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Young Children's Memories for Social Actions: Influences of Age, Theory of Mind, and Motor Complexity

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Children learn actions performed by a social partner better when they misremember these actions as their own. Identifying the factors that alter the propensity to make *appropriation errors* is critical for optimizing social learning. In two experiments ($N = 110$), we investigate the developmental trajectory of appropriation errors and examine social-cognitive and motor-related factors in 3- to 8-year-olds. Children with better theory of mind (ToM) skills made fewer appropriation errors for motorically complex actions. Appropriation errors did not differ as a function of ToM if children could perform the corresponding actions. A second experiment replicated this effect and found no influence of collaborative context on appropriation errors. This research sheds light on the complex relations among development, social-cognition, and motor-related factors.

One of the most prominent ways for children to gain new knowledge is through their interactions with and observations of other individuals. In addition to formal learning contexts such as schooling, informal interactions with social partners are systematic and incredibly rich sources of information in the everyday lives of young children. When interacting with a parent, for example, young children can learn about the function of different objects and tools, about the actions that are necessary to achieve certain goals, and about the language used to label objects and events (Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009). The evidence that children begin learning from these interactions as early as infancy is plentiful (e.g., Csibra & Gergely, 2011).

From a young age, infants are prone to copy the actions they see performed by another person (Meltzoff, 2007). Imitative learning in infancy is often tested in the context of memory for actions, as in Bauer's seminal delayed imitation tasks (e.g., Lukowski et al., 2005). This kind of imitative learning is a precursor to more complex and collaborative interactions with social partners. In the third year, children begin to engage in increasingly complex social interactions that include coordinating complementary actions over time to achieve a common goal with a social partner (Endedijk et al., 2015; Meyer, Bekkering, Paulus, & Hunnius, 2010). During joint actions, children's learning about how to perform the actions or achieve a joint goal is dependent upon memory for the actions produced by both themselves and their social partner. In addition to remembering how to produce actions, accurate memory for these events involves recalling the source of each action: who performed which role. This could be important, for example, if children recognize that they need a partner to help them to carry out a particular step of an action that they cannot do themselves.

Memory for Actions: The Appropriation Error

In previous research examining children's memory for actions carried out in social contexts, a curious two-fold effect has been found. As expected, children form memories of the actions carried out during social interactions such that they can recall and perform many of the actions performed by

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both themselves and their social partner (Sommerville & Hammond, 2007). Interestingly, however, children show a systematic bias in the errors they make regarding the source of the actions. That is, when asked who performed which action, children tend to take credit for the actions of their partner more often than they misremember actions carried out by themselves as completed by their partner (Foley, Passalacqua, & Ratner, 1993; Foley & Ratner, 1998).

Even though this *appropriation bias* is termed an error, evidence indicates that these kinds of errors can actually lead to better learning about how to perform the actions carried out by a partner. For example, in Sommerville and Hammond (2007), children were more likely to accurately recall how to perform the actions originally performed by a social partner if they mistakenly thought they had carried out those actions themselves. Despite its role in learning new actions, evidence about the developmental trajectory of this error and the mechanisms underlying its occurrence is scarce. The aim of this research is to begin filling the current gap in research by addressing the developmental trajectory of this error and how it is influenced by social-cognitive skills like theory of mind (ToM) and motor-related factors like the motoric complexity of the social partner's action.

Developmental Change in the Appropriation Error

In early work on the appropriation error, Foley, Ratner, and colleagues (Foley et al., 1993) found that 4-year-olds were more likely to systematically make appropriation errors than 6- or 8-year-olds. The authors of this work noted, however, that the developmental effect in this research could have been a function of the difficulty of the particular task used (i.e., that the error rates may have varied by age as a function of task difficulty rather than as a function of changes in the propensity to make appropriation errors). This suggests that whether and how these errors change across developmental time is still an open question. More recent research (Hala, Brown, McKay, & San Juan, 2013; Hala, McKay, Brown, & San Juan, 2016) has found appropriation errors in children as young as 2.5 years. This calls for systematic research into how they change over development. In order to provide a comprehensive developmental assessment of how the propensity to make these errors changes across development, we use a task suitable for children across a wide age range and measure age continuously. Using an identical task for participants between 3 and 8 years of age allows us to test a conceptual replication of the developmental changes found by Foley et al. (1993) while controlling for general task difficulty.

The Appropriation Error and ToM

Theory of mind refers to the ability to understand one's own and others' mental states and differentiate between the two. ToM skill is classically identified by the passing of explicit false belief tasks and emerges around 4 years of age (Wellman, Cross, & Watson, 2001, but cf. Baillargeon, Scott, & He, 2010). Beyond this age, however, higher order ToM skills continue to emerge. For example, Strange Stories (Happé, 1994) require identification of others' mental states in naturalistic stories that incorporate complex behavior in social scenarios. Performance on this task relates to performance on more standard measures of ToM but continues to improve into adolescence (Devine & Hughes, 2013).

Given that ToM skills encompass keeping representations about oneself and others apart, this skill set may influence the propensity to commit appropriation errors. Specifically, children with better ToM should be better able to differentiate their own thoughts, actions, and beliefs from those of another individual (in this case, a social partner). Therefore, they might be less likely to merge representations of their own and others' actions when recalling actions carried out in a social context. Previous research has found that ToM skills influence source monitoring such that better ToM skills decrease susceptibility to alternative suggestions when recalling the source of information (Bright-Paul, Jarrold, & Wright, 2008). Ford, Lobao, Macaulay, and Herdman (2011) found more direct support for the effects of ToM on appropriation errors in those 4- to 5-year-old children who had better ToM scores made fewer appropriation errors than those with lower ToM scores. Whether such a relation is present throughout early childhood is unknown. In order to conceptually replicate this finding with a larger set of participants and explore the role of individual differences in social- cognition throughout early childhood, we combine false belief and Strange Stories tasks to measure ToM of children in this research in relation to appropriation errors (between 3 and 8 years of age).

