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Children's planning of efficient tool use in a social context

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Abstract

Efficient joint action requires that we anticipate situational demands both regarding our own and another person's perspective, and adapt our actions accordingly. Accordingly, when handing over a tool somebody else, it is advantageous to anticipate our future hand orientation (motor imagery), as well as the future orientation of the tool (mental rotation) relative to the other person, in order to make the transfer as smooth and efficient as possible. Furthermore, familiarity with specific tools might facilitate planning. We tested thirty-two 5.5- to 7-year-old children on a tool transfer task, asking if they consider another person's comfort when handing over different tools, and whether tool familiarity, motor imagery, and mental rotation are related to their grip choices. We compared the children's performance to that of an adult control group. Besides a rather low performance on the transfer task, we found differences in children's consideration of another person's comfort related to the specific tools they interacted with. Specifically, the unfamiliar tool (a bar) was transferred more efficiently than the familiar tools (hammer/brush). In addition, the results suggest a relation between children's consideration of another person's comfort and their mental rotation score, but no relation with their motor imagery score.

KEYWORDS
action planning, end-state comfort effect, joint action, mental rotation, tool use

1 | INTRODUCTION

Efficient tool use is an important capacity for meeting the challenges of our daily lives. It extends our action range by the possibility to use external objects as means for achieving specific goals. One of the key requirements of efficient tool use is the ability to plan efficient tool-related movements and anticipate their consequences. By taking environmental constraints into account, we can optimize our movements and achieve our tool-related goals efficiently. Correspondingly, when we reach for a hammer in order to pound in a nail, we usually adapt our hand orientation to the orientation of the hammer prospectively, so that we can immediately grasp it by the handle without the need to readjust our grip before using the hammer. In many studies, adults have been found to maximize efficiency in their grasp choices (see Rosenbaum et al., 2012 for a review). One manifestation of this phenomenon is the "end-state comfort effect" (ESC; Rosenbaum et al., 1990). This effect describes the tendency to grasp objects uncomfortably at the beginning of a grasping action in order to end in a comfortable position, which enables further manipulatory steps. As an example, when grasping an inverted glass in order to pour water into it, adults tend to grasp it with a twisted wrist and the thumb pointing downward at the beginning of the action (e.g., Hughes, & Franz, 2008). Recently, the planning of efficient actions has been examined from a social perspective. Gonzalez, Studenka, Glazebrook, and Lyons (2011) conducted a study investigating the ESC in adults in the context of a social interaction. They report that, apart from satisfying own ESC, adults also pay attention to supporting their partners' starting state comfort when transferring objects to them. This is in line with research investigating "joint action," indicating that adults tend to incorporate the goals of co-workers into their own action plans and treat them similar to their own goals (Sebanz, Bekkering, & Knoblich, 2006). Regarding development, researchers have recently started investigating children's efficient motor planning ability in the context of object-related interactions with a social partner. Extant studies suggest an onset of the consideration of other people's comfort between 5 and 7 years of age (Meyer, van der Wel, & Hunnius, 2016; Paulus, 2016; Scharoun & Bryden, 2014). However, the question of which factors might influence the development of the consideration of other people's comfort is still insufficiently examined. Regarding motor planning in a solitary context with children acting alone, the type of object manipulated (Jovanovic & Schwarzer, 2017a) and specifically the familiarity of the objects (Knudsen, Henning, Wunsch, Weigelt, & Aschersleben, 2012) have emerged as factors influencing the extent to which ESC is expressed. In addition, motor imagery has been found to impact performance in ESC planning tasks in children (Toussaint, Tahej, Thibaut, Possamai, & Badets, 2013). Accordingly, the goal of the present study was to investigate how far these factors, tool familiarity, motor imagery, and mental rotation, might also play an important role for children's consideration of other people's comfort. To this end, we designed a study in which children were familiarized with simple tasks that required the use of either an unfamiliar (magnetic bar) or a familiar (hammer and brush) tool, and then had to give the respective tool to an experimenter so that he could perform the same task. We examined to what extent children's actions would reveal a consideration of their social partner's comfort. Concurrently, we investigated children's performance on a test of motor imagery and a test of mental rotation. In a further study, we examined adults as a comparison group on the same task.

1.1 | The Development of Efficient Motor Planning in Children

Action plans can specify goals on different level of complexity. On the lowest level, also termed first-order planning (Rosenbaum et al., 2012), these can be as simple as reaching out to grasp an object. The successful realization of such basic actions requires an adaptation to central object features such as shape and size and develops across the first year of life already (e.g., von Hofsten, 2004). Second-order planning, in contrast, is characterized by its relatedness to temporally more distant goals in an action sequence (Rosenbaum et al., 2012) and efficient adaptations of movements to this distant goal. As an example, a cup can be grasped either by the top (opening) or by the handle. In general, both actions are equally possible; however, they might not be equally efficient regarding further action steps. If a person decided to put the cup into a cupboard, he or she might find it more efficient to grasp it by the top. If, however, the person wanted to drink from the cup, this grasp choice would be quite inefficient, because by grasping the cup by the top, the hand would interfere with drinking. One paradigm that captures efficiency in action planning is the ESC paradigm developed by Rosenbaum et al. (1990). In the classic task, participants are asked to grasp a horizontal bar and place it at a vertical position left or right from the midline with one of its ends pointing up. The findings from numerous studies (see Rosenbaum, et al., 2012 for a review) have revealed that adults tend to finish their grasping movements in a comfortable end posture and to adopt more awkward postures at the beginning of their movements. This pattern has been explained as originating in the aim to establish a stable starting position for subsequent actions.

Developmental studies applying similar tasks indicate that children start considering ESC by 3 years of age (e.g., Jovanovic, & Schwarzer, 2011; Weigelt, & Schack, 2010) and arrive at an adult level by about 10–14 years (Wilmut & Byrne, 2014). However, children's performance depends on several factors, such as the exact motor requirements of the task (Jovanovic & Schwarzer, 2011; Jovanovic & Schwarzer, 2017a) and object characteristics, as, for example, object familiarity (Jovanovic & Schwarzer, 2017b; Knudsen et al., 2012). Accordingly, Knudsen et al. (2012) compared two tasks in which children were required to grasp and rotate either an inverted cup or a vertically oriented bar around the horizontal axis. They tested how far children would begin with grasping the objects with an uncomfortable thumb-down grip in order to end up with a comfortable thumb-up grip. Although the two tasks had the same spatial arrangement and motor requirements, children performed better in the cup rotation task than in the bar rotation task. The authors suggested that object familiarity might have exerted a positive effect on the planning of efficient actions. Similarly, Jovanovic and Schwarzer (2017b) presented 3- and 4- to 5-year-old children with a task that required them to rotate different tools (cup, bottle, shovel, pencil) and measured their consideration of ESC. Similar to the study by Knudsen et al. (2012), although the movements required for rotating the objects were nearly identical, children's level of efficiency differed across the objects. The authors explained this pattern by the children's higher level of familiarity with a subset of the objects (cups and bottles).

