1,4	2,0	83,9	34,6	38,3	46	75,2
10-year-olds	13,0	11,3	35,5	0,7	1,1	92,5	39,3	43,0	46	85,5
Adults	13,7	11,9	35,1	0,3	0,8	97,7	31,1	43,3	46	67,7

Note. The table shows the values for performance in the Mosaic-task. According to the different test protocols, possibly reachable points varied (see last row). The task was terminated if participants failed to solve three consequtive patterns du to 1) time exceedance or 2) the builing of an incorrect pattern. Correctly solved items indicate those items, which were solved within the time limit, without a second trial, and without failures in the pattern. In thetest protocol of older children and adults, time boni could be reached; the faster the pattern is built, the more points participants get. For statistical anlyses, points without time bonus were used.

A6. Mean performance on the D2-task divided by age groups.

	IDS 3-5				IDS 5-10				D2-R			
	Processed items	**Mistakes**	**Points**	**Total**	**Processed items**	**Mistakes**	**Points**	**Total**	**Processed items**	**Mistakes**	**Points**	**Total**
	[# of items]	[# of items]	[# of points]	[% of total points]	[# of items]	[# of items]	[# of points]	[% of total points]	[# of items]	[# of items]	[KL total]	[% of total points]
3-year-olds	26,9	0,7	26,1	36,3	--	--	--	--	--	--	--	--
4-year-olds	34,7	0,5	34,2	47,5	--	--	--	--	--	--	--	--
5-year-olds	--	--	--	--	61,0	7,8	53,2	28,1	--	--	--	--
6-year-olds	--	--	--	--	77,8	8,7	69,1	36,6	--	--	--	--
7-year-olds	--	--	--	--	94,7	8,9	85,8	45,4	--	--	--	--
8-year-olds	--	--	--	--	105,4	6,1	99,3	52,5	--	--	--	--
9-year-olds	--	--	--	--	127,3	5,6	121,7	64,4	--	--	--	--
10-year-olds	--	--	--	--	139,1	4,3	134,9	71,4	--	--	--	--
Adults	--	--	--	--	--	--	--	--	191,5	7,2	177,5	43,1

Note. The number of processed items reflect the summarized number of items in each row up to the last item which was sketched out. Mistakes can either be missed items, or items that have falsly sorted out. Points indicate the number of processed items with the number of mistakes subtracted. The total percentage of reached points was taken for statistical analyses.

Supplement B – Informed consent declaration

UNIVERSITÄT PADERBORN
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FAKULTÄT FÜR NATURWISSEN-SCHAFTEN

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Sehr geehrte Eltern,

ich bin Doktorandin der Sportwissenschaft an der Universität Paderborn und arbeite im Bereich motorischer Entwicklung bei Kindern im Arbeitsbereich Sportpsychologie.

Moment arbeite ich an einer Studie, bei der es um den Zusammenhang von motorischen Greiffähigkeiten und kognitiven Fähigkeiten bei Kindern im Alter von 3 bis 10 Jahren geht. Ziel der Studie ist es, die Entwicklung von Greifbewegungen und deren Zusammenhang zur Entwicklung kognitiver Funktionen bei Kindern zu untersuchen. Wir vermuten, dass sich diese im Altersabschnitt von 3 bis 6 Jahren einstellen und sich dann bis in die Pubertät hin ständig weiterentwickeln. Diese Entwicklung ermöglicht den Menschen, die Art des Greifens bereits im Voraus zu planen, sofern ihnen das Ziel der Handlung bekannt ist.

Die Untersuchung wird ca. 70-90 Minuten pro Kind in Anspruch nehmen. Die Erfassung, Speicherung und Verarbeitung personenbezogener Daten wird nur in **anonymisierter** Form erfolgen. Ich garantiere Ihnen den Schutz der Daten Ihres Kindes. Es besteht kein körperliches oder geistiges Risiko. Für die Teilnahme gibt es keine finanzielle Entlohnung; diese erfolgt freiwillig und kann zu jedem Zeitpunkt von Ihrem Kind abgebrochen werden. Hierdurch entsteht Ihrem Kind kein Nachteil. Die Testung findet an der Universität, Gebäude SP1 statt. Gerne können Sie Ihr Kind direkt zur Testung vorbeibringen. Andernfalls übernehmen wir die volle Aufsichtspflicht für Ihr Kind. Wir holen es zu vereinbarter Uhrzeit in der Kurzzeitbetreuung ab und bringen es nach Ende der Untersuchung wieder dorthin zurück. Zur Terminvereinbarung kontaktiere ich Sie gerne telefonisch.

Die Studie wird in Zusammenarbeit mit Prof. Dr. Matthias Weigelt aus dem Arbeitsbereich Sportpsychologie des Departements für Sport und Gesundheit der Universität Paderborn erfolgen. Beginn der Datenerhebung ist der **09.07.2012**. Ab dann können kontinuierlich Termine vereinbart werden.
Zur Terminabsprache bestehen zwei Möglichkeiten:

1.) Sie sind mit der Untersuchung einverstanden und geben Ihre Einverständniserklärung einfach bei einer Mitarbeiterin in der Kurzzeitbetreuung ab. Diese kontaktiert mich und ich hole das Kind zur Testung ab und bringe es danach wieder in die Betreuung. Sie haben keinerlei Aufwand. Die Möglichkeit kommt nur in Betracht, wenn Sie beabsichtigen, ihr Kind **länger als 2 Stunden** in die Betreuung zu geben.
2.) Sie wissen, dass sich Ihr Kind nur ca. 1-1.5 Stunden in der Betreuung befinden wird (z.B. während einer Vorlesung). Sie können ihr Kind dann direkt bei mir vorbeibringen (Gebäude SP 1, 508) und zu vereinbarter Zeit wieder hier abholen. Die Einverständniserklärung bringen Sie direkt mit zu mir.

Während der gesamten Untersuchung obliegt Ihr Kind der Aufsichtspflicht des jeweiligen Testleiters. Es wird zu jedem Zeitpunkt betreut und beaufsichtigt. Wenn Sie damit einverstanden sind, dass Ihr Kind an der Studie teilnehmen darf, möchte ich Sie bitten, die Einverständniserklärung zu unterzeichnen und zum ausgemachten Termin mitzugeben bzw. bei einer der Erzieher/innen abzugeben. Zur Terminvereinbarung erreichen Sie mich gerne unter o.a. Telefonnummer. Gerne rufe ich Sie auch zurück. Hinterlassen Sie hierfür auf der Rückseite bitte Ihre Telefonnummer / email-Adresse. Diese Daten werden sofort nach Terminvereinbarung wieder gelöscht.

Vielen herzlichen Dank

Kathrin Wunsch

Einverständniserklärung

Hiermit bestätige ich, dass mein Kind (Vor- und Nachname)____

(männlich ☐, weiblich ☐) geboren am ____________________ (Tag/Monat/Jahr) an **der Studie zur Entwicklung von Greifbewegungen** teilnehmen ☐ nicht teilnehmen ☐ darf.

Mein Kind geht momentan in die _______ Klasse der ______________________________________ Schule

bzw. in den __________________________________ Kindergarten in ___________________________.