The Appropriation Error and Motoric Complexity

There are many proposed sources of appropriation errors. Sommerville and Hammond (2007) found that children made more appropriation errors following a more collaborative task (with a shared goal) than a less collaborative task (with different goals for each individual). One proposal for why children might make more errors following a shared task is because collaborative tasks require an individual to tune in to their social partner in order to predict his or her upcoming actions. In support of this notion, research has shown that asking participants to imagine performing actions leads to an increase in appropriation errors relative to passive viewing of the actions (Foley & Johnson, 1985). This merging of self and other when imagining or predicting another's actions could be supported by a shared neural system. The sensorimotor cortex responds during both the observation of others' actions and during the execution of one's own actions (Pineda, 2008; Rizzolatti & Fogassi, 2014). Furthermore, previous work by Meyer, Hunnius, van Elk, van Ede, & Bekkering (2011) indicated that the sensorimotor cortex was preferentially engaged during action observation when 3-year-olds were involved in an interaction with the person being observed, relative to when they were observing that person acting but were not engaged in joint play with them. Sommerville and Hammond (2007) suggested that such sensorimotor activity during observation of a partner's actions may underlie both appropriation errors and improved learning of the actions carried out by a social partner.

If sensorimotor activity does play a role in appropriation errors, then factors that alter the degree to which the system is engaged (motor-related factors) should influence the occurrence of appropriation errors. For example, sensorimotor activity is significantly influenced by motoric experience such that there is more activity when an individual observes actions he or she has previously produced than when he or she observes unfamiliar actions which are not in the observer's motor repertoire (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Gerson, Bekkering, & Hunnius, 2015; Gerson, Meyer, Hunnius, & Bekkering, 2017). In the current research, we test the hypothesis that appropriation errors are more likely to occur for actions that are motorically simple (i.e., within a child's motor repertoire) relative to actions that are motorically complex (i.e., outside the child's motor repertoire).

Potential Interactions Between ToM and Motoric Complexity

Importantly, and beyond the scope of previous investigations, this integrative approach allows us to look at whether individual differences in social cognition interact with or are independent of potential effects of motor complexity. One possibility is that ToM skills and motoric complexity play independent roles (i.e., each produce main effects). An alternative possibility is that children's social-cognitive and motoric skills interact in relation to making appropriation errors. For instance, those with better ToM skills may be better able to distinguish which actions are motorically simple versus complex for oneself versus another because of a better sense of self (Saxe, Moran, Scholz, & Gabrieli, 2006; Sodian, Hülsken, & Thoermer, 2003) and, thus, a better grasp of one's own action capabilities. If this were true, children with better ToM skills would be less likely to make appropriation errors for actions that they know they cannot perform themselves (i.e., motorically complex actions) than for actions they know they can perform (i.e., motorically simple actions). Consequently, this approach has the potential to unravel putative multifaceted roles of different factors on the propensity to perform appropriation errors in early childhood.

The Current Research

In the current study, we systematically investigated three potential contributors to children's propensity to make appropriation errors: age, social cognition (ToM skills), and motor-related factors (motoric complexity of actions). Children between 3 and 8 years of age participated in a social interaction with an experimenter in which they took turns performing actions (cued by photographs of the action outcome) to achieve a shared goal. The actions the child produced were chosen to be feasible for all children participating so that we could ensure they could accurately state that they performed the action themselves. The actions performed by the experimenter, however, varied in terms of whether we expected children to have the motor capacity to perform them. That is, although some actions were defined as motorically simple, in that we expected most children to be able to perform them without a struggle (e.g., velcroing a strap in place), we assumed that other, motorically complex, actions would be outside the motor repertoire of the majority of children in the sample (e.g., tying shoelaces). Following the social interaction, children engaged in a short (about 3 min) assessment to measure ToM. Children then saw the same photos that were used to prime each action during the shared task and were asked who had previously performed each action. For each action previously performed by the child, the child could either correctly label it as self-performed or mistakenly label it as performed by the experimenter (*You Did It* error). For the actions previously performed by the experimenter, the child could correctly label it as experimenter performed or commit an appropriation error such that he or she mislabeled it as self-performed (*I Did It* error). Across ages, we could then assess whether appropriation errors were consistently more common than source errors for one's own actions, as expected from previous research (Foley & Ratner, 1998; Foley et al., 1993; Sommerville & Hammond, 2007). ToM assessments were conducted to examine whether children who performed better at ToM tasks would make fewer appropriation errors. Varying the motor complexity of the experimenter's actions allowed us to assess whether appropriation errors were more likely for (simple) actions within the motor repertoire of children than for (complex) actions outside their motor repertoire, while controlling for age differences. We also assessed potential relations between individual differences in ToM and motoric complexity on children's propensity to commit appropriation errors.