Although familiarity with tools often has positive effects on action planning, like enhancing object use, it can also have detrimental effects, as captured by the concept of functional fixedness. The concept of functional fixedness was introduced long ago by Duncker (1945) to describe the finding that prior use of tools for a specific purpose restricts the use of the same tools for another purpose, and therefore makes tool use less flexible. Starting from the idea that functional fixedness should develop along with the concept of artifacts as being designed for specific functions, German, and Defeyter (2000) conducted a problem-solving study similar to the classical study by Duncker (1945), in which 5- to 7-year-old children were presented with a toy bear, who unsuccessfully tried to reach a high shelf. When asked to help the bear, they were supposed to use a box also present in the scene as a support for the bear. Six- and seven-year-old children's use of the box was influenced by the box's prior use: if it had been used as a container before, they were much less likely to use it as a support than if it not had any designated prior function. However, 5-year-old children's behavior was not affected by prior use. Accordingly, the authors claimed that younger children were "immune" to functional fixedness. More recent studies, however, indicate that behavioral pattern indicating functional fixedness might be found in younger children already. As an example, Elsner, and Schellhas (2012) found that 24-month-old children had difficulties adapting a once learned way of using a novel tool to a changed situation, and thus, demonstrated perseveration. In another study by Barrett, Davis, and Needham (2007), 12- to 18-month-old children had the task to use a spoon to turn on the lights in a box by pushing a switch behind a small opening. Crucially, only the spoon's grip fitted in the opening, so that children had to hold the spoon by the bowl in order to accomplish the task. It was found that children tended to hold the spoon by its grip even if this made solving the task impossible. When, however, the same task was presented using a novel tool that looked very similar to the spoon, they had no problems using the tool correctly to accomplish the task. In a wider sense, these results could also be interpreted as instances of functional fixedness, and hint at the possibility that perseveration may arise from "manipulation knowledge" (Munoz-Rubke, Olson, Will, & James, 2018).

Another factor that has been proposed to influence ESC planning in children is motor imagery. Motor imagery has been conceptualized as an integral part of action representation, in the sense of an internal simulation of an action that is being prepared (e.g., Jeannerod, 2001). As such, it has been proposed to share neural mechanisms with real action performance. Numerous studies have supported a close relation between imagined and actually performed actions (e.g., Decety, & Grezes, 2006; Lohrey et al., 2013). Reasoning that motor imagery might play an important role for the efficient planning of actions, Toussaint et al. (2013) correlated 6- to 8-year-old children's performance on an ESC task with their motor imagery scores measured in the hand laterality task. The hand laterality task requires participants to judge whether a depicted hand is a left or right hand when presented in different orientations. Interestingly, they found a correlation between motor imagery and ESC scores in the group of 6-year-old children, supporting their hypothesis of a relationship between efficient motor planning and motor imagery. Also in support of this relation are studies indicating that children with developmental coordination disorder (DCD), who have been found to score low on tasks testing ESC planning, show deficits in motor imagery (e.g., Adams, Lust, Wilson, & Steenbergen, 2017), as well as improvements in motor planning after a motor imagery training (Adams, Smits-Engelsman, Lust, Wilson, & Steenbergen, 2017). Taken together, this might indicate that being able to mentally simulate aspects of planned actions enhances efficient planning (Fuelscher, Williams, Wilmut, Enticott, & Hyde, 2016). In a similar vein, Stöckel, Hughes, and Schack (2012) found that ESC planning was related to children's ability to mentally represent comfortable grasp postures and differentiate them from uncomfortable ones.

Interestingly, in the study by Toussaint et al. (2013; see also Cayenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009), the extent to which children were able to mentally rotate an object not related to the body did not correlate with children's ESC performance. Taken together, existing data suggest that object familiarity and motor imagery can support efficient motor planning in children.

1.2 | Acting with Others: The Development of Coordination

Acting with other people in order to achieve a joint goal is an easy task for adults. A number of studies indicate that when adults interact with others, they tend to incorporate the goals of their cooperation partners into their own action plans (see Sebanz, Bekkering, & Knoblich, 2006 for a review). Considering children, it has been shown that efficient cooperation is rather slow to develop, with children of up to 2 years being dependent on their parents' scaffolding when acting together (Brownell, 2011). Only at 2–3 years of age have children been found to display beginning cooperation by being able to coordinate with peers (e.g., Brownell & Carriger, 1990). The engagement in and coordination for achieving joint goals is an achievement that develops even later, starting by 3 years (Ashley, & Tomasello, 1998; Brownell, 2011; Meyer, Bekkering, Paulus, & Hunnius, 2010). As an example, only by 3.5 years of age, children have been found to begin to successfully handle role reversals in a joint coordination task (Ashley & Tomasello, 1998). The task of giving tools to another person can be conceptualized as one special case requiring coordination. On this task, adults have been found to enable "beginning-state comfort" (BSC) for other persons, that is, make them start from a comfortable condition (Gonzalez, et al., 2011). In the study by Gonzalez, et al. (2011), adults were asked to use one of three different tools—a hammer, a calculator, or a stick across alternating blocks of trials—in a self-context and then, in a social context, give the tools to the experimenter so that he/she could finish the action. The tools were oriented either toward or away from the participant. The authors report that in all cases the participants grasped the tools in such a way that they ended up in a comfortable grasping condition themselves, as well as presented the objects in a comfortable grasping position to the experimenter.

Recently, developmental researchers have started to examine planning for BSC in children. Meyer, et al. (2016) involved children from 2.5 to 5 years of age in a social cup stacking game, in which they were asked to pass a cup to an experimenter. The experimenter had one hand occupied, and the children were expected to offer the cup to the unoccupied side if they considered comfort. The results indicated that only at age 5 did children start to accommodate their partner's actions in their planning and even at this age children were just above chance (in 56% of all trials). Although here the relevant variable was choice of the side of cup presentation, Scharoun and Bryden (2014) conducted a cup study in which they looked more closely at the way children presented the cup to the experimenter. Children from 3 to 12 years of age had the task of passing an initially inverted cup to an experimenter comfortably, who would then go on to pour the water into the cup. The data indicated that by 7 years of age children tended to consider another person's BSC at a high, nearly adult-like level.

In another developmental study on BSC, Paulus (2016) asked different groups of children, aged from 3 to 7 years, to give an unfamiliar bar with two different ends to an experimenter in order to switch on the light in a box. Crucially, only one of the ends was functional for operating the lights, and the author tested whether children would consider orienting the bar "correctly" toward the experimenter so that she/he could fit the end of the bar into the opening of the box. Interestingly, 3- and 5-year-old children performed at chance, although they were able to perform the task correctly alone. Only at 7 years did the author find above-chance performance in the children. These findings contrast with the study by Scharoun, and Bryden (2014), who claim to have found adult-like performance at this age.

Although these studies are very revealing about the children's planning in a social context, the data are controversial regarding the age at which children become proficient at enabling BSC for other people. Scharoun and Bryden (2014) found 7-year-old children to be very proficient at considering BSC, even more proficient than at considering their own comfort. In contrast, Paulus (2016) found that even 7-year-old children were below chance concerning their consideration of BSC on the first trials.

