Journal of Experimental Child Psychology xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations

Ildikó Király [a,*], Gergely Csibra [b], György Gergely [b]

[a] Department of Cognitive Psychology, Eötvös Loránd University, Budapest H-1064, Hungary
[b] Department of Cognitive Science, Central European University, Budapest H-1051, Hungary

A R T I C L E I N F O

Article history:
Available online xxxx

Keywords:
Rational imitation
Relevance-guided imitation
Teleological stance
Natural pedagogy
Social Learning
Ostensive communication

A B S T R A C T

The principle of rationality has been invoked to explain that infants expect agents to perform the most efficient means action to attain a goal. It has also been demonstrated that infants take into account the efficiency of observed actions to achieve a goal outcome when deciding whether to reenact a specific behavior or not. It is puzzling, however, that they also tend to imitate an apparently suboptimal unfamiliar action even when they can bring about the same outcome more efficiently by applying a more rational action alternative available to them. We propose that this apparently paradoxical behavior is explained by infants' interpretation of action demonstrations as communicative manifestations of novel and culturally relevant means actions to be acquired, and we present empirical evidence supporting this proposal. In Experiment 1, we found that 14-month-olds reenacted novel arbitrary means actions only following a communicative demonstration. Experiment 2 showed that infants' inclination to reproduce communicatively manifested novel actions is restricted to behaviors they can construe as goal-directed instrumental acts. The study also provides evidence that infants' reenactment of the demonstrated novel actions reflects epistemic motives rather than purely social motives. We argue that ostensive communication enables infants to represent the teleological structure of novel actions even when the causal relations between means and end are cognitively opaque and apparently violate the efficiency expectation derived from the principle of rationality. This new account of imitative learning of novel means shows how the teleological stance and natural pedagogy—two separate cognitive adaptations to interpret

* Corresponding author.
E-mail address: kiralyi@caesar.elte.hu (I. Király).

0022-0965/$ - see front matter
http://dx.doi.org/10.1016/j.jecp.2012.12.003

instrumental versus communicative actions—are integrated as a system for learning socially constituted instrumental knowledge in humans.

Introduction

The principle of rationality as a fundamental factor governing action selection in knowledge-based systems was introduced by Newell (1982): "If an agent has knowledge that one of its actions will lead to one of its goals, then the agent will select that action" (p. 102). The rationality principle has also been proposed to be the central inferential principle in Gergely and Csibra's (2003) theory of human infants' teleological action interpretation mechanism. This core system is a cognitive adaptation to represent instrumental actions in terms of their teleo-functional properties. It implements human infants' naive theory of rational action in the domain of instrumental agency by representing actions as efficient means to bring about specific goal states in the world. The main tenets of the rationality principle are that (a) actions serve to bring about future goal states and (b) goal states are realized by the most efficient action available to the actor within the constraints of the situation (Gergely & Csibra, 2003). Teleological reasoning (just like mentalistic or practical reasoning about actions) relates three aspects of action interpretation—goals, actions, and situational constraints—in a systematic manner by the "rationality assumption": Given information about any two of the three elements, one can infer (and predict) what the third element ought to be (Csibra, Bíró, Koós, & Gergely, 2003).

Using violation of expectation and eye-tracking paradigms, ample evidence confirms that infants can make inferences about observed actions with the help of teleological reasoning (Gergely, Nadasdy, Csibra, & Bíró, 1995; see also Biro, Csibra, & Gergely, 2007; Biro, Verschoor, & Coenen, 2011; Csibra, 2007; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Csibra et al., 2003; Gredebäck & Melinder, 2010; Gredebäck & Melinder, 2011; Hernik & Southgate, 2012; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Sodian, Schoeppner, & Metz, 2004; Southgate & Csibra, 2009; Verschoor & Biro, 2012; Wagner & Carey, 2005; Woodward & Sommerville, 2000).