Experiment 1

Method

Participants

Fifty-three children (24 males) between 3 and 8 years were included in the final sample (M_{age} = 5.51 years [*SEM* = .15]). An additional six children participated but were not included in final analyses due to being over 8 years of age ($n = 2$), missing birth date information ($n = 1$), or missing video recording necessary for coding ($n = 3$). Children were recruited at a science centre in Dundee, Scotland and a zoo in Edinburgh, Scotland and were tested in these settings that same day. Although specific demographic information was not collected, both Dundee and Edinburgh have largely Caucasian populations (94% and 91.7% white according to 2011 Census; http://www.ons.gov.uk/census, http://www.scotlandcensus.gov.uk). Entry fees to these sites range from £6.50 to £19.95. Parents or guardians of children completed written informed consent and children gave verbal assent. All research was approved for the project 'Did I Do That? Influences of Social Interactions on Memory and Action Learning' by the local ethics committee at Cardiff University (Blinded for review; approval EC16.06.14.53). Children received a sticker for participating.

Materials

The stimuli used in this experiment included a variety of toys that afforded a range of actions (see Figure 1 for a list of actions). For about a third of the actions, a "dress up pirate" doll that is made for children to practice different dressing skills was used. The pirate afforded, for example, buttoning a pocket, zipping a shoe, tying a shoe, and velcroing a strap in place. Other actions involved beads, strings, a bending dinosaur toy, novel tools, and a medicine box. For each of the 18 actions, a photograph depicting the end state of the action was presented as a cue to the action during both the turn-taking game and the recall phase (see Figure 1). The four phases of each experimental session were recorded using a video camera with a profile view of the child and the child's behavior.

Procedure

Phase 1: Turn-taking game. All children participated in a turn-taking game with the experimenter in which they took turns carrying out actions in order to achieve a joint goal (i.e., helping a pirate prepare and keep his treasure safe). Each action was depicted in a photograph and the photographs were presented sequentially, one at a time. The child and the experimenter each carried out nine actions in alternation and the experimenter said they were working together to prepare the pirate and his treasure. The experimenter began by pointing at the first photograph and saying "I'm going to make it look like this. (Perform action) See? Look. I made it look like the picture." She then turned the page to reveal the next action and said, "Now it's your turn. Can you make it look like that?" The experimenter and child took turns performing the 18 actions.

The actions carried out by the child were all designed to be possible for all children to carry out without assistance. If the child did not respond to the initial action prompt, the experimenter would repeat the prompt and ensure the child's attention was directed towards the photograph. If necessary, the experimenter also pointed toward the object the child could use. If the child was struggling to perform the action, the experimenter would again draw their attention to the relevant objects and mimic how the action could be completed. The child was allowed to carry out the action in any way he or she chose as long as the child reached the goal indicated in the picture. In this way, the

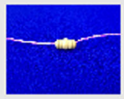
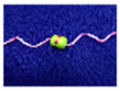
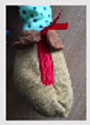
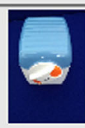
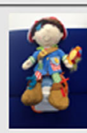
Experimenter Actions (order)	Action Description	Motoric Difficulty (percentage of children successful)	Child Actions (order)	Action Description
 (1)	Move bead with yellow tool	Middle (82%)	 (1)	Move bead with purple tool
 (2)	Place bead in pocket with orange tool	Difficult (63%)	 (2)	Place yellow bead on string
 (3)	Place green bead on string	Easy (100%)	 (3)	Snap button
 (4)	Button pocket	Middle (90%)	 (4)	Place sword in pocket
 (5)	Velcro strap	Easy (100%)	 (5)	Zip shoe
 (6)	Tie shoe	Difficult (27%)	 (6)	Unfold dino
 (7)	Open box	Difficult (16%)	 (7)	Place beads in box
 (8)	Place dino in box	Easy (100%)	 (8)	Close box
 (9)	Place bandana on box	Middle (91%)	 (9)	Seat pirate on box

Figure 1. The photos shown to children to depict each of the experimenter and child's actions as carried out in Experiment 1 are listed and described. For the actions carried out by the experimenter, the actual rates of success and rated complexity of each action, as found in the difficulty assessment, are noted. In the bottom right corner, the order in which each of the experimenter's and child's actions were carried out is noted (e.g., the experimenter's first action was moving the bead with the yellow tool and her ninth action was placing the bandana on the box).

child achieved a sense that he or she had successfully carried out each of his or her nine actions.

In order to ensure that the experimenter's actions differed in terms of motoric complexity in this age range, a separate group of 3- to 8-year-old children (n = 65; M_{age} = 5.91 years [SEM = .16]) engaged in a difficulty assessment task in which they attempted to reconstruct each action after viewing it performed by an experimenter. These children were recruited and tested at a science centre in Cardiff, Wales. According to a UK census, Cardiff is 84.7% White (info is from Census data collected in 2011, http://www.ons.gov.uk/census). Children were at ceiling in performing three of the nine actions. In contrast, the remaining six actions varied in the percentage of children who could perform them without assistance. Figure 1 depicts the range of actions in order of increasing complexity according to this separate group of children. During this difficulty assessment, children were only coded as successful if they could carry out the action in the manner demonstrated by the experimenter and did not get credit, for example, for moving the orange tool and the bead to the pocket independently with his or her fingers (experimenter Action 2 in Figure 1). This figure also shows the cut-offs for those actions defined as simple or complex, as defined in analyses below.

Phase 2: ToM assessment. Following the turn-taking game, children answered four questions assessing ToM reasoning. The first two questions were based on the well-established unexpected contents task (Gopnik & Astington, 1988). Children were shown a box of band-aids (plasters) and were asked what they thought would be inside the box. After children stated that they expected to see band-aids, they were shown that, instead, a small Lego figurine was hidden inside the box. The figurine was returned to the box and then children were asked the following two questions (in a set order): (a) "Do you remember what you thought was inside the box before we opened it?" (b) "If we asked my friend [name of experimenter not in the room], and she didn't see us open it, what would she think was inside the box?" For both answers, "band-aids" was considered a correct answer and "Lego" or "man" was considered an incorrect answer.