One explanation that might account for differences in findings across studies is that possibly, children found it easier to transfer familiar objects than unfamiliar objects efficiently. As an example, Scharoun and Bryden (2014) found relatively high performance with a familiar object, a cup, whereas Paulus (2016), who found a relatively low performance, employed a relatively unfamiliar object, namely, a bar. Accordingly, our first main question was how far children's efficiency might be influenced by tool familiarity when transferring objects to other persons. To this end, we engaged them in two tool-use tasks with familiar tools (brush and hammer) and in one task with a novel tool (magnet bar).

The second main question of our study was how far motor imagery and mental rotation play a role for the consideration of ESC concerning other people's actions. As pointed out above, motor imagery has been found to support action planning in general, and specifically, to correlate with children' s performance on ESC tasks in a solitary condition. If we assume that motor imagery can support efficient action planning in general, it would be plausible to assume that it is also beneficial for planning efficient interactions with others, this being a subcategory of action planning in general. Importantly, motor imagery has been found to be involved in joint action (Vesper, Knoblich, & Sebanz, 2014) and to be affected by a joint action condition in the same way as overt action execution is. This relation is plausible, as the successful monitoring of one's own hand orientation might support planning in general, regardless of whether it is directed at reaching solitary or social goals. Thus, our second goal was to investigate whether motor imagery is also related to efficient joint action performance in the present tool-use task, as being able to imagine how one should orient one's own hand while handing over a tool might have a beneficial effect on planning another person's BSC.

Furthermore, as introduced by Toussaint et al. (2013), we differentiated between motor imagery and mental rotation. In contrast to motor imagery, which has been conceptualized as body related, mental rotation rather pertains to the ability to imagine changes in an external object's orientation. In their study on the relation between motor imagery and ESC planning in children, Toussaint et al. (2013) found no evidence of a correlation between ESC planning and mental rotation of an object (see also Cayenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009). However, in the present study we anticipated that for enabling BSC, mental rotation might nevertheless play an important role, because anticipating the most advantageous tool orientation might help participants to reorient the handles efficiently. In fact, although motor areas in the brain have primarily been found to be activated by mental hand rotation tasks as opposed to mental object rotation tasks (e.g., Kosslyn, Digirolamo, Thompson, & Alpert, 1998), recent studies have found bidirectional relations between action and mental object rotation (Antrilli & Wang, 2016; Janczyk, Pfister, Crognale, and Kunde, 2012; Wexler, Kosslyn, & Berthoz, 1998). Importantly, Janczyk et al. (2012) showed that preceding mental rotations have an impact on subsequent action planning. Specifically, mental rotations have been found to facilitate manual rotations with compatible visual effects on a subsequent rotation task. Accordingly, we tested whether we can uncover a relationship between mental rotation and action performance on the present task.

In Study 1, we tested 5- to 7-year-old children assuming that this is a suitable age range, because BSC might just have started to develop or was already in place. We thus expected this age range to deliver data with sufficient variance. In Study 2, we tested a group of adults as comparison group, because research indicates that even adults' grasp choices are to some extent influenced by object identity and associated grasping habits (Herbort & Butz, 2011). By including the adult sample, it should be easier to differentiate "real" developmental effects from more general object familiarity effects found across age groups. However, we did not take measures regarding motor imagery or mental rotation from adults.

In order to test the planning of efficient transfer, participants in both studies were involved in a task, in which they were first required to use a specific tool in a predefined task context (solitary context), in order to familiarize the participants with the tasks, and then were asked to give the tools to the experimenter in another block of trials (social context). Regarding the child sample in Study 1, two tasks testing motor imagery and mental rotation, respectively, were also administered.

2 | STUDY 1

2.1 | Method

2.1.1 | Participants

Thirty-two 5- to 7-year-old children, 18 female and 14 male, participated in our study. Mean age was 79.34 months (*SD* = 7.10; range: 65–90 months). Children were invited to the laboratory by contacting their parents by phone or mail based on information from the local birth registers. They were accompanied by one of their parents and tested individually in a laboratory at the university. Written informed consent from the children's parents was obtained before participation. After participation, each child received a small toy as a gift.

2.1.2 | Stimuli and tasks

Three different tools were used in the three different task conditions: a brush, a hammer, and a bar. The tasks resembled those used by McCarty, Clifton, and Collard (2001). The brush and the hammer were children's replicas of the conventional tools. The brush was a 16-cm long wooden baby brush with soft bristles and a 7.5-cm long grip. The hammer was entirely made of lightweight wood and measured 14 cm,

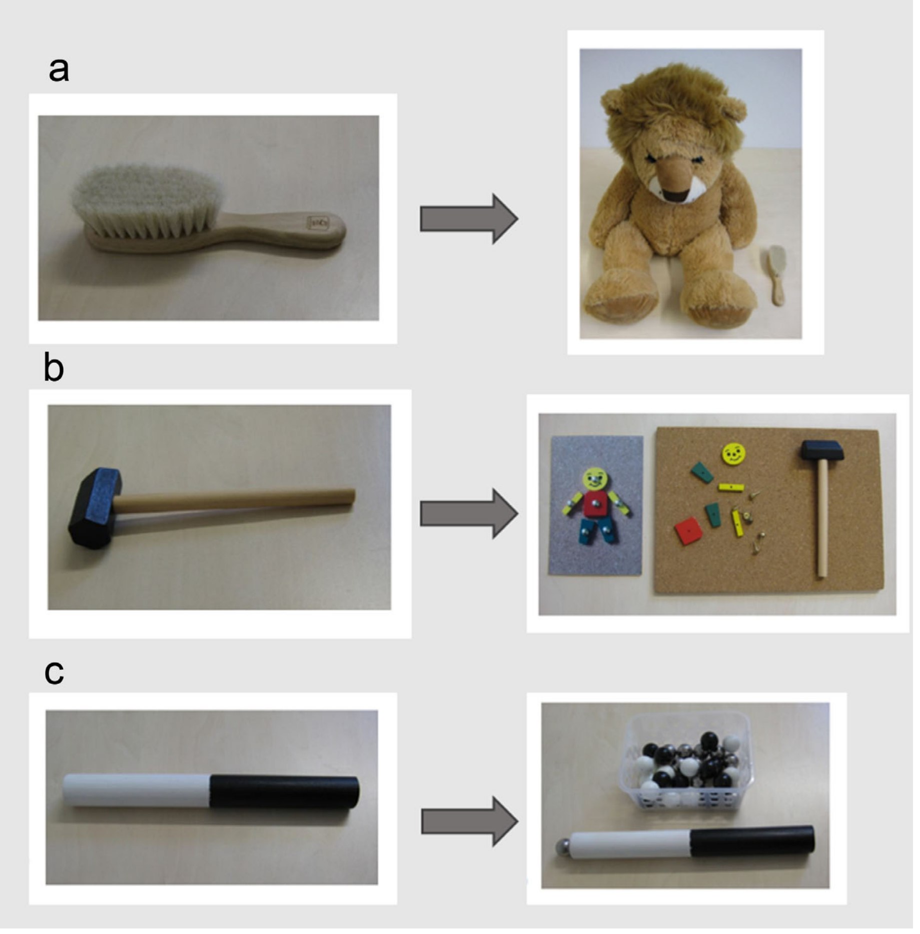

FIGURE 1 Pictures show the tools and associated stimuli in the different tool-use tasks. (a) Brush task. (b) Hammer task. (c) Bar task

with its grip being 12 cm long and measuring 1 cm in diameter. The bar largely corresponded to the bars used in numerous ESC studies. It consisted of an elongated wooden cylinder, with 25 cm in length and 2.7 cm in diameter, with one end painted black and the other one white. In order to provide the bar with a tool character, the white end contained a magnet, so that the bar could be used for picking up small metal balls.