Mein Kind ist Rechtshänder ☐ Linkshänder ☐

Wie bewältigt Ihr Kind den Weg zum Kindergarten bzw. zur Schule?
☐ zu Fuß ☐ Fahrrad ☐ (Schul-)Bus ☐ Auto ☐ Sonstiges: _______________________

Spricht Ihr Kind außer Deutsch noch weitere Sprachen? ☐ ja, und zwar _______________________
☐ nein

Welchen Aktivitäten geht Ihr Kind in seiner Freizeit nach? Nennen Sie die 3 häufigsten Freizeitbeschäftigungen (z.B. Sport, Basteln/ Malen, Lesen, Fernsehen, Musikinstrumente, usw.)

1. ____
2. ____
3. ____

Mein Kind treibt regelmäßig Sport (in einem Verein): Ja ☐ Nein ☐ Wenn ja, welchen?

Sportart 1: ________________________ __________ x pro Woche

Sportart 2: ________________________ __________ x pro Woche

Sportart 3: ________________________ __________ x pro Woche

Sportart 4: ________________________ __________ x pro Woche

Falls eine persönliche Terminvereinbarung gewünscht wird:

Meine Telefonnummer: ____

Meine E-Mail-Adresse: ____

Ich bin am besten _______________________ (Wochentag/e) zwischen _____________ Uhr und

_______________ Uhr erreichbar.

Ich bin ausreichend über den Zweck der Studie aufgeklärt und damit einverstanden, dass mein Kind während der Durchführung von den Versuchsleitern betreut sowie ggf. aus der Kurzzeitbetreuung abgeholt und wieder dorthin zurückgebracht wird.

______________________________ ____

Ort, Datum Unterschrift

Supplement C – Stamp card (randomization)

Laufkarte

Liebe/r ________________,

deine offizielle Startnummer ist heute die

Nummer ______

Im Laufe dieser „Olympiade“ musst du insgesamt sechs verschiedene Stationen absolvieren. Bitte halte dabei unten stehende Reihenfolge ein!

Station Nummer	Absolviert
6	
1	
5	
3	
4	
2	

Wenn du alle Stationen erfolgreich hinter dich gebracht hast, bekommst du eine kleine Überraschung ☺

Supplement D – Test instructions and protocols

D1. Instruction and test protocol for the bar-transport-task

For task and procedure for the bar-transport-task, please see Chapter 3.2.2.1.1.

D1.1. Instruction

„Bitte stelle dich hier hinter diese Linie [ca. 10 cm vor der Tischkante]. *Stehe aufrecht und lasse beide Arme seitlich am Körper locker herunterhängen, so dass die Handflächen die Oberschenkel berühren.*

Vor dir auf dem Tisch siehst du einen zweifarbigen Stab. Dieser ist auf einer Seite schwarz, auf der anderen Seite weiß. Kannst du mir einmal die weiße Seite zeigen? Und die schwarze?

Sehr gut. Ich werde dich nun anweisen, entweder das schwarze oder das weiße Ende des Stabes in diese Öffnung zu stecken [zeigen!]. *Greife daraufhin den Stab mit der Stempelhand und stecke die Seite des Stabes, die ich dir zuvor genannt habe, in die Öffnung ein. Achte darauf, dass du den Stab fest mit der ganzen Hand umschlossen hältst. Löse daraufhin deinen Griff und lasse beide Hände wieder seitlich am Körper hängen wie zuvor.*

Ich lege den Stab dann wieder zurück und werde dir wieder eine Farbe nennen. Hast du noch Fragen? Gut, dann starten wir jetzt.“

D1.2. Test protocol

Vpn ________
Ausgeführt mit welcher Hand? ________________

Versuch		Orientierung		Instruktion	Griffauswahl	ESC Ja/Nein
1				w		
2				s		
3				w		
4				w		
5				s		
6				s		

Vpn ________
Ausgeführt mit welcher Hand? ________________

Versuch		Orientierung		Instruktion	Griffauswahl	ESC Ja/Nein
1				w		
2				s		
3				s		
4				w		
5				s		
6				w		

Legend. Versuch = trial
Orientierung = orientation
Instruktion = instruction
Griffauswahl = grasp choice
ESC Ja/Nein = showed ESC Yes/No
w = white(weiß)
s = black (schwarz)

Note. Here, two exemplary test protocols are depicted. Every participant had six trials (Versuche), and the start orientation (Orientierung) was counterbalanced across participants, as color-coded in the protocol. The instruction (Instruktion) was assigned randomly, with "w" meaning "white" (weiß), "s" meaning "black" (schwarz). Grasp choice was noted ("OH" ("Oberhand") for an overhand grip, "UH" ("Unterhand") for an underhand grip), and the presence of ESC was recorded in the last row (ESC Ja/Nein).

D2. Instruction and test protocol for the sword-rotation-task

For task and procedure for the sword-rotation-task, please see Chapter 3.2.2.1.2.

D2.1. Instruction

„Bitte stelle dich hier hinter diese Linie [ca. 10 cm vor der Tischkante]. *Stehe aufrecht und lasse beide Arme seitlich am Körper locker herunterhängen, sodass die Handflächen die Oberschenkel berühren.*

Vor dir auf dem Tisch siehst du ein Schwert. Du kannst es dir gerne anschauen. Aber pass auf: Die Klinge ist scharf! Du darfst das Schwert nur hier am Griff anfassen, so wie es ein Pirat auch machen würde.

Jetzt kannst du uns zeigen, ob du auch schon ein richtiger Pirat bist. Wir möchten von dir lernen, wie man das Schwert richtig in die Holzbox steckt. Kannst du uns das einmal zeigen? [Versuch #1 immer in Position 1]. *Bitte nimm dazu die Stempelhand. Sobald es in der Box steckt, lass es bitte los und lasse die Arme wieder seitlich neben dem Körper hängen.*

Gut das klappt ja schon super. Das machen wir jetzt noch einige Male, damit ich sehe, ob du das immer so gut kannst. Aber denke daran: greife das Schwert immer nur am Griff, und greife es immer fest mit der ganzen Hand. Du musst es fest halten, sodass es sich nicht in deiner Hand bewegt oder herunterfällt.

Ich werde das Schwert immer wieder hier vor dich auf den Tisch legen und du versuchst dann, es mit der Klinge in die Box zu stecken. Danach lässt du es los und stellst dich wieder so hin wie jetzt gerade. Hast du noch Fragen? Gut, dann starten wir.“

D2.2. Test protocol

Vpn ______

Ausgeführt mit welcher Hand?____________

Versuch		Orientierung		Griffauswahl	ESC Ja/Nein
1		1			
2		4			
3		2			
4		5			
5		3			
6		6			

Versuch		Orientierung		Griffauswahl	ESC Ja/Nein
7		5			
8		2			
9		3			
10		6			
11		1			
12		4			

Versuch		Orientierung		Griffauswahl	ESC Ja/Nein
13		1			
14		2			
15		5			
16		6			
17		3			
18		4			

Legend. Versuch = trial
Orientierung = orientation; numbers 1 to 6 indicate the start orientation of the sword
Griffauswahl = grasp choice
ESC Ja/Nein = showed ESC Yes/No

Note. Every participant had eighteen trials (Versuche), divided into three blocks, with every orientation of the sword (Orientierung) appearing once in a block in a randomized fashion. Grasp choice was noted (“hin” (“towards”) for a grip with the thumb pointing to the blade of the sword, “weg” (“away”) for a grip with the thumb pointing to the blade). Presence of ESC was recorded in the last row (ESC Ja/Nein).