We also included two questions from another measure of ToM more suitable for older children: Strange Stories. The stories were taken from examples used in previous research (Happé, 1994). In the first story, children were told about a child who said that a banana was a telephone during pretend play. They were asked whether it was true what she said (that the banana was a telephone) and why this was said. In the second story, a boy did not pay attention to or thank his mother when she brought him his meal and the mother sarcastically called the boy polite. Children were asked whether it was true what she said (that the boy was polite) and why she said this. In both cases, the correct answer was "no" (that the statement was not true). This implies a basic understanding of pretense and sarcasm, two high order mental states. The ToM assessment typically took approximately 3 min.

For all tasks, the experimenter repeated the child's response aloud to ensure it was audible on the video recording. All four ToM tasks were coded via video offline by a trained researcher who assigned the child a 1 for each correct answer and a 0 for no answer or incorrect answers. Children's first response was taken as their answer even if they later changed their answer. The proportion of correct answers (out of four) was calculated for each participant.

Phase 3: Recall. In the recall phase, children were shown the photographs depicting the actions carried out in the turn-taking game (the same photos previously used to prompt the action) and were asked to recall who had completed each action (the experimenter or the child). The photographs were shown in one of two pseudorandom orders. For each picture, the experimenter referred to the picture and asked the child if he or she completed the action or if the experimenter did so. If the child did not answer, the experimenter reminded the child that it was okay to guess. The experimenter then repeated the child's answer to ensure that it was audible on video. Approximately 25% of videos were randomly chosen to be reliability coded by a trained coder and the two coders agreed as to who the child stated had completed the action on 100% of coded trials (Cohen's $\kappa = 1.00$).

Phase 4: Reconstruction. Finally, children had the option to participate in a reconstruction phase; this phase was optional given the time constraints of testing in a public setting. Due to the smaller sample size ($N = 38$) and the departure from the main aims of the current research, we do not discuss or analyze this data in the present report but include it here for transparency.

Results

Because children performed nine actions and the experimenter performed nine actions, children could commit between zero and nine *I Did It* errors (claiming they performed an action the experimenter had performed) and between zero and nine *You Did It* errors (claiming the experimenter performed an action the child had performed). For each child, we calculated the proportion of trials for which the child committed each type of error such that the number of *I Did It* errors was divided by nine and the number of *You Did It* errors was divided by nine.

In order to investigate the role of motoric complexity, we also separately calculated *I Did It* errors for motorically Simple and motorically Complex actions. The number of *I Did It* errors made on the three actions rated as motorically Simple (see Figure 1) was divided by 3 to create an *I Did It Simple* errors proportion score. The number of *I Did It* errors made on the three actions rated as motorically Complex (see Figure 1) was divided by 3 to create an *I Did It Complex* errors proportion score. The three actions that fell in the middle of the complexity scale were left out of this analysis to focus on the more extreme actions on each end of the scale.

Given the non-normal distribution of proportion scores, all proportion scores were arcsine transformed (two times the arcsine of the square root of the proportion) before being entered into analyses.

Group Differences in Errors

As an initial test of whether we replicated the general effect of appropriation errors such that children made more *I Did It* than *You Did It* errors, we conducted a paired samples *t*-test comparing transformed proportion scores for each of these error types. Across children of all ages, we replicated this effect, $t(52) = -2.73$, $p = .009$, Cohen's $d = .59$, with children performing *I Did It* errors (nontransformed $M = .13$, $SEM = .01$) more often than *You Did It* errors (nontransformed $M = .06$, $SEM = .08$).

Effects of Age, ToM Skills, Condition, and Motoric Complexity on Appropriation Errors

We then conducted a Repeated Measures analysis of covariance (ANCOVA) to examine the potential roles of age and ToM on the different kinds of errors described above. The within-subjects factor was type of errors (3: *I Did It Simple, I Did It Complex, You Did It*). ToM score was entered as a between-subjects factor. Age was entered as a covariate. One participant was not included in this analysis because they did not complete all of the ToM tasks. This analysis revealed a significant main effect of age, $F(1, 47) = 10.59$, $p = .002$, $\eta_p^2 = .18$, such that younger children made more errors overall than older children. A significant interaction between error type and ToM score, $F(6, 96) = 2.87$, $p = .013$, $\eta_p^2 = .16$, also emerged. No other main effects or interactions were significant (Fs < 1.70, ps > .19).

Interaction: ToM Skills by Motoric Complexity

In order to follow-up on the error type by ToM score interaction and to better understand how individual differences contribute to different types of errors, we conducted separate regressions for each error type. For each regression, transformed error proportion scores were entered as the dependent variable (in three separate regressions: *I Did It Simple, I Did It Complex, You Did It*), age was added as a predictor in the first step, and ToM score was added to the model as a predictor in the second step.

For *I Did It Simple* errors, the regression that only included age as a predictor provided the best fit (see Table 1). The model that included both age and ToM score did not significantly improve the model. Age was a significant predictor of errors, but ToM score was not. As age increased, proportion of *I Did It Simple* errors decreased. For *I Did It Complex* errors, the regression that only included age was marginally significant (see Table 1). The model that added ToM scores as a predictor provided a better fit. Age and ToM score were both significant predictors of errors. Older children and children with better ToM scores made fewer *I Did It Complex* errors. For *You Did It* errors, neither regression was significant (see Table 1). Neither age nor ToM scores were significant predictors.