At the beginning of each trial, irrespective of the context, one of the tools was presented lying on the table in front of the participant, with the grip facing either toward the participant (toward orientation) or away from the participant (away orientation). The angular difference between the two orientation conditions subtended 180°. On different blocks of trials, participants were asked to grasp the specific tool and either perform the designated task with it (solitary context) or to give it to the experimenter so that he could perform the task (social context). Given that the orientations of the tools were identical, motor requirements for picking them up were very similar.

Each tool was assigned to a specific task, the brushing task, the hammering task, and the magnet task, respectively (Figure 1). In the brushing task (Figure 1a), the participants were instructed to take the brush and brush a plushy toy lion. The lion was about 75 cm in size and laid on the table, in front of the participants. In order to separate different trials from one another, the participants brushed different body parts of the lion on consecutive trials. For the hammering task (Figure 1b), we used a common "hammer game" that consisted of a corkboard, metal pins, and different wooden shapes with holes in the middle. The task required the participants to fixate the shapes onto the corkboard by pounding in the pins with the hammer, in order to assemble a predefined figure. The figure the participants were instructed to assemble was a manikin made up of six parts, two arms, two legs, a body, and a head. One trial consisted of hammering one of the shapes onto the corkboard. The goal figure was demonstrated to the participants by showing them a photo of a corresponding ready-made figure. The magnet task (Figure 1c) consisted of using the white end of the magnetic bar to extract six metal balls out of a basket, one on each trial. The basket contained 30 white, black, and silver balls, 10 of each color, but only the silver balls could be picked up by using the bar. In the self-context, participants performed the tasks on their own; in the social context, they were asked to give the respective tool to the experimenter so that he could perform the action. The experimenter sat at the opposite side of the table.

In addition to the tool-use tasks, the group of children (but not the adults) performed a mental rotation and a hand rotation test. The mental rotation test was the so-called picture rotation test (BiRT) developed by Marke (2008) for children from 4 to 6 years of age. It consists of 16 different target pictures (e.g., a bear) presented

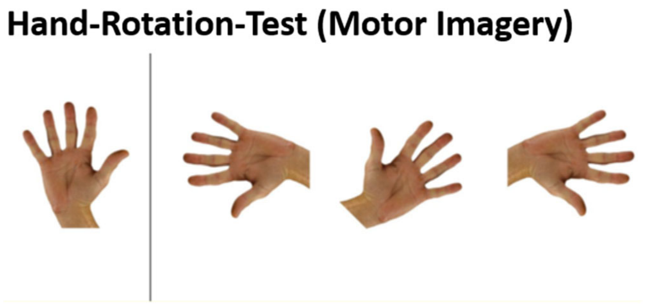

FIGURE 2 Example of an item of the hand rotation test. On the left-hand side, the target picture is depicted; the test stimuli are shown on the right-hand side

to the children, which have to be compared to three test pictures, respectively, depicting either the same picture viewed from a different rotation angle or two mirrored pictures, also presented from different orientations. The children's task was to identify the one test object that was the same as the target object, as it corresponded to the target picture when rotated back. Children were given three practice trials before the test was administered. At test, children were given one error point for each incorrect decision. The total score corresponded to the sum of committed errors (i.e., theoretically the score could range from 0 to 16 points). We constructed a hand rotation test by taking photographs of right and left hands (Figure 2), as viewed from above and presenting them from different rotation angles. In analogy to the BiRT, children were presented with one target picture that then had to be matched to one of the test pictures. In sum, children were presented with six trials and the total score was represented by the number of errors committed.

2.1.3 | Design and procedure

Each tool use task consisted of six trials, on which participants were instructed to pick up the tool and perform a specific action. Across the six trials, the orientation of the tool grip was varied. On three trials, the grips of the tools were presented toward the participants ("toward orientation"); on further three trials, the tool grips pointed away from the participants ("away orientation") and toward the experimenter, who, as already mentioned, sat opposite to the participants. The order of toward and away trials was randomized. First, the participants performed one task (e.g., the hammer task) in the solitary context, afterward the experimenter picked up the materials and the participants performed the task related to the same tool in the social context. Then they proceeded with the next tool-use task, until all tasks were finished. The children always performed the solitary task first, in order to learn about what was required to be done with each of the tools, or, in the case of the bar, how it functioned. Task order was counterbalanced across participants. In addition to the tool-use tasks, the children performed the picture rotation and the hand rotation tasks. Half of the children performed the rotation tasks before and half of them after the block of tool-use tasks.

2.1.4 | Measures and scoring of the tool-use tasks

The procedure was videotaped and the participants' grip patterns regarding their tool-related grasping movements were coded off-line. Depending on the orientation of the tool grips and the task context (solitary/social), different patterns related to ESC planning could be expected.

Coding in the solitary condition

In the solitary condition, participants were given one point for every trial that ended with a comfortable grip on the tool and enabled a comfortable use of the tool at the outset of the required action. If participants ended up in an awkward, uncomfortable hand position or had to adjust their grip during the course of the movement (e.g., switch hands or readjust the grip position), they were given a score of 0 for the respective trial, because in this case the movement could not be counted as well-planned. The scores were added per tool and orientation condition (away/toward), and divided by the number of executed trials per condition, resulting in a measure of mean relative frequency and a range of scores between 0 (minimum) and 1 (maximum).

Coding in the social condition

In the social condition, we analyzed the extent to which participants considered the experimenter's BSC when transferring the tool to him. When at the beginning the grip of the tool pointed toward the participant, the tool had to be reoriented before passing it to the experimenter, so that the experimenter would be able to use it functionally right from the beginning. As an example, when transferring the hammer from a starting position, in which the hammer grip pointed to the participant, he or she would need to rotate the grip toward the experimenter. In contrast, the away condition, when the tool grip pointed away from the participant at the beginning, should be quite easy, because the tool's grip already pointed toward the experimenter and therefore needed no reorientation.