D3. Instruction and test protocol for the grasp-height-task

For task and procedure for the grasp-height-task, please see Chapter 3.2.2.1.3.

D.3.1. Instruction

„Bitte stelle dich hier hinter diese Linie [10 cm vor den Regalböden] *vor die mittlere Plattform. Stehe aufrecht und lasse beide Arme seitlich am Körper locker herunterhängen, sodass die Handflächen die Oberschenkel berühren. Ich mache jetzt ein Video von dir, wie du diese Aufgabe ausführst. Mit Hilfe dieses Videos soll später ein Roboter programmiert werden, der sich dann genau so bewegen soll wie du. Es ist daher sehr wichtig, dass du die Aufgabe genau so ausführst, wie ich sie dir gerade erkläre.*

Du hast gleich die Aufgabe, den Pömpel vor dir entweder nach oben, nach unten, oder in die Mitte des Regals zu stellen. Wohin genau, sage ich dir immer, sobald du wieder die Ausgangsposition eingenommen hast. Du solltest dazu mit den Füßen hinter der Linie stehen und deine Arme rechts und links am Körper hängen lassen.

Ich werde dir vorher immer sagen, wohin du den Pömpel stellen sollst. Also warte bitte immer in der Ausgangshaltung, bis ich dir eine Anweisung gebe. Greife dann nach dem Pömpel und halte ihn fest in der Hand, damit er nicht verrutscht während du ihn auf die Regalhöhe stellst, die ich dir zuvor genannt habe. Benutze hierfür immer die Stempelhand.

Wenn du keine Fragen mehr hast, beginnen wir. Bitte nimm die Ausgangshaltung ein.“

D3.2. Test protocol

Vpn: ______________________

Alter des Probanden in Monaten: __________ Größe des Probanden:______________

Höhe des mittleren Regalbodens: _____________

Testreihenfolge:	Oben	□	Griffhöhe: _____________ cm
	Oben	□	Griffhöhe: _____________ cm
	Oben	□	Griffhöhe: _____________ cm
	Unten	□	Griffhöhe: _____________ cm
	Unten	□	Griffhöhe: _____________ cm
	Unten	□	Griffhöhe: _____________ cm

Vpn: ______________________

Alter des Probanden in Monaten: __________ Größe des Probanden: _____________

Höhe des mittleren Regalbodens: _____________

Testreihenfolge:	Unten	□	Griffhöhe: _____________ cm
	Unten	□	Griffhöhe: _____________ cm
	Unten	□	Griffhöhe: _____________ cm
	Oben	□	Griffhöhe: _____________ cm
	Oben	□	Griffhöhe: _____________ cm
	Oben	□	Griffhöhe: _____________ cm

Legend. Vpn = participant
Alter des Probanden in Monaten = age of participant in moth
Größe des Provbanden = height of participant
Höhe des mittleren Regalbodens = height oft he middle shelf board
Testreihenfolge = testing sequence
Unten = lower shelfboard
Oben = high shelf board
Griffhöhe = Grasp height

Note. Here, the two possible test protocols are depicted. Every participant had six trials, divided into two blocks, with shelf heights blocked. The start height was counterbalanced across participants. Grasp height was analyzed offline, using a frame-by-frame video software (Super), stopping the video at the time of the first contact with the plunger. Then, grasp height was counted relative to the plunger base.

D4. Instruction and test protocol for the Tower-of-Hanoi-task

For task and procedure for the Tower-of-Hanoi-task, please see Chapter 3.2.2.2.1.

D4.1. Instruction

„Auf diesem Bild siehst du einen Turm. Deine Aufgabe ist es, diesen Turm stets auf dem markierten Stab (dem Gleichen, den du auf dem Bild siehst) nachzubauen. Aber die Anfangsposition ist immer eine andere. Du kannst dir das Bild jederzeit anschauen.

Es gelten jedoch einige Regeln:

1. *Du darfst immer nur eine Scheibe bewegen.*
2. *Die Scheiben sind entweder in deiner Hand oder auf einer der drei Stäbe; du darfst sie nicht auf dem Tisch oder dem Gestell ablegen.*
3. *Du darfst nur kleinere Scheiben auf größere Scheiben setzen, keine größere Scheibe auf eine kleinere.*

Bitte versuche, den ersten Turm nachzubauen. Du darfst mich gerne fragen, sollte dir etwas unklar sein.

Das hat ja super geklappt. Ich werde nun einen Sichtschutz hier aufstellen, während ich deine neue Aufgabe vorbereite. Sobald ich diesen entferne, darfst du beginnen. Ich werde dann die Zeit stoppen. Aber: Es ist wichtiger, dass du die Aufgabe richtig löst, anstatt sie schnell zu lösen. Lass dir daher ruhig Zeit und denke gut nach. Hast du noch Fragen? Gut, dann beginnen wir: Fertig – los!“

D4.2. Test protocol for 3- to 4-year old children

Tower of Hanoi (3 & 4 J.)

VP-Nummer: ____________________ Datum: ____________________

Alter des Probanden in Monaten: _________

Legende: kleinste = gelb, 2.-kleinste = rot, mittlere = grün, 2.-größte = blau, größte = schwarz

		Ubungsitem		**(3-Disk)**		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
2	**rot**	**blau**	**schwarz**			

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

		1. Item		**(3-Disk)**		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
3		**grün+rot**	**schwarz**			

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

		2. Item		**(3-Disk)**		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
4	**blau**	**rot+gelb**				

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

		3. Item		**(3-Disk)**		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
5	**schwarz**	**blau**	**rot**			

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

		4. Item		**(3-Disk)**		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
6	**schwarz +grün**		**gelb**			

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	5. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
7		Blau+rot+gelb	schwarz			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: □ ja □ nein Zeit: ___________

	6. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
8	blau+grün+gelb	schwarz				

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: □ ja □ nein Zeit: ___________

	7. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
9	grün+rot	blau	gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: □ ja □ nein Zeit: ___________

	8. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
10	blau	schwarz+grün	gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: □ ja □ nein Zeit: ___________

	9. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
11	schwarz	grün	rot+gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: □ ja □ nein Zeit: ___________

	10. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
15	Blau+grün+rot+gelb					

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: □ ja □ nein Zeit: ___________

D4.3. Test protocol for 5- to 6-year old children

Tower of Hanoi (5 & 6 J.)