Discussion

The results both conceptually replicate and extend previous research concerning the developmental trajectory and distinct social-cognitive and action-related factors affecting the appropriation error. Consistent with prior research, we found that children make more *I Did It* than *You Did It* errors when recalling actions carried out in a social context (Foley & Ratner, 1998; Foley et al., 1993). This was true for a wider age range than previously tested (between 3 and 8 years).

Building upon this initial finding, we investigated three factors that might alter rates of *I Did It* errors: ToM skills, motor complexity, and age. We found a main effect of age such that errors decreased as children got older and a significant interaction between ToM and error type that indicated that the effects of ToM differed for different levels of motoric complexity. Regressions indicated that *I Did It* errors for both motorically simple and complex actions decreased across age, consistent with prior research (Foley et al., 1993). While it is unsurprising that older children make fewer

Table 1
Regressions by Error Type

Dependent variable	Predictor	b	b 95% CI [LL, UL]	β	t	Fit	Difference
Experiment 1							
Motorically simple	(intercept)	1.56	[0.63, 2.50]		3.37*		
	Age	−0.18	[−0.35, −0.019]	−.3	−2.23*		
						R^2 = .091*	
	(intercept)	1.88	[0.76, 2.99]		3.37*		
	Age	−0.19	[−0.35, −0.02]	−.3	−2.26*		
	Theory-of-mind (ToM) score	−0.39	[−1.15, 0.38]	−.14	−1.01		
						R^2 = .11*	Change in R^2 = .019
Motorically complex	(intercept)	1.19	[0.34, 2.05]		2.79*		
	Age	−0.15	[−0.30, 0.003]	−.27	−1.97^		
						R^2 = .07^	
	(intercept)	1.76	[0.76, 2.76]		3.55*		
	Age	−0.15	[−0.30, −0.005]	−.27	−2.08*		
	ToM score	−0.71	[−1.39, −0.022]	−.27	−2.07*		
						R^2 = .15*	Change in R^2 = .075*
You Did It errors	(intercept)	0.76	[0.21, 1.31]		2.80*		
	Age	−0.079	[−0.18, 0.018]	−.23	−1.64		
						R^2 = .051	
	(intercept)	0.55	[−0.10, 1.20]		1.69^		
	Age	−0.078	[−0.18, 0.019]	−.22	−1.62		
	ToM score	0.26	[−0.19, 0.71]	.16	1.18		
						R^2 = .077	Change in R^2 = .026
Experiment 2							
Motorically simple	(intercept)	1.33	[0.54, 2.13]		3.36*		
	Age	−0.19	[−0.34, −0.039]	−.32	−2.5*		
						R^2 = .10*	
	(intercept)	1.4	[0.60, 2.21]		3.48*		
	Age	−0.16	[−0.32, −0.004]	−.28	−2.05*		
	ToM score	−0.3	[−0.89, 0.29]	−.14	−1.03		
						R^2 = .12*	Change in R^2 = .017
Motorically complex	(intercept)	1.69	[0.83, 2.56]		3.93*		
	Age	−0.25	[−0.41, −0.088]	−.38	−3.088*		
						R^2 = .15*	
	(intercept)	1.91	[1.10, 2.72]		4.73*		
	Age	−0.17	[−0.32, −0.007]	−.26	−2.099*		
	ToM score	−0.94	[−1.53, −0.36]	−.39	−3.22*		
						R^2 = .28*	Change in R^2 = .14*
You Did It errors	(intercept)	0.24	[−0.17, 0.65]		1.17		
	Age	−0.016	[−0.094, 0.061]	−.057	−0.42		
						R^2 = .003	
	(intercept)	0.24	[−0.18, 0.66]		1.12		
	Age	−0.018	[−0.10, 0.065]	−.062	−0.43		
	ToM score	0.019	[−0.29, 0.32]	.018	0.12		
						R^2 = .003	Change in R^2 < .001
Motorically simple (five actions)	(intercept)	1.76	[1.015, 2.50]		4.74*		
	Age	−0.25	[−0.39, −0.11]	−.44	−3.58*		
						R^2 = .19*	
	(intercept)	1.8	[1.04, 2.56]		4.75*		
	Age	−0.24	[−0.38, −0.086]	−.41	−3.16*		
	ToM score	−0.17	[−0.72, 0.38]	−.079	−0.61		
						R^2 = .20*	Change in R^2 = .006

*p < .05, ^p < .10.

memory errors than younger children, we also see descriptively that the rates of *I Did It* errors, and not *You Did It* errors, seem to change with age. However, there was no significant age by type of error interaction.

The interaction between ToM and error type was driven by the fact that ToM score was related to *I Did It Complex* errors but not other error types. This implies that children with higher ToM abilities were able to recognize that these actions may be beyond their motoric capacities and were thus less likely to mistakenly claim these actions as their own than children with lower ToM abilities. This is the first evidence to suggest that ToM plays a role in the ability to differentiate how one's own physical affordances may differ from a social partner's. Importantly, the effects of ToM were present even when controlling for age, suggesting that it is development of this particular social cognitive skill, rather than general maturation, that plays a role.