To operationalize comfort, we analyzed tool orientation at the end of each transfer movement. We defined such actions as realizing comfort, in which the tool's handle was oriented toward the experimenter at the end of the transfer. Ideally, this was realized by grasping the object by the functional part, with a goal-end grip (e.g., the hammer head; see Figure 3a), and passing the tool's grip more or less horizontally to the experimenter. Transfers were also counted as realizing comfort when participants grasped the tool by the grip, but then, relative to the vertical plane, inclined it toward the experimenter (Figure 3b). In contrast, if participants presented the tool to the experimenter with the tool's grip pointing downward vertically, without any inclination toward him, this was not counted as enabling comfort. For each "comfort-enabling" grasp, children received a score of 1, else, they received a score of 0. Furthermore, participants received a 0 score if they needed to adjust their grip during the course of the movement. The scores were added per tool and orientation condition (away/toward), and divided by the number of executed trials per condition, resulting in a measure of mean relative frequency that could take a value between 0 and 1.

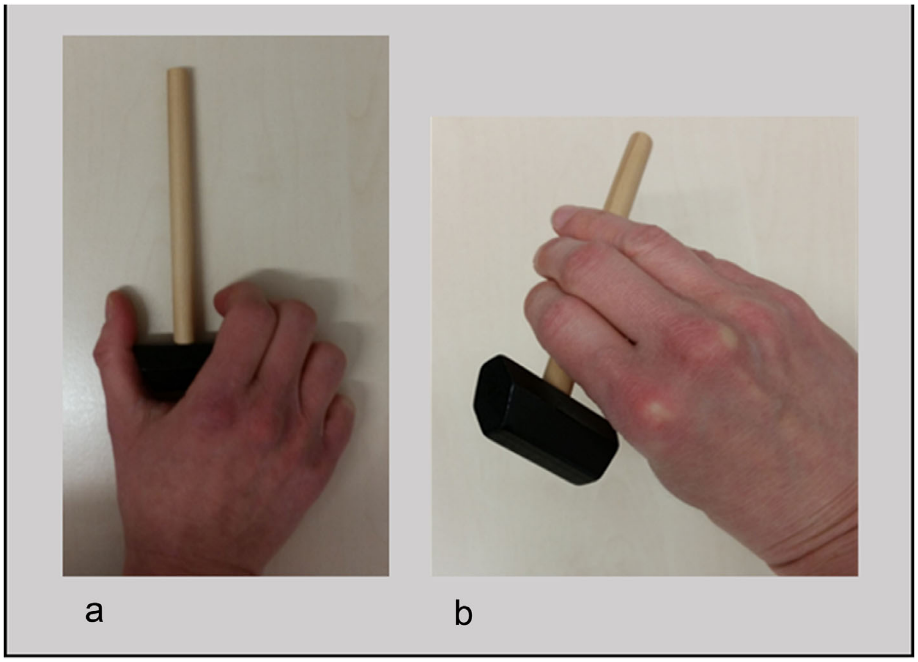

FIGURE 3 (a) Comfort-enabling goal-end grip, realized by grasping the object by the functional part. (b) Variant of comfort-enabling grip

Fifty percent of the data were coded by independent second independent coder. As an index of interrater reliability, we calculated Pearson correlations between the coders, which amounted to $r = .89$.

2.1.5 | Data analysis

We submitted the data from the solitary and the social context to separate repeated measures ANOVAs with tool (bar, brush, hammer) and orientation (toward participant/away from participant) as within-participant variables. In order to test for a relation between planning for BSC in the social condition and the two rotation tasks (object/hand rotation), we calculated Pearson correlations between participants' scores regarding the different tools and each of the picture rotation scores, respectively, partialing out age in months as a potentially relevant factor.

3 | RESULTS

For both contexts, we first performed a set of preliminary analyses to test for eventual effects of test order (rotation task first/ESC first) and of the order of tool presentation. As the inclusion of these variables yielded no significant effects, we performed the main analyses without these factors.

3.1 | Solitary context

An ANOVA on the data in the solitary context with tool (bar, brush, hammer) and orientation (toward participant/away from participant) as within-participant variables revealed no significant main effect for tool ($p > .01$), but a significant main effect of orientation (F (1,31) = 12.74, $p < .001$, $\eta = .29$), which was qualified by a significant interaction between orientation and tool (F (2, 62) = 6.04, $p = .004$, $\eta = .16$). An inspection of the mean relative frequencies for the tools in the different orientation conditions indicated that on the brush and hammer tasks, children performed better when the tool grips were oriented toward them than when they were oriented away from them (see Figure 4). Two post hoc t-tests comparing the means of the toward and away orientation for each of the two tools separately indicated that both of these differences were significant (Bonferroni-corrected, both p's $< .05$). A corresponding comparison regarding the bar task was not significant. On this task, children performed equally well, independent of orientation.

3.2 | Social context

In the ANOVA, the Mauchly test of sphericity reached significance for the interaction between the factors tool and orientation. For this reason, the results regarding this interaction are reported using the Huynh–Feld correction. The ANOVA revealed a significant main effect of tool (F (2, 62) = 7.76, $p = .001$, $\eta = .20$), a highly significant main effect of orientation (F (1, 31) = 33.40, $p < .001$, $\eta = .52$), and a significant interaction between tool and orientation (F (2, 62) = 3.74, $p = .049$, $\eta = .11$). The main effect of tool is mirrored in the significantly higher overall performance on the bar task as compared to the other two tool tasks (Figure 5). However, this main effect was qualified by the interaction between tool and orientation. The interaction indicated that, compared to all other conditions, children performed best in the