VP-Nummer: ____________________ Datum: ____________________

Alter des Probanden in Monaten: __________

Legende: kleinste = gelb, 2.-kleinste = rot, mittlere = grün, 2.-größte = blau, größte = schwarz

	Ubungsitem			(3-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
3		rot+gelb	Grün			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	1. Item			(3-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
4	schwarz	blau+rot				

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	2. Item			(3-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
5	schwarz	blau	Grün			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	3. Item			(3-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
6	blau+grün		Gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	4. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
7		grün+rot+ gelb	Blau			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	5. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
8	blau+grün+rot	schwarz				

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	6. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
9	blau+rot	schwarz	Gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	7. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
10	blau	schwarz+grün	Gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	8. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
11	schwarz	grün	rot+gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	9. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
13	blau	Schwarz+grün	rot			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	10. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
15	blau+ grün+rot+gelb					

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

D4.4. Test protocol for participants aged 7 years and older

Tower of Hanoi (ab 7 J.)

VP-Nummer: ____________________ Datum: ____________________

Alter des Probanden in Monaten: __________

Legende: kleinste = gelb, 2.-kleinste = rot, mittlere = grün, 2.-größte = blau, größte = schwarz

	Übungsitem			(3-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
6	schwarz+rot		gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	1. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
7		blau+grün+gelb	schwarz			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	2. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
9	blau+rot	schwarz	gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	3. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
10	grün	schwarz+rot	gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	4. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
11	blau	grün	rot+gelb			

Regelverstoß: R1________ R2_________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	5. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
13	Schwarz+blau +rot		grün			

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	6. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
15	schwarz+blau+ grün+gelb					

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	7. Item			(5-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
20	blau	Schwarz + grün	rot + gelb			

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	8. Item			(5-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
24	schwarz+blau		grün+rot +gelb			

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	9. Item			(5-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
27		schwarz+blau +rot	grün+gel b			

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

	10. Item			(5-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
31		schwarz+blau + grün+rot+gel b				

Regelverstoß: R1________ R2__________ R3________ Latenz: ___________

Abbruch: ☐ ja ☐ nein Zeit: ___________

Legend. VP = participant
Übungsitem = familiarization trial
Anzahl benötigter Züge = number of moves
Anzahl Fehler = Amount of mistaken moves
Zeitpunkt 1. Fehler = move withf first mistake
Regelverstoß = breach of a rule
Latenz = latency
Abbruch ja/nein = breakup yes/no
Zeit = time needed
schwarz = black
blau = blue
grün = green
rot = red
gelb = yellow

Note. Above, the three different test protocols were depicted: one for 3- to 4-year-olds, one for 5- to 6-year-olds, and one for all participants aged 7 years and older (including adults). Each participant started with a familiarization trial ("Übungsitem"). On the very left of each table, the number of moves is depicted, which are needed to solve the item correctly, without any additional moves. The next three columns indicate the start position of the discs (i.e. which disc is on which peg at the beginning). In the next column, the number of moves were checked, while participants performed their moves ("Anzahl benötigter Züge") The number of mistakes were captured in the next column ("Anzahl Fehler"), and the move, where the first mistake was made, was recorded in the last row ("Zeitpunkt 1. Fehler"). Below, an example is shown (test protocol for 5- to 6-year-olds, item 6).

	6. Item			(4-Disk)		
Moves	Peg 1	Peg 2	Peg 3	Anzahl benötigter Züge	Anzahl Fehler	Zeitpunkt 1. Fehler
9	blau+rot	schwarz	Gelb	~~IIII~~ ~~IIII~~ III	IIII	4

Regelverstoß: R1 X   R2 ____   R3 ____   Latenz: 4 sec.

Abbruch: ☐ ja   ☒ nein   Zeit: 36 sec.

Figure 31. Example for an item-protocol of the Tower-of-Hanoi-task.

D5. Instruction and test protocol for the Mosaic-task

For task and procedure for the Mosaic-task, please see Chapter 3.2.2.2.2. In the following, an example is given, according to the test protocol of the HAWIVA-III. The instructions were quite similar for all the tests, only the point in time, when a model or a picture was shown, if a second trials was given or not, and the points for each accomplished pattern differed regarding to the test protocol.

D5.1. Instruction

Wir spielen nun ein Spiel mit Würfeln. Dafür habe ich rote, weiße und rot-weiße Würfel mitgebracht (zeigen!).

Nun lass uns mit den Würfeln spielen. Schau mir zu / schau dir das Bild an [Modell bauen / Bild mit zu bauendem Muster aufstellen! Das Kind erhält die genaue Anzahl der benötigten Würfel].

Jetzt mach du das mal. Versuche, das Muster so schnell wie möglich nachzubauen und sage mir, wenn du fertig bist. Hast du noch Fragen? Los geht's!"

D5.2. Test protocol for 3- to 4-year old children (HAWIVA-III)

Start: Alter 2;6–3;11: Item 1

Abbruch: Nach 3 Items mit 0 Punkten in Folge

Bewertung: Bewerten Sie mit 0 für falsch
1 oder 2 für richtig

Protokollieren Sie die Bearbeitungszeit in Sekunden für jedes Item.

Bei falscher Lösung zeichnen Sie im Raster die vom Kind angebotene Lösung ein.

Item	Muster	Raster	Benötigte Würfel	Versuch	Methode	Zeitlimit	Zeit in Sekunden	Punkte	
2;6–3;11 1.			4 rote	1	Modell	30 Sek.		0 1 2	Teil A: Rotationsfehler werden nicht bestraft
				2	Modell	30 Sek.			
2.			6 rote	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
3.			6 rote	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
4.			4 rote	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
5.			2 rote, 2 weiße	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
6.			4 rote, 2 weiße	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
7.			2 rote, 2 weiße	1	Modell	30 Sek.		0 2	
8.			6 rote	1	Modell	45 Sek.		0 2	
9.			4 rote, 4 weiße	1	Modell	45 Sek.		0 2	
10.			4 rote, 4 weiße	1	Modell	45 Sek.		0 2	
11.			4 rot-weiße	1	Modell	45 Sek.		0 2	Teil B: Bei Rotationsfehlern 0 Punkte
12.			4 rot-weiße	1	Modell	60 Sek.		0 2	
13.			4 rot-weiße	1	Modell	60 Sek.		0 2	
14.			4 rot-weiße	1	Modell	60 Sek.		0 2	
15.			4 rot-weiße	1	Modell	60 Sek.		0 2	
16.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
17.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
18.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
19.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
20.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
21.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
22.			4 rot-weiße	1	Bild	60 Sek.		0 2	
23.			4 rot-weiße	1	Bild	60 Sek.		0 2	
							Rohwertsumme (Maximum = 46)		

D5.3. Test protocol for 4- to 6--year old children (HAWIVA-III)

Start:
Alter 4;0–5;11: Item 7
Alter 6;0–6;11: Item 10

Umkehr:
Wird *eines der ersten beiden Items* der entsprechenden Altersgruppe mit 0 Punkten bewertet, wird in umgekehrter Reihenfolge zurückgegangen, bis 2 Items hintereinander richtig bearbeitet werden.

Abbruch:
Nach 3 Items mit 0 Punkten in Folge

Bewertung:
Bewerten Sie mit 0 für falsch
1 oder 2 für richtig

Protokollieren Sie die Bearbeitungszeit in Sekunden für jedes Item.