Building on these results, we conducted a second experiment with two main aims. Our primary aim was to replicate the findings from Experiment 1. Given the wide age range and novelty of the paradigm, we felt that replicating our findings with a similar paradigm (varying task-specific aspects that should not drive findings, as described below) and using matching analyses techniques would bolster the conclusions from Experiment 1 (Chambers, 2019; Munafò et al., 2017). As a secondary goal, we manipulated the degree to which the social interaction was collaborative in order to investigate whether similar effects of ToM skills and motoric complexities are found in these different contexts. As described in the introduction, previous research has found that more collaborative interactions are more likely to induce appropriation errors than less collaborative interactions (Sommerville & Hammond, 2007). Whether this is equally true for children high or low in ToM skills and whether this pattern is specific to motorically simple actions that are within a child's motor repertoire are open questions. It might be that children with lower ToM skills are especially prone to making appropriation errors in more collaborative contexts, whereas children with higher ToM skills are better able to distinguish between their own and the other's mind state and are thus less affected by the collaborative context. In terms of the role of motor complexity, it may be that differences between less and more collaborative contexts only emerge for simple, but not complex, actions. Experiment 2 aims to address these possibilities.

Experiment 2

Method

Participants

Fifty-seven children between 3 and 8 years were included in the final sample, each randomly assigned to one of two conditions: high collaborative (n = 29, 15 males, M_{age} = 5.28 years [*SEM* = .23]) or low collaborative (n = 28, 13 males, M_{age} = 5.12 years [*SEM* = .20]). An additional six children participated but were not included in final analyses due to being too old (n = 1), having incomplete information on their consent form (n = 2), or experimenter error (n = 3). Children were recruited at a science centre in Dundee, Scotland and a zoo in Edinburgh, Scotland and were tested in these settings that same day. Although specific demographic information was not collected, both Dundee and Edinburgh have largely Caucasian populations (94% and 91.7% white according to 2011 Census; http://www.ons.gov.uk/census, http://www.scotlandcensus.gov.uk). Entry fees to these sites range from £6.50 to £19.95.

Materials

The stimuli used in this experiment were identical to those used in Experiment 1. The only difference was that two sets of Pirates and two separate books of photographs were used in the low collaborative condition.

Procedure

Phase 1: Turn-taking game. As in Experiment 1, the experimenter and child took turns carrying out actions. The actions carried out by each individual were modified slightly from Experiment 1 so as to ensure that the experimenter and child could each act on separate objects and in their own spaces in the low collaboration condition. This also allowed us to test whether any effects found in Experiment 1 were due to the specific actions carried out by each individual or a function of a more general phenomenon. The actions carried out by the child included five of the actions carried out by the child in Experiment 1 and the addition of experimenter Actions 1, 3, 4, and 5 from Figure 1. The actions carried out by the experimenter included five of the actions carried out by the experimenter in Experiment 1 and the addition of child Actions 6, 7, 8, and 9 from Figure 1.

The high collaboration condition provided a near replication of Experiment 1. The verbal prompts and cues given by the experimenter in Experiment 1 were matched in this experiment and the child and experimenter took turns carrying out the 18 actions on a shared set of objects in a shared space. In the low collaboration condition, the child and experimenter each had a separate pirate and treasure set. They also had separate booklets with photographs of the actions to be carried out. The experimenter began by saying, "We're going to each get our own pirates and their different kinds of treasures and we're going to take turns getting our pirates ready ··· This is going to be your pirate and I've got a different pirate." As in Experiment 1 and the high collaboration condition, the experimenter started by performing the first action depicted in her booklet and saying, "I get to make mine look like this." After completing her action, she then drew the child's attention to the child's booklet and asked, "Can you make yours look like that?" They then alternated performing actions from each of their booklets on their separate toys.

The actions carried out by the child were intended to all be feasible for the child without assistance. Although two of the actions that children were requested to perform in this experiment were not successfully performed by all children in the difficulty assessment (see Figure 1), we note that, as described above for Experiment 1, the requirements for succeeding during the difficulty assessment were more arduous than those required in the turn-taking task (i.e., they had to model the means of achieving the goal in the difficulty assessment but could emulate the outcome by a different means and be considered successful in the turn-taking task). Four of the 57 children needed assistance with one or two (of nine) actions in Experiment 2 and these children were distributed across the two conditions.

The motor complexity of the actions carried out by the experimenter was based on the same difficulty assessment ratings used in Experiment 1. Children were at ceiling in performing five of the nine actions carried out by the experimenter (unfold dino, place dino in box, place beads in box, close box, seat pirate on box). The remaining four actions varied in the percentage of children who could carry them out without assistance, with the three actions defined as motorically complex matching the three motorically complex actions defined in Experiment 1.

Phases 2, 3, and 4

The ToM tasks, recall phase, and reconstruction phase were all carried out in an identical manner to Experiment 1 for both conditions in Experiment 2. They were scored in the same manner as well. Approximately 25% of recall session videos were randomly chosen to be reliability coded by a trained coder and the two coders agreed as to who the child stated had completed the action on 100% of coded trials (Cohen's $\kappa = 1.00$). As in Experiment 1, the reconstruction phase was not analyzed.

Results

I Did It and *You Did It* error proportion scores were calculated and transformed in the same manner as Experiment 1 before being entered into analyses. The same three actions defined as most complex in Experiment 1were used to calculate the proportions of errors for the *I Did It Complex* condition. To further closely match calculations of the *I Did It Simple* error proportions from Experiment 1, we chose three of five actions carried out by the experimenter for which children performed at ceiling levels. Two of the chosen actions were included in the *I Did It Simple* calculations from Experiment 1 and the third action was closely matched in terms of content (placing beads in the box was considered similar to placing the dino in the box).

For transparency and to ensure that the selection of these three actions did not bias any results, we created an additional *I Did It Simple* error score including all five actions for which children were at ceiling level performance. All outcomes are nearly identical to the three pseudorandomly selected simple actions. See the bottom of Table 1 for regressions including all five actions in the motorically simple calculation.