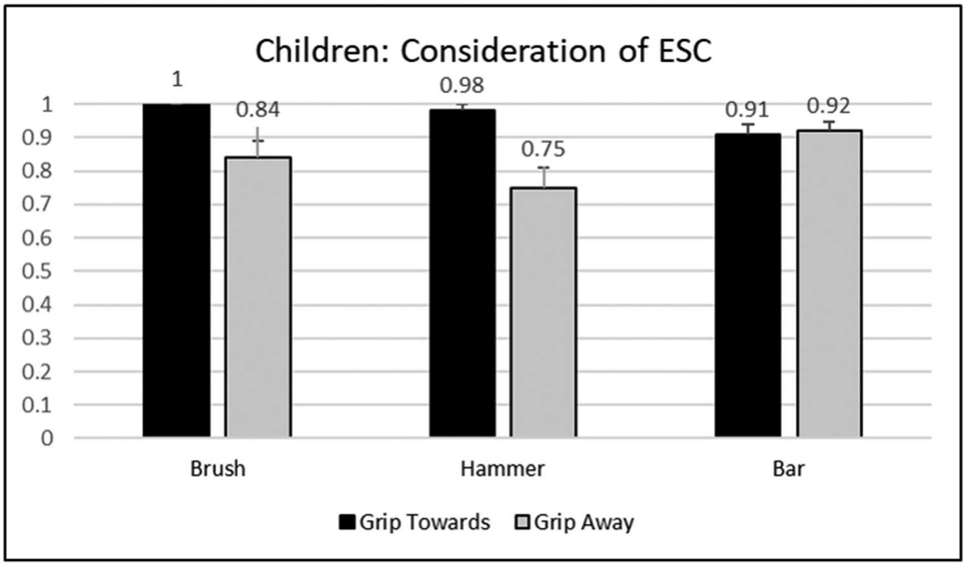

FIGURE 4 Children's mean relative ESC frequency across trials

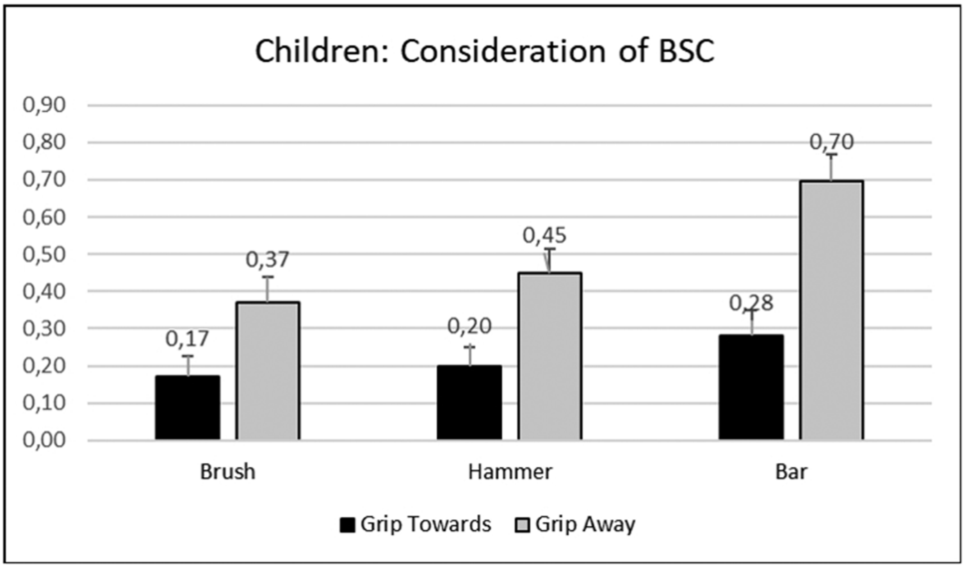

FIGURE 5 Children's mean relative BSC frequency across trials

away condition on the bar task with a mean frequency of $M = 0.07$, $SE = 0.39$. In contrast, in the other tool/orientation conditions performance was very poor, ranging between $M = 0.17$, $SE = 0.32$, in the toward orientation of the brush task, and $M = 0.45$, $SE = 0.39$, in the away condition of the hammer task. In order to test whether this difference was significant, we calculated a contrast between the mean frequency of the away condition on the bar task and the weighted mean frequency on the toward and away conditions of the other tasks. There was a statistically significant difference between the mean frequency in the away condition on the bar task as compared to all other conditions ($M = 0.405$, $SE = 0.08$) (F (1,31) = 25.74, $p < .001$; Bonferroni-adjusted). During the inspection of the videos, it became apparent that there was one difference between the handling of the different tools that could at least partially account for the difference in successful performance between the away condition of the bar task and those of the hammer and brush tasks. This was a reluctance on the children's part to grasp the brush and the hammer by the functional part instead of the grip ("goal-end grip," after McCarty, Clifton & Collard, 1999) that was less pronounced in the bar task. Actually, in the away condition, grasping the tool by its functional end would have been the easiest way to give the tool to the experimenter, because the grip was oriented toward him already. The mean number of trials on which children grasped the bar tool by using a goal-end grip when transferring it to the experimenter was $M = 1.25$, $SE = 0.23$, whereas the mean number of trials in the

	Mental rotation	Motor imagery
Brush towards	-0.27 *p* = .14	-0.18 *p* = .34
Brush away	0.032 *p* = .86	-0.26 *p* = .16
Hammer towards	**-0.36*** *p* = .046	0.12 *p* = .51
Hammer away	0.11 *p* = .57	0.02 *p* = .90
Bar towards	**-0.48*** *p* = .007	-0.28 *p* = .14
Bar away	0.14 *p* = .46	-0.08 *p* = .69

FIGURE 6 Correlation coefficients with age partialled out between the ESC tasks, split by tool and orientation, and the mental rotation and motor imagery tasks, respectively. Significant correlations are marked with asterisks

brush condition was $M = 0.61$, $SE = 0.18$ and in the hammer condition $M = 0.66$, $SE = 0.16$. We submitted these data to an ANOVA for dependent measures with tool as a three-level variable. The ANOVA yielded a significant effect of tool (F (2, 60) = 5.34, $p = .015$, $\eta = .15$) (Huynh–Feld correction for a significant test of sphericity). In separate post hoc tests comparing the mean numbers of goal-end grasp trials regarding each tool, we found that, after a Bonferroni correction, the differences between the brush condition and the bar condition (t (30) = 2,49, $p = .054$) and between the hammer and the bar condition (t (31) = 2.42, $p = .066$) remained marginally significant, whereas there was no significant difference between the hammer and brush tasks. As expected, the number of goal-end grips on each task correlated with the mean relative frequency of ESC in the away conditions of each tool task. For the bar task, the Pearson correlation amounted to r (32) = .55, $p = .001$, for the brush task it was r (31) = .73, $p < .001$, and for the hammer task the correlation was r (32) = .52, $p = .002$.

3.3 | Correlations between the tool-use tasks in the social condition and the mental rotation/motor imagery scores

Children's performance on the mental rotation and motor imagery (picture/hand rotation) tasks was quite high, which was plausible, because the test was optimal for slightly younger children between 4 and 6 years. On the mental rotation task, the mean number of errors was $M = 2.5$, $SE = 0.39$, with a range between 0 and 8 errors (out of 16 possible), which means that they made errors on approximately 15% of the items. In the motor imagery task, the mean number of errors was $M = 1.09$, $SE = 0.27$, with a range between 0 and 6 (out of 6 possible), which corresponds to an error rate of 18%. The difference between the percentages of errors in the two tasks was statistically not significant. In order to investigate whether children's BSC performance might be related to mental rotation or motor imagery, we calculated Pearson correlations between the different tool task scores, divided per orientation condition, and the mental rotation and motor imagery scores of each participant, respectively. In these analyses, we controlled for age by partialing out age in months. Two significant correlations appeared in the analysis (see Figure 6), namely, between the mental rotation score and the performance on the bar task when the bar was oriented toward the participant (r (29) = −.48, $p = .007$), and between the mental rotation score and the performance on the hammer task, also in the toward condition (r (29) = −.36, $p = .046$).

4 | DISCUSSION

Taken together, the analyses indicate that in the self-context of the ESC tasks children were at a very high performance level already. Especially on the familiar hammer and brush tasks, they were nearly perfect (except for one trial) when grasping the tools with the grips oriented toward them. This is not surprising, because this corresponds to the tools' usual orientation and represents ordinary tool use. On the unfamiliar bar task, children also reached an overall very high level of performance with a mean frequency of $M = 0.91$.