Bei falscher Lösung zeichnen Sie im Raster die vom Kind angebotene Lösung ein.

Item	Muster	Raster	Benötigte Würfel	Versuch	Methode	Zeitlimit	Zeit in Sekunden	Punkte	
1.			4 rote	1	Modell	30 Sek.		0 1 2	Teil A: Rotationsfehler werden nicht bestraft
				2	Modell	30 Sek.			
2.			6 rote	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
3.			6 rote	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
4.			4 rote	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
5.			2 rote, 2 weiße	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
6.			4 rote, 2 weiße	1	Modell	30 Sek.		0 1 2	
				2	Modell	30 Sek.			
4;0–5;11 ► 7.			2 rote, 2 weiße	1	Modell	30 Sek.		0 2	
8.			6 rote	1	Modell	45 Sek.		0 2	
9.			4 rote, 4 weiße	1	Modell	45 Sek.		0 2	
6;0–6;11 ► 10.			4 rote, 4 weiße	1	Modell	45 Sek.		0 2	
11.			4 rot-weiße	1	Modell	45 Sek.		0 2	Teil B: Bei Rotationsfehlern 0 Punkte
12.			4 rot-weiße	1	Modell	60 Sek.		0 2	
13.			4 rot-weiße	1	Modell	60 Sek.		0 2	
14.			4 rot-weiße	1	Modell	60 Sek.		0 2	
15.			4 rot-weiße	1	Modell	60 Sek.		0 2	
16.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
17.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
18.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
19.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
20.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
21.			4 rot-weiße	1	Modell & Bild	60 Sek.		0 2	
22.			4 rot-weiße	1	Bild	60 Sek.		0 2	
23.			4 rot-weiße	1	Bild	60 Sek.		0 2	

Rohwertsumme
(Maximum = 46)

3

D5.4. Test protocol for 7- to 10-year old children (HAWIK-IV)

Start
Alter 6–7: Aufgabe 1
Alter 8–16: Aufgabe 3

Umkehrregel
Alter 8–16: Kann eine der ersten beiden vorgegebenen Aufgaben nur mit **0** oder **1** Punkt bewertet werden, werden die vorhergehenden Aufgaben in umgekehrter Reihenfolge so lange vorgegeben, bis zwei aufeinanderfolgende Aufgaben richtig gelöst wurden.

Abbruch
Nach **3** aufeinanderfolgenden Bewertungen mit 0 Punkten.

Bewertung
Aufgabe 1–3: 0, 1 oder 2 Punkte
Aufgabe 4–8: 0 oder 4 Punkte
Aufgabe 9–14: 0 Punkte oder Punktanzahl entsprechend des Zeitbonus.

MT ohne Zeitbonus
Aufgabe 1–3: 0, 1 oder 2 Punkte
Aufgabe 4–14: 0 oder 4 Punkte

	Muster	Präsentations-methode	Zeitgrenze (Sekunden)	Lösungszeit	Richtiges Muster	Nachgebautes Muster	Erreichte Punktzahl
6–7	1. Kind / Testleiter/-in	Modell	30″		J N	Versuch 1 Versuch 2	2. Versuch 1. Versuch 0 1 2
	2.	Modell	45″		J N	Versuch 1 Versuch 2	2. Versuch 1. Versuch 0 1 2
8–16	3.	Modell und Bild	45″		J N	Versuch 1 Versuch 2	2. Versuch 1. Versuch 0 1 2
	4.	Bild	45″		J N		0 4
	5.	Bild	45″		J N		0 4
	6.	Bild	75″		J N		0 4
	7.	Bild	75″		J N		0 4
	8.	Bild	75″		J N		0 4
	9.	Bild	75″		J N		31–75 21–30 11–20 1–10 0 4 5 6 7
	10.	Bild	75″		J N		31–75 21–30 11–20 1–10 0 4 5 6 7
	11.	Bild	120″		J N		71–120 51–70 31–50 1–30 0 4 5 6 7
	12.	Bild	120″		J N		71–120 51–70 31–50 1–30 0 4 5 6 7
	13.	Bild	120″		J N		71–120 51–70 31–50 1–30 0 4 5 6 7
	14.	Bild	120″		J N		71–120 51–70 31–50 1–30 0 4 5 6 7

Rohwertsumme (Max. = 68)

Rohwertsumme ohne Zeitbonus (Max. = 50)

3

D5.5. Test protocol for adults (WIE)

Umkehrregel
bei 0- oder 1-Punkt-Lösungen für Aufgabe 5 oder 6 werden die Aufgaben 1 bis 4 in absteigender Folge vorgegeben, bis zwei Aufgaben in Folge mit 2-Punkt-Lösungen erzielt wurden

Abbruch
nach 3 falsch oder nicht gelösten Aufgaben in Folge

Bewertung
bei den Aufgaben 1 bis 6 jeweils 2 Punkte für jede richtige Lösung im ersten Versuch, 1 Punkt für eine richtige Lösung im zweiten Versuch, 0 Punkte für jede Aufgabe, die in beiden Versuchen falsc oder nicht gelöst wurde, bei allen weiteren Aufgaben 0 Punkte für jede falsch oder nicht gelöste Aufgabe, 4 bis 7 Punkte für richt Lösungen

Testperson

Richtige Lösung	Zeitgrenze	Falsche Lösung	Lösungszeit in Sekunden	Lösung richtig / falsch	erreichte Punktzahl umkreisen
1.	30"	1.Versuch 2.Versuch		R F	0 · 2. Versuch 1 · 1. Versuch 2
2.	30"	1.Versuch 2.Versuch		R F	0 · 2. Versuch 1 · 1. Versuch 2
3.	30"	1.Versuch 2.Versuch		R F	0 · 2. Versuch 1 · 1. Versuch 2
4.	30"	1.Versuch 2.Versuch		R F	0 · 2. Versuch 1 · 1. Versuch 2
START 5.	60"	1.Versuch 2.Versuch		R F	0 · 2. Versuch 1 · 1. Versuch 2
6.	60"	1.Versuch 2.Versuch		R F	0 · 2. Versuch 1 · 1. Versuch 2
7.	60"			R F	0 · 16"–60" 4 · 11"–15" 5 · 6"–10" 6 · 1"– 7
8.	60"			R F	0 · 16"–60" 4 · 11"–15" 5 · 6"–10" 6 · 1"– 7
9.	60"			R F	0 · 21"–60" 4 · 16"–20" 5 · 11"–15" 6 · 1"–1 7
10.	120"			R F	0 · 36"–120" 4 · 26"–35" 5 · 21"–25" 6 · 1"– 7
11.	120"			R F	0 · 66"–120" 4 · 46"–65" 5 · 31"–45" 6 · 1"– 7
12.	120"			R F	0 · 76"–120" 4 · 56"–75" 5 · 41"–55" 6 · 1"–4 7
13.	120"			R F	0 · 76"–120" 4 · 56"–75" 5 · 41"–55" 6 · 1"–4 7
14.	120"			R F	0 · 66"–120" 4 · 46"–65" 5 · 36"–45" 6 · 1"– 7