Group Differences in Errors

As an initial test of whether we replicated the effect of error type and whether this differed by condition, we conducted a repeated measures analysis of variance with error type (*I Did It* vs. *You Did It*) as the within-subjects factor and condition as the between-subjects factor. This revealed a main effect of error type, $F(1, 55) = 20.91$, $p < .001$, $\eta_p^2 = .28$, and no interaction between error type and condition, $F(1, 55) = 0.23$, $p = .63$, $\eta_p^2 = .004$, or main effect of condition, $F(1, 55) = 0.08$, $p = .78$, $\eta_p^2 = .001$. We therefore replicated the main effect of error type seen in Experiment 1, with children performing more *I Did It* errors (nontransformed $M = .11$, $SEM = .02$) than *You Did It* errors (nontransformed $M = .03$, $SEM = .01$).

Effects of Age, ToM Skills, Condition, and Motoric Complexity on Appropriation Errors

We then conducted a Repeated Measures ANCOVA to examine the potential roles of ToM, motor complexity, and age on the different kinds of errors described above. The within-subjects factor was type of errors (3: *I Did It Simple, I Did It Complex, You Did It*). ToM score and condition (high or low collaboration) were entered as between-subjects factors. Age was entered as a covariate. This analysis revealed a significant main effect of age, $F(1, 46) = 4.31$, $p = .043$, $\eta_p^2 = .086$, such that younger children made more errors than older children. A significant interaction between error type and ToM score, $F(6.83, 78.54) = 2.21$, $p = .043$, $\eta_p^2 = .16$ (greenhouse-geisser corrected for nonsphericity), also emerged. This replicates the findings of Experiment 1. A marginal main effect of ToM score, $F(4, 46) = 2.24$, $p = .079$, $\eta_p^2 = .16$, and a marginal interaction between condition and ToM score, $F(4, 46) = 2.48$, $p = .057$, $\eta_p^2 = .18$, also emerged. Because these were not significant and did not include interactions with error type (our main question of interest), we did not follow up on these marginal effects. No other main effects or interactions were marginal or significant (Fs < 1.75, ps > .18).

Interaction: ToM Skills by Motoric Complexity

In order to follow-up on the error type by ToM score interaction in line with Experiment 1 and to better understand how individual differences contribute to different types of errors, we conducted separate regressions for each error type. As in Experiment 1, for each regression, transformed error proportion scores were entered as the dependent variable (in three separate regressions: *I Did It Simple, I Did It Complex, You Did It*), age was added as a predictor in the first step, and ToM score was added to the model as a predictor in the second step. Given that we found no main effect or interactions with condition, these analyses were collapsed across conditions (and thus identical to Experiment 1). Outcomes for all errors are consistent with Experiment 1.

That is, for *I Did It Simple* errors, the regression that only included age as a predictor provided the best fit (see Table 1). The model that included both age and ToM score did not significantly improve the model. Age was a significant predictor of errors, but ToM score was not. As age increased, proportion of *I Did It Simple* errors decreased. For *I Did It Complex* errors, the regression that only included age was significant (see Table 1). The model that added ToM scores as a predictor provided a better fit. Age and ToM score were both significant predictors of errors. Children with better ToM scores made fewer *I Did It Complex* errors and as age increased, *I Did It Complex* errors decreased. For *You Did It* errors, neither regression was significant (see Table 1). Neither age nor ToM scores were significant predictors of errors.

Discussion

We carried out Experiment 2 with two goals. The first goal was to provide a near replication of the findings from Experiment 1 with a new group of children. The second aim was to investigate whether modifying the collaborative context of the social interaction altered the effects seen in Experiment 1. With regards to our first aim, we found a robust replication of the effects from the first experiment. There was no evidence, however, of a modification of these findings based on collaborative context.

The replication of Experiment 1 is important for a variety of reasons. At a minimum, the replication of both group effects (i.e., *I Did It* errors > *You Did It* errors) and individual differences (nearly identical regressions across the two experiments) instils confidence in these novel findings during a time when replication is sorely needed in science (Chambers, 2019; Munafò et al., 2017). Additionally, the results replicated even when altering some design factors that we had no theoretical reason to believe would be related to the outcomes. In Experiment 2, we altered about half of the actions that were carried out by the experimenter versus the child. The fact that findings remained the same despite this change implies that the effects are not specific to particular actions carried out by the experimenter in Experiment 1. An even stronger replication would test a paradigm using a completely different set of actions (varying in motoric complexity) in a different laboratory. While we encourage this endeavor, it is beyond the scope of the current research.

At first glance, the lack of effect of collaborative context seems to contradict previous research indicating that the degree to which the interaction is social and collaborative alters the propensity to commit appropriation errors (Sommerville &

Hammond, 2007). Previous research finding an effect of collaborative context only tested 3- and 4-year-olds, so one possibility is that the modulation of appropriation errors based on collaborative context does not apply to the wider age range tested in the current experiment. An alternative to this possibility, however, is that the methodological approach taken in the current research played a role.

We note that the methodological differences between the high and low collaborative conditions in this experiment were relatively minor in order to provide strict experimental control. For example, although the experimenter and child each had their own set of toys and acted in their own space in the low collaborative condition, they were both playing on the same table and coordinated in time. Breaking up one's own set of tasks in order to watch the experimenter carry out her actions between each action step may have led the child to believe that they were playing a game together despite verbal cues contradicting this and acting on different objects. It is possible that this general shared spatial and temporal context provided a cue to the children that the task was shared. Potentially having the child carry out his or her set of actions all in one series before or after watching the experimenter carry out her set of actions would have better highlighted the independence of their tasks (as in Sommerville & Hammond, 2007). This, however, would have created a confound of attention and timing that would make it difficult to interpret any potential differences between conditions in the current research. Given these methodological constraints and the between-subjects nature of the design, it is difficult to know whether children perceived the high and low collaborative conditions as differentially social or collaborative. It therefore remains unclear whether the effects of ToM and motoric complexity on appropriation errors might still be modified by more or less social and collaborative contexts in more extreme contexts.