Children's performance in the social context was rather low, as compared to the findings by Scharoun and Bryden (2014) or the adult findings by Gonzalez et al. (2011), except for the away condition of the bar task. This supports other findings indicating that the consideration of comfort in other persons develops relatively late (Meyer, van der Wel, & Hunnius, 2016; Paulus, 2016). The interaction between tool and orientation indicates an effect of object familiarity on children's performance on the tool transfer tasks, as children's performance was highest on the unfamiliar bar task when the tool was pointing toward the experimenter, and lower on trials with the familiar tools. We assumed that this unexpected pattern originated from the children being reluctant to grasp the familiar tools (brush and hammer) by their functional parts, but preferring to grasp them by the handles, a tendency that was less observable in the bar task. This suggests some extent of functional fixedness regarding tool use, with the children being unable to overcome habitual grasping strategies with the familiar tools in favor of acting more efficiently. In case of the unfamiliar bar tool, children again acted more flexibly, supposedly because they had no habitual experience with it.

Regarding our hypotheses concerning the correlations between the BSC measures and the mental rotation and motor imagery tests, we found two significant correlations. Specifically, we found significant correlations between children's mental rotation score and their performance on the bar task when the bar was oriented toward the participant (r (29) = –.48, p = .007), as well as between their mental rotation score and their performance on the hammer task, also in the toward condition (r (29) = –.36, p = .046). The correlations are negative, because the mental rotation score was actually an error score. However, we found no significant correlations of between children's consideration of comfort and the hand rotation task. As the children scored relatively low on the task in the social condition, we thought that it would be useful to have an adult comparison group. On the one hand, we wanted to look at potential tool-related performance differences regarding BSC performance even in adults; on the other hand, we wanted to look at adults' grasping strategies regarding the grip versus handle of the tools. Therefore, in Study 2 we conducted a control study with adults.

5 | STUDY 2

5.1 | Method

5.1.1 | Participants

In the second study, we tested 17 adult participants, 13 female and four male. The adults were students who participated in the study for course credits and had a mean age of 21.6 years (range: 18–28). Written informed consent from all participants was signed before participation. Participants were tested individually in a laboratory at the university.

5.1.2 | Stimuli and tasks/design and procedure

The stimuli and design were identical to Study 1, with the exception that adults did not perform the mental rotation/motor imagery test.

5.1.3 | Measures and scoring of the tool-use tasks

Procedures were identical to Study 1.

5.1.4 | Data analysis

Identical to Study 1, except for the correlation analyses.

5.2 | Results

5.2.1 | Solitary context

In the solitary context, all participants reached the maximum value (i.e., 100% ESC) on each task. Therefore, there was no point in running the ANOVA on this condition. It is important to note, however, that, similar to the children, the adults also used the same two strategies interchangeably for grasping the bar.

5.2.2 | Social context

As expected, in the social context, the adults performed much better than the children (Figure 7). However, in comparison to the data by Gonzalez et al. (2011), they were not perfect. The planned ANOVA with tool (bar, brush, hammer) and orientation (toward participant/away from participant) as within-participant variables yielded no significant main effects, neither for tool nor for orientation (both Fs < 1), but a significant interaction between the factors (F (2, 32) = 5.59, p = .008, η = .26). An inspection of the data pattern indicated that this interaction was due to the difference between the performance in the toward and away conditions of the bar task, which was not significant in the other tool tasks. On the bar task, participants had a higher mean frequency in the away condition ($M = 0.90$, $SE = 0.06$) than in the toward condition ($M = 0.65$, $SE = 0.46$). A post hoc t-test, however, was not significant after a Bonferroni-adjustment, t (16) = 2.19, adjusted $p > .05$.

In Study 1, we found that for children the tendency to grasp the tools by their functional ends (goal-end grip) in order to transfer them to the experimenter differed between tools. Thus, in our adult sample, we also looked at the mean number of goal-end grips in the away conditions of the different tool-use tasks. In the adult sample, the means were higher than in the child sample, with the exception of the bar condition. The mean number of goal-end grips for the bar task was $M = 1.0$, SE = 0.27, for the brush task $M = 1.94$, $SE = 0.31$, and for the hammer task $M = 1.69$, $SE = 0.36$. As in the first study, we calculated an ANOVA with

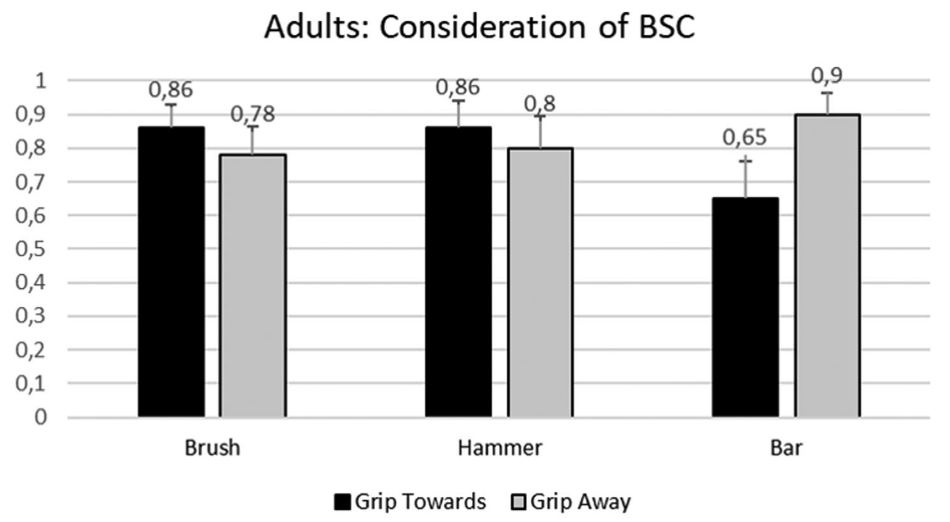

FIGURE 7 Adults' mean relative BSC frequency across trials

the mean number of goal-end grips in the away condition of the three-tool-use task as a three-level repeated measures variable. However, this analysis revealed no significant effect (F (2, 30) = 2.75, p = .80), indicating that adults were applying goal-end grips about equally often on the different tool-use tasks. In order to test our assumption regarding children's reluctance to grasp the brush and the hammer by their respective functional part, we tested how often adults used this strategy as compared to the children. A comparison between children and adults concerning the mean number of goal-end grips in the brush condition indicated a significant difference between the groups (F (1, 45) = 15.35, $p < .001$, $\eta = .25$). A corresponding analysis regarding the performance differences between the two groups in the hammer task yielded similar results (F (1, 46) = 9.21, $p = .004$, $\eta = .17$), indicating that adults initiated significantly more goal-end grips than the children when transferring the brush and the hammer to the experimenter in the away condition. This supports the idea that specifically children were reluctant to grasp the familiar objects' functional parts, whereas adults had overcome this strong tendency. Regarding the unfamiliar bar, however, children grasped it as often by its functional part as adults did.

5.3 | Discussion

Altogether, this second study revealed that adults were perfect in the solitary context and expressed a much higher level of BSC planning than the children in the social context, although they were not perfect, as in the study reported by Gonzalez et al. (2011). This indicates that object familiarity might play a minor role in adults' grasping as well. In addition, adults differed from the children in the extent to which they were able to inhibit habitual grasping toward the objects' handles. This enabled most of them to act very efficiently in the social context.