Testleiter(in)

Rohwertsumme
(Maximum = 68)

Legend. Muster = pattern
Raster = grid
Benötigte Würfel = Amount of blocks needed
Versuche = trials

(Präsentations-)Methode (Modell vs. Bild) = method of presentation (model vs. picture)
Zeitlimit / Zeitgrenze = time limit
(Lösungs-)Zeit in Sekunden = solution time in seconds
Punkte / erreichte Punktzahl = reached points
Rot = red
Weiß = white
Rohwertsumme = total value of reached points
Richtiges Muster = right pattern
Nachgebautes Muster = recreated pattern
Richtige / falsche Lösung = right / wrong solution

Note. Above, the four different test protocols were depicted: one for 3- to 4-year-olds, one for 4- to 6-year-olds (HAWIVA-III; differ only in the number of start item), one for 7-10-year-olds (HAWIK-IV) and one for adults (WIE). In the first row, the different goal-patterns are depicted. For younger children, the end-posture was painted in the boxes beside them. Then, the number of cubes is identified ("Benötigte Würfel"), and the number of trials, which can be possibly obtained ("Versuch"). For younge children, it is declared afterwards, if a model ("Modell") or a picture ("Bild") serves as the target pattern. The time-limit ("Zeitlimit") indicates the given time, before the items is not successfully accomplished. Then, the time needed is recoreded, and points are given depending ont either the time needed, or the successful accomplishment of building the correct pattern.

D6. Instruction and test protocol for the D2-task

For task and procedure for the D2-task, please see Chapter 3.2.2.2.3.

D6.1. Instruction and test protocol for 3- to 5-year old children (IDS 3-5)

D6.1.1. Instruction

"*Vor dir siehst du einen Stift auf dem Tisch liegen. Ich gebe dir nun immer nacheinander einen Stapel Karten. Auf diesen Karten siehst du verschiedene Enten. Wir wollen jetzt alle Enten finden, die einen gelben Schnabel haben. Diese Enten legen wir zu diesem Stift. Die Enten mit weißem Schnabel legen wir dahin (links vom Stift). Bei einigen Enten scheint noch die Sonne, aber das ist nicht wichtig. Du musst nur auf den Schnabel schauen.*

Versuch du jetzt, alle Enten mit einem gelben Schnabel zu finden, und lege sie hier zum Stift. [Eingewöhnungsstapel; hier wird auch noch korrigiert].

Du sollst nun aus den Karten, die ich dir gebe, alle Enten mit einem gelben Schnabel suchen und hier zum Stift legen, und zwar sollst du das so schnell wie möglich machen! Ob die Sonne scheint oder nicht, ist nicht wichtig.“

Figure 32. Example for correct ducks in the IDS 3-5. All ducks with a yellow snail need to be sorted out, no matter if the sun is shining or not.

D6.1.2. Test protocol

Erreichte Punkte nach 30 Sekunden		Wert
GSK	Gesamtanzahl sortierter Karten	
GFA	Gesamtzahl fälschlicherweise ausgelassener Karten	
GFS	Gesamtzahl fälschlicherweise aussortierter Karten	
	Total nach 30 Sekunden (GSK – GFA – GFS):	

Erreichte Punkte nach 60 Sekunden		Wert
GSK	Gesamtanzahl sortierter Karten	
GFA	Gesamtzahl fälschlicherweise ausgelassener Karten	
GFS	Gesamtzahl fälschlicherweise aussortierter Karten	
	Total nach 60 Sekunden (GSK – GFA – GFS):	

Erreichte Punkte nach 90 Sekunden		Wert
GSK	Gesamtanzahl sortierter Karten	
GFA	Gesamtzahl fälschlicherweise ausgelassener Karten	
GFS	Gesamtzahl fälschlicherweise aussortierter Karten	
	Total nach 90 Sekunden (GSK – GFA – GFS):	

Legend. Erreichte Punktzahl nach 30 Sekunden = reached points after 30 seconds
GSK (Gesamtzahl sortierter Karten) = total amount of sorted cards
GFA (Gesamtzahl falschlicherweise ausgelassener Karten) = total amount of mistakenly missed cards
GFS(Gesamtzahl fälschlicerweise aussortierter Karten) = total amount of mistakenly cards sorted out
Wert = value/ amount

D6.2. Instruction and test protocol for 6- to 10-year old children (IDS 5-10)

D6.2.1. Instruction

„Hier siehst du drei Enten. Jede dieser Enten hat zwei orange Körperteile. Die Erste Ente hat 2 orange Schnabelhälften, die zweite Ente hat zwei orange Füße und die dritte Ente hat eine orange Schnabelhälfte und einen orangen Fuß – zusammengezählt sind das auch zwei orangene Körperteile. Jede Ente, die zwei orange Körperteile hat, sollst du durchstreichen. Mach das jetzt bei diesen drei Enten.

Auch in dieser Reihe sollst du alle Enten mit zwei orangen Körperteilen durchstreichen. Pass gut auf, denn alle anderen Enten dürfen nicht durchgestrichen werden. Es gibt auch noch eine zweite Regel! Neben den Enten die auf diese Seite (rechts) sehen, gibt es auch Enten die auf die andere Seite sehen (links). Enten die auf die andere Seite (links) sehen, dürfen nie durchgestrichen werden, egal, wie viele orange Körperteile sie hat.

Streich jetzt jede Ente durch, die nach rechts schaut und zwei orange Körperteile hat. Wir schauen nun gemeinsam, ob du auch alle richtigen Enten durchgestrichen hast.

Auf der Rückseite befinden sich viele Reihen mit Enten. In jeder Reihe sollst du wieder Enten mit zwei orangen Körperteilen, die nach rechts schauen durchstreichen, wie du das eben getan hast. Nach 15 Sekunden sage ich jeweils „Stop! Nächste Reihe!". Dann geh sofort zur nächsten Riehe und streiche dort wieder alle Enten mit 2 orangen Körperteilen durch. Versuch so schnell wie möglich vorwärtszukommen, aber auch keine Fehler zu machen. Falls du eine falsche Ente durchgestrichen hast, mach einfach ein Kreuz und fahre schnell mit der nächsten Ente fort.

Hast du noch Fragen? Ich drehe das Blatt nun um. Nimm den Stift in die Hand und beginne hier oben mit der ersten Zeile wenn ich los sage. Achtung, Los!"