General Discussion

Together, the current research suggests that children commit appropriation errors across early childhood (3–8 years). The fact that, across both experiments, appropriation errors decreased across ages replicates and extends the findings of Foley et al. (1993), who found that appropriation errors were more common in 4-year-olds than 6- or 8-year-olds. The linear effect across a continuous (and wider) age range further extends this previous research. Additionally, Foley and colleagues were concerned that the age effect they found could be specific to the difficulty of the task they used. Given that we used a novel task and varied the actions carried out across our two experiments suggests that this effect of age on appropriation errors is robust across tasks. The fact that there was no age- by- error interaction means caution is warranted in the interpretation of this finding.

Importantly, the current research found an interaction between ToM skills and motoric complexity, even when controlling for age. Ford et al. (2011) previously found that ToM skills were inversely related to appropriation errors in 4- and 5-year-olds. The fact that ToM scores were only related to *I Did It Complex*, but not *I Did It Simple*, errors in our experiments implies that ToM skills are particularly important for ruling out a social partner's actions as one's own when the actions may be beyond one's own motor abilities.

In order to successfully identify the actions children could not perform themselves, children needed to recognize that their own motor capacities might differ from an adult's (because the adult always succeeded at performing even the motorically complex actions). Similarly, in order to succeed in ToM tasks, children need to recognize that their knowledge state might differ from someone else's. Although indirect evidence suggests that sensitivity to different knowledge states and physical affordances between self and other develops around the same developmental period as ToM is improving (e.g., Bennett-Pierre, Asaba, & Gweon, 2018; Bridgers, Altman, & Gweon, 2017; Kim, Paulus, Sodian, & Proust, 2016; Paulus & Moore, 2011), to our knowledge, no one has addressed whether ToM and perception of own motoric capacity interact. Our findings with regards to appropriation errors are the first to suggest an interplay between these factors.

If, as in previous research (Sommerville & Hammond, 2007), a higher proportion of appropriation errors relates to better learning about how to perform the observed actions, the current findings raise intriguing questions about how social- cognitive and motor-related factors might influence social learning. For example, the current findings might imply that children with less sophisticated ToM skills, who mistakenly claim motorically complex actions as their own, would show improved learning about the motorically complex observed actions relative to their peers with more advanced ToM skills. It seems unlikely that children could learn how to perform an action outside of their motor repertoire simply by mistakenly assuming they had performed it previously, but if true, it would be an important learning avenue. It would also raise questions about whether the benefits of appropriation errors decrease with improved social cognitive skills. An alternative explanation is that children with more sophisticated social cognitive skills still benefit from appropriation errors when observing actions they could perform on their own, suggesting that they have a refined capacity for social learning that is adapted for honing into observational learning at an achievable level. In contrast, children with less sophisticated social cognitive skills might waste energy and resources attempting to recreate actions they do not realize they cannot perform themselves. Future research should assess these different possibilities.

One limitation of the present research is that the assessments of motoric complexity were based on children of the same age participating in a separate experiment. Although we would like to know whether children are more or less likely to make *I Did It* errors for actions that vary in terms of their own, personal motoric capacities, and theoretical and practical issues prevented us from carrying out both the social interaction and motoric complexity ranking with the same children. Theoretical concerns were that if we had assessed children's motoric abilities prior to participation in the social interaction, interpretation of the Recall phase would be challenging because children would have, in fact, attempted all actions themselves in addition to watching some being carried out by an experimenter. Logistically, the time constraints of testing in a public setting did not allow us to assess children's motoric abilities after the first three phases. Our conclusions regarding motor complexity are thus based on group- level performance rather than individual motoric skill and it is likely that some of the complex actions were within the motor repertoire of the participating children.

Related to this issue, the interaction between ToM and motoric complexity would be easier to interpret if we knew whether children explicitly recognized actions as within or outside their motor repertoire. Because we could not ask children about whether or not they thought they could perform the actions, we can only assume that fewer errors for motorically complex actions in the high ToM children was due to the fact that they were less likely to take on actions as their own if they recognized them as outside their motor repertoire. Although alternative explanations for this effect are possible, this description is both parsimonious and in line with theoretical assumptions about ToM and the appropriation error (e.g., Ford et al., 2011). Future research is needed, however, to both replicate this effect and determine how these interacting social- cognitive and motor-related factors influence one another.

Conclusions

Overall, this research implies that children's memory for their own and others' actions continues to develop into middle childhood and provides direct evidence that children's ToM abilities and motoric abilities interact in their influence on these memories. It suggests a complex interaction among social interactions, social cognition, motor development, and memory across early childhood (see also Nelson & Fivush, 2004; Sommerville & Decety, 2006; Thelen & Smith, 1996; Tomasello, 2000). Children's increasing understanding of the self and others both play a role in decreasing appropriation errors. Future research is needed to unravel the role of each of these factors in learning from interactions with others. For example, when do social cognitive and motor-related factors facilitate versus inhibit learning from appropriation errors? Identifying the developmental dynamics that influence social memory is a first step in optimizing social learning for all children.

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