6 | GENERAL DISCUSSION

The present studies investigated 5.5- to 7-year-old children's planning of efficient grasping in a social context, focusing on the impact of tool familiarity and its relation to mental rotation and motor imagery. We assumed that an important factor involved in BSC planning might be visual perspective taking, because children had to orient the tool correctly in relation to the experimenter and to anticipate which orientation would be comfortable from the experimenter's perspective. This assumption was partly supported by our findings of a relation between children's performance on the toward conditions of the bar and hammer tasks and the mental rotation score that measures similar spatial processes. The toward condition was the condition in which the tools had to be rotated in order to give them to the experimenter. The data should be interpreted with some caution, however, as the correlations were not overly high, and in the brush condition the correlation was not significant. However, this might also be related to the fact that the mental rotation test was conceptualized for children between 4 and 6 years, and therefore the variance in the present sample was reduced. Flavell (1974) and Flavell, Everett, Croft, and Flavell (1981) studied children's ability to determine what objects look like from another person's perspective (Level 2, perspective taking) and found out that it is not before 4 to 5 years of age that children start gaining this kind of understanding (Pillow, & Flavell, 1986). By 7 years of age, children have been found to show an increase in performance on more complex matching tasks (Frick, Möhring, & Newcombe, 2014). In the present study, which could be taken as an example of a complex matching task, children might thus have struggled with figuring out how best to present the tools to the confederate in order to facilitate his tool use. Interestingly, in contrast to the findings by Toussaint et al. (2013), the motor imagery measure was not correlated with the children's BSC performance on the tool use tasks. This could be partly due to the fact that the motor imagery task was composed of a lower number of items than the mental rotation task and therefore correlations were more difficult to detect. Another possible reason could be that motor imagery as measured by the usual hand rotation task has explicitly been related to an egocentric perspective (e.g., Brady et al., 2011), whereas findings from joint action studies imply the perception of other people's affordances or attentional focus might be linked to the ability to switch from an egocentric to an allocentric perspective (Böckler, Knoblich, & Sebanz, 2011; Creem-Regehr, Gagnon, Geuss, & Stefanucci, 2013)

Regarding our second central question, we also found an influence of tool familiarity on children's BSC planning, namely, higher performance on the unfamiliar bar task relative to the other tool tasks. This was surprising, as we had rather expected a facilitation of BSC on tasks with familiar tools, corresponding to the findings from studies on ESC planning (e.g., Knudsen et al., 2012). We assume that the pattern found in the present study could be explained by an interaction between the habitual and planned grasping strategies. Probably, children's habitual experience with the two familiar tools, the hammer and the brush, played an important role in their task performance. For both tools, children may already have developed a habitual mode of holding the objects, which is by the handle. Obviously, holding the hammer by the handle, however, impedes offering the handle to another person, which would represent a comfort-enabling behavior. Thus, children's grasping habits might have interfered with efficient grasping. In contrast, the bar was a novel tool, and children were not bound to grasping it in a habitual way, because they not had the chance of developing one. In turn, they were more flexible and efficient, and showed efficient planning on 70% of the trials in the away condition. Jovanovic and Schwarzer (2017b) already provided evidence in favor of an influence of tool-related grasping habits on efficient grasping. Although grasping habits might be helpful when grasping tools efficiently for one's own use, because they might have been elaborated and practiced across a long period of time and replace complex planning processes, they might interfere with flexible planning when tools have to be grasped in an unusual way. As mentioned in the introduction, such negative influences of object familiarity might also be related to functional fixedness, which might be especially strong in the tested age range. Maybe the fact that the solitary part of the task always preceded the social part might even have strengthened the associations between the objects and their functions regarding the familiar objects. For the unfamiliar object, however, the solitary part was necessary for learning the function of the object. These few instances, however, might not have sufficed for creating a strong association between the tool and a specific way of manipulating it, and therefore, children were more flexible on the transfer task. This was also underscored by the fact that they tended to grasp the bar at its functional end more often than they did with the hammer and brush. Similarly, the difference between children's and adults' performance regarding the consideration of another person's comfort might derive from the fact that adults were better able to override their habits and grasp the tools by their functional ends. This is supported by the finding that adults and children differed significantly on the mean number of trials on which they adopted this strategy when transferring the hammer or the brush. One could object that the functional parts of the familiar objects were more salient than the functional part of the unfamiliar object. However, children's performance in the solitary part of the task indicated that they had no problems in discerning the functional from the nonfunctional part when handling it. Also, the lower distinctiveness should have led to a worse, not to a better, performance on the children's part. Although these results indicate that tool familiarity might play a role for the efficient planning of actions oriented toward other people, this interpretation is somewhat limited by the fact that the number of objects used was low, as only one unfamiliar object was compared with two familiar objects. Taken together, the present paper indicates that efficient planning in a social context seems to be difficult for children, especially when they are dealing with objects that they are well-trained in using. In addition, slightly different processes seem to be involved when using tools for fulfilling their own goals that when giving objects to another person, in that mental rotation might be an important process when planning the transfer of a tool to another person, but not when planning own tool use.

Finally, the results also point to the fact that children's consideration of other people's comfort in the social context is still rather low at an age of 5–7 years. In fact, it ranged at about 20%–40% of the trials, especially when they acted with very familiar objects. This finding is in line with the study by Paulus (2016), but contrasts with the results by Scharoun, and Bryden (2014), who found a nearly adult-like performance on a cup transfer task in 7-year old. Obviously, tool familiarity cannot explain the differences in finding, as the familiar tools used in the present study were those that were associated with the worst performance. One more plausible reason for this difference in findings might be grounded in a structural difference between the objects used. The objects used in the present study had handles that had to be oriented toward one of the users for enabling proper use, and their optimal orientations regarding own use versus the use by another person were maximally different from each other. Therefore, they had to be rotated in contrary directions and this required mental rotation capacity and was cognitively taxing. In contrast, in the cup task employed by Scharoun and Bryden (2014), the requirement of reorienting the cup from an upside down to a right side up orientation was the same for own use as well for the use by another person. The only aspect that probably differed was grasp placement on the cup. This had to be considered when transferring the cup to the experimenter so that he could grasp it comfortably. Therefore, it seems plausible that task complexity was somewhat higher in the present study and this could explain children's lower performance.

Taken together, our data present first evidence of a potential influence of tool familiarity and mental rotation on 5.5- to 7-year-old children's consideration of another person's comfort. This relation could be further explored in future studies by using a greater number of different unfamiliar tools and applying a battery of perspective taking tasks in order to specify the exact processes by which these spatial skills are related to children's consideration of BSC. Interestingly, children's performance of the BSC tasks was very low. Although children's social sensitivity might be strongly developing at that age, given that children are able of representing other people's goals and can collaborate with them from 3 to 4 years of age already (e.g., Meyer et al. 2010), the exact and efficient integration of these goals into their own action plans still remains challenging.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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