D6.2.2. Test protocol

.ids Intelligence and Development Scales **Testbogen Aufmerksamkeit Selektiv**

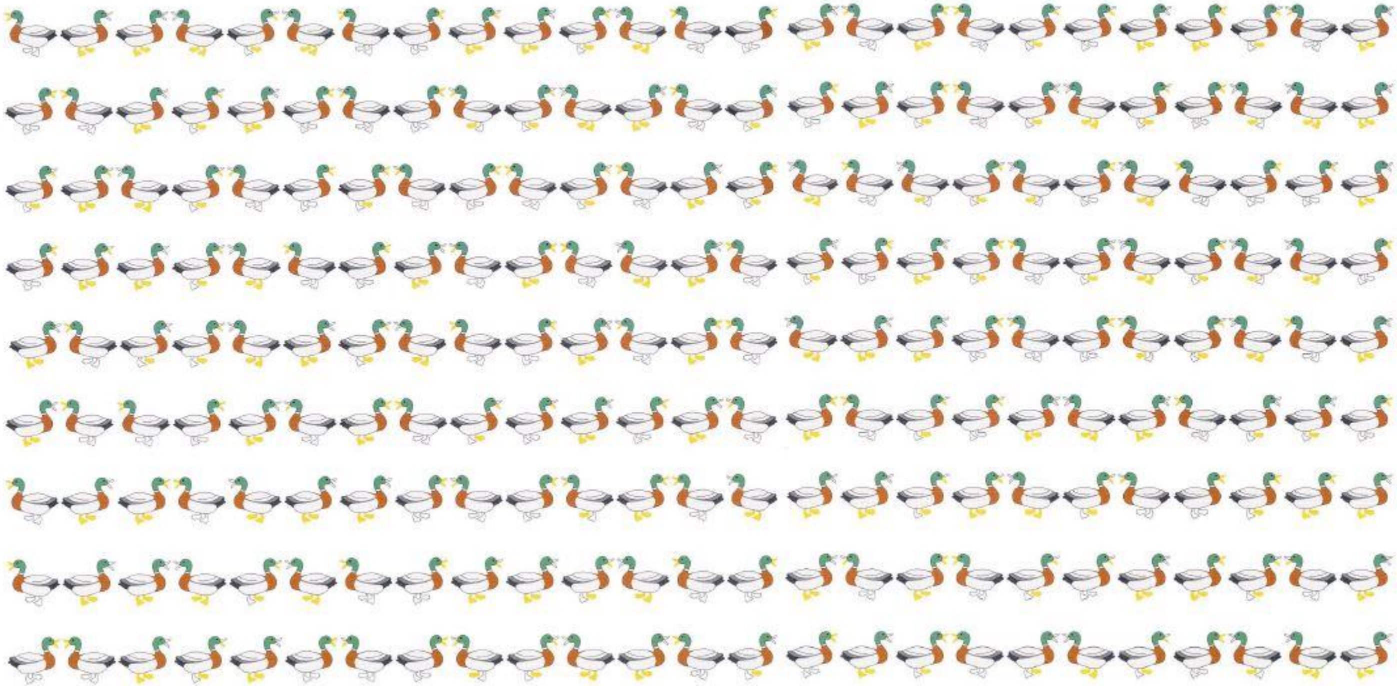
Datum:	Nr.:
Name:	Vorname:
Geschlecht:	Alter:

Beispiele:

Übungszeile:

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

HUBER
Bestellnummer 03 147 04



BE	F1	F2
GBE:	GF:	

GBE: .... – GF: .... = ______

Legend. BE (bearbeitete Enten) = amount of processed items / ducks per line
F1 (Fehler 1) = total amount of mistakenly missed items / ducks
F2 (Fehler 2) = total amount of mistakenly items / ducks sketched out
GBE (Gesamtzahl bearbeiteter Enten) = total amount of processed items / ducks
GF (Gesamtzahl Fehler) = total amount of F1 and F2

D6.3. Instruction and test protocol for adults (D2-R)

D6.3.1. Instruction

„Wir wollen mit dem folgenden Versuch feststellen, wie gut du dich auf eine bestimmte Aufgabe konzentrieren kannst. Fülle bitte auf dem Blatt „Kurzanleitung" die Fragen zu deiner Person aus.

Pass jetzt bitte gut auf! Schaue in die Kurzanleitung. Unter den Fragen zur Person, die du gerade beantwortet hast, wird deine Aufgabe genannt: Du sollst gleich jedes d (wie Dora), das zwei Striche hat, durchstreichen!

Im Kästchen siehst du die gesuchten Zeichen. Jeder Buchstabe d hat zwei Striche. Das erste d hat zwei Striche oben, das zweite zwei Striche unten, und das dritte d hat einen Strich oben und einen Strich unten.

Rechts daneben siehst du Zeichen, die du nicht durchstreichen sollst: Das kann ein d sein, das weniger oder mehr als zwei Striche hat. Ebenfalls nicht durchstreichen sollst du den Buchstabe p (wie Paula), egal mit wie vielen Strichen es versehen ist.

Führe Übung 1 durch. Streiche jedes d mit zwei Strichen durch. Die gesuchten Zeichen sind hier markiert.

Führe nun Übung 2 durch. Streiche jedes d mit zwei Strichen durch – nun ohne Hilfe. Falls du einmal ein falsches Zeichen durchstreichst, durchkreuze einfach den Strich.

Lege nun den Stift hin und höre gut zu. Drehe den Testbogen erst um, wenn ich dich dazu auffordere. Auf dem Testbogen befinden sich 14 Zeilen mit den gleichen Zeichen wie in den Übungen. Fange gleich links oben mit der ersten Zeile an. Streiche – wie in den Übungen- jedes d mit zwei Strichen durch. Nach 20 Sekunden sage ich „Halt! Nächste Zeile!“. Dann hörst du sofort aus und fängst mit der nächsten Zeile an. Nach weiteren 20 Sekunden erfolgt wieder der Zuruf „Halt! Nächste Zeile!“. Beginne dann wieder sofort mit der nächsten Zeile.

Arbeite so schnell wie möglich - aber möglichst ohne Fehler.

Hast du noch eine Frage?

In der Kurzanleitung unten sind noch einmal die wichtigsten Punkte genannt, die du bitte im Test beachtest. Schaue in die Kurzanleitung: Von links nach rechts arbeiten“ Bei „Halt“ Nächste Zeile!“ sofort mit der nächsten Zeile anfangen. Schnell und dabei möglichst fehlerfrei arbeiten.

Nimm den Stift zur Hand. Drehe das Testblatt um. Fange auf mein Kommando an. Achtung – Los!

D6.3.2. Test protocol

Kurzanleitung d2-R

Name/Code-Nr.: ____________________ Datum: ____________

Alter: ______ Jahre

Geschlecht: ☐ männlich ☐ weiblich

Schulart/Klasse: ____________

oder Studienfach: ____________

oder Beruf: ____________

Sehhilfe benötigt?
☐ ja, verwendet
☐ ja, aber nicht verwendet
☐ nein

Händigkeit:
☐ rechtshändig
☐ linkshändig

Jedes *d*, das *zwei* Striche hat, durchstreichen!

d	d	d
2 Striche *oben*	2 Striche *unten*	1 Strich *oben* 1 Strich *unten*

***Nicht* durchstreichen:**

d mit weniger oder mehr als 2 Strichen:	d	d	d	d	d
p, egal mit wie vielen Strichen:	p	p	p	p	p

Übung 1: Jedes d mit 2 Strichen (weiße Felder) durchstreichen!

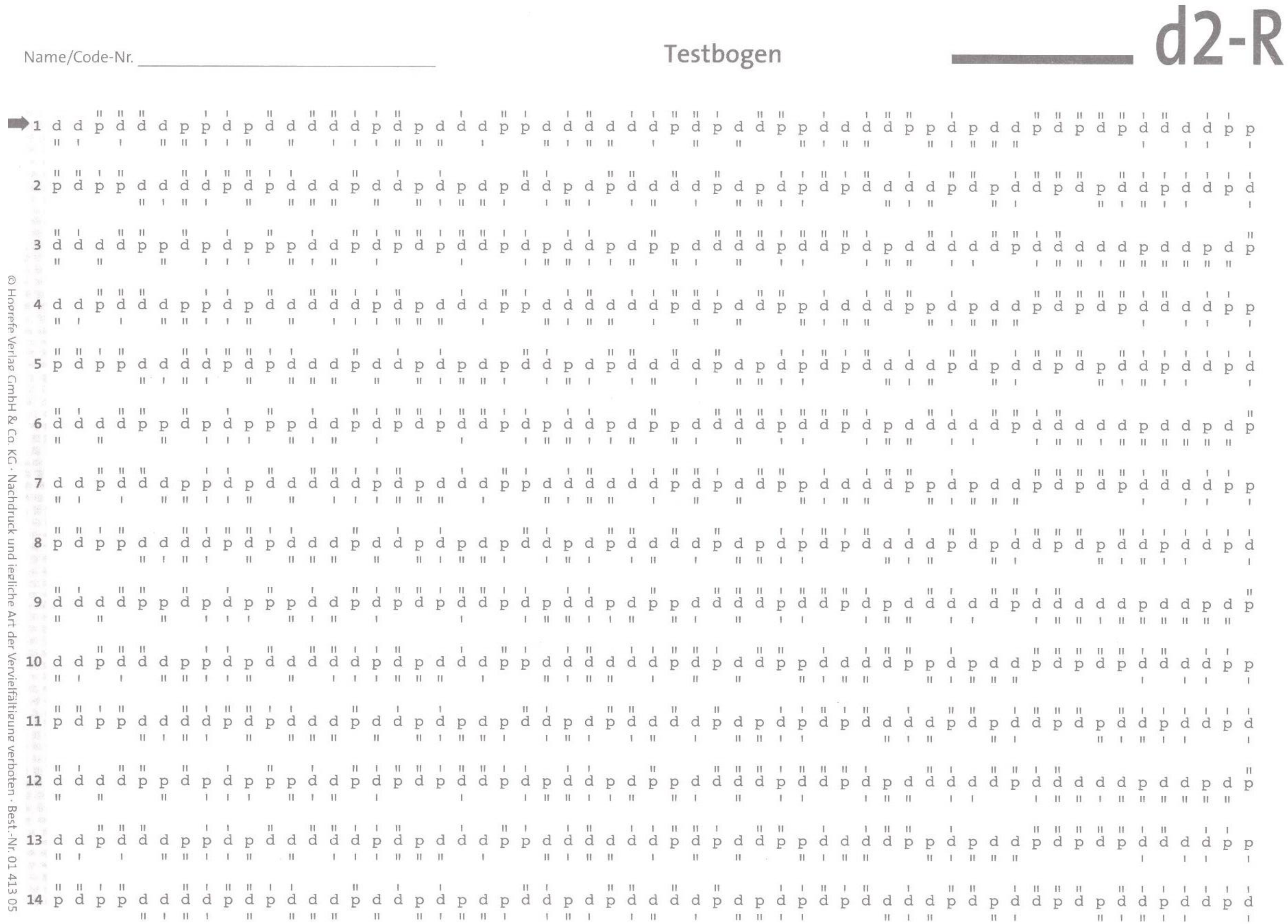
d p d d d d d d p p d d d d d p p d d d d d p

Übung 2: Nun ohne Hilfe jedes d mit 2 Strichen durchstreichen!

d p d p d d p d d d p d d d p p d d d p d p d

Im Test bitte beachten:

– Von links nach rechts arbeiten.
– Bei „Halt! Nächste Zeile!" *sofort* mit der nächsten Zeile anfangen.
– *Schnell und dabei möglichst fehlerfrei arbeiten!*


Name/Code-Nr.
Testbogen
d2-R
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Note. Above, the tree different test protocols for the D2-task were depicted: one for 3- to 5-year-olds (preschoolers, IDS 3-5), one for 5- to 10-year-olds (school children, IDS 5-10), and one for adults (D2-R). All participants had to sort out cards, or to cross out items with a specific feature: duck with yellow snails (in the task for the youngest children), ducks with two yellow bodyparts (in the task for the school children), or “d’s” with two lines. Evaluation was almost the same: The number of correctly detected items was counted, as well as mistakes (those items, which were mistakenly not sorted out, and those items, which were sorted out, but did not coincide with the required pattern). In the end, a total score was computed.

Statutory Declaration

I declare that I have developed and written the enclosed thesis entitled “Anticipatory planning in childhood – The development of anticipatory planning and ist relationship to executive functions” entirely by myself and have not used sources or means without declaration in the text. Any thoughts or quotations, which were inferred from these sources, are clearly cited as such. This thesis was not submitted in the same or in a substantially similar version, not even partially, to any other authority to achieve an academic grading and was not published elsewhere. In accordance with §9 section 4 of the examination regulations of the Faculty of Natural Science at the University of Paderborn from the 12th of November 2012, Chapter 2 is based on a publication in the *Journal of Motor Learning and Development* in 2013. Other contents of the thesis have not been published to this day. Both studies (Chapter 2 and 3) originated in cooperation with other researchers. My contributions comprise the conception of the study designs, the implementation of testing, preparation and evaluation of the data, the documentation and the discussion (and in Chapter 2: the publication) of results.

Paderborn, 05.11.2014 Kathrin Wunsch

Eidesstattliche Versicherung

Hiermit versichere ich an Eides statt, dass die vorliegende Arbeit mit dem Titel „Anticipatory planning in childhood – The development of anticipatory planning and ist relationship to executive functions“ von mir selbstständig und ausschließlich unter Verwendung der angegebenen Quellen angefertigt wurde. Alle Stellen, die wörtlich oder sinngemäß aus Veröffentlichungen entnommen sind, habe ich als solche kenntlich gemacht. Die Arbeit wurde bisher in gleicher oder ähnlicher Form, auch nicht in Teilen, keiner anderen Prüfungsbehörde vorgelegt. Im Einklang mit §9 Absatz 4 der Promotionsordnung der Fakultät für Naturwissenschaften der Universität Paderborn vom 12. November 2012 basiert Kapitel 2 auf einer Veröffentlichung im Journal of Motor Learning and Development von 2013. Weitere Inhalte der Dissertation wurden bislang nicht veröffentlicht. Beide Teilstudien (Kapitel 2 und 3) entstanden in Kooperation mit weiteren WissenschaftlerInnen. Mein eigener Beitrag in beiden Teilen umfasst sowohl die Konzeption der Studiendesigns, die Durchführung der Studie, die Aufbereitung sowie die Auswertung der Daten sowie die Dokumentation (und in Kapitel 2 die Veröffentlichung) der Ergebnisse.

Paderborn, 05.11.2014 Kathrin Wunsch

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