If infants expect other agents to act rationally by choosing to perform the most efficient means available to the goal, one would expect infants themselves to rely on the same principle of rationality to guide their own choices of instrumental actions as well. This prediction, however, was apparently contradicted by the results of Meltzoff's (1988) seminal imitation study, in which infants chose to reenact a model's unusual and subefficient head action to illuminate a light box instead of just using their hands to induce the same effect. Optimizing to "least effort," operating the light box by touching it with one's hand seems more efficient (and hence more rational) than bending forward from the waist to use one's forehead to achieve the same end. To address this puzzle, Gergely, Bekkering, and Király (2002) developed a modified version of Meltzoff's (1988) imitation paradigm to test whether efficiency evaluations could modify infants' action choice and production by introducing a new context condition in which the demonstrator's hands were occupied when she performed the unfamiliar head action to operate the touch lamp (*hands-occupied* condition). Whereas in the original *hands-free* condition 69% of infants reenacted the head action (replicating Meltzoff's results), the number of "imitators" dropped significantly to only 21% in the hands-occupied condition. Gergely and colleagues (2002) referred to this phenomenon of context-sensitive learning of novel means actions as "rational imitation." Since the original demonstration, the finding of selective rational imitation has been replicated several times and shown to generalize across a range of different task contexts with 12- and 14-month-olds (Buttelmann, Carpenter, Call, & Tomasello, 2008; Király, 2009a; Schwier, van Maanen, Carpenter, & Tomasello, 2006; Zmyj, Daum, & Aschersleben, 2009).

The explanation of context-sensitive and selective reenactment of novel actions in terms of rational imitation, however, has been challenged on several grounds. One alternative account developed by Paulus, Hunnius, Vissers, and Bekkering (2011a, 2011b) suggests that the phenomenon is attributable to the interaction between automatic motor resonance elicited by the observed actions and the limited motor capabilities of infants. Another contrasting view was proposed by Beisert, Zmyj, Liepelt, Jung, Prinz and Daum (2012), who considered the selectivity of infants' action imitations to differences in attentional factors that are assumed to be induced by the different levels of saliency of the head action when observed in the hands-free versus hands-occupied contexts. Finally, our current account also argues (on different grounds) that the original explanation of selective head touch imitation purely in terms of the application of the rationality principle fails to capture all of the relevant aspects of the phenomenon. Below we advance and empirically test a new proposal that combines teleological action understanding (Gergely & Csibra, 2003) with the theory of natural pedagogy (Csibra & Gergely, 2009; Gergely & Jacob, 2012) to provide a more satisfactory explanatory account of the nature of selective imitation and learning of communicatively demonstrated novel means actions (for an earlier formulation of this hypothesis, see Gergely & Csibra, 2005, 2006). Because the original demonstration of selective rational imitation and the different alternative accounts proposed have all concentrated on the head touch paradigm, we decided to use the very same task to test our new proposal as well in order to make a systematic comparison of the various theoretical accounts possible.

The original rational imitation explanation as presented by Gergely and colleagues (2002; see also Buttelmann et al., 2008) focused on infants' differential performance in the new hands-occupied condition and attributed the decreased likelihood of reenacting the unfamiliar head action to infants' evaluation of the rationality of the demonstrated act to bring about the goal given the context of the demonstrator's situational constraints. But why did the majority of infants reenact the novel head action in the hands-free condition? Here both the model's and infant's own hands were free, so infants could have (rationally) opted for emulating the goal by performing the more efficient "hand action" available to them to contact the light box rather than reenacting the awkward and clearly suboptimal nonrational head action.[1] And, as a matter of fact, they did so; all infants in Gergely and colleagues' (2002) study (see also Paulus et al., 2011b) performed at least one hand action to bring about the goal, and they typically chose to perform the hand action as their first response to operate the light box. Even more striking, and in spite of that, 69% of the infants in the hands-free condition went on to reenact the novel head action of the model.

The rational imitation proposal (Gergely et al., 2002; see also Buttelmann et al., 2008) suggests that the reproduction of this apparently nonrational action reflected infants' assessment of the novel act as manifesting some unknown reason that must justify the action as rational and so they reproduced the odd head action as a way of figuring (learning) what the agent's (rational) reason for his action might have been. The main problem with this proposal as it stands is that it essentially makes the idea of appealing to the rationality principle unfalsifiable; when infants did not reproduce the demonstrated action (in the hands-occupied condition), it was treated as evidence of the application of the rationality principle, and when they did reproduce it (in the hands-free condition), it was also interpreted as evidence for the operation of the same inferential principle (cf. Gergely & Jacob, 2012).

Our new approach to the selective imitation phenomenon attempts to explain not only why infants refrained from imitating the novel action when it seemed rational but also why they reproduced it when it was obviously not efficient. Our account relies on the theory of natural pedagogy (Csibra & Gergely, 2009, 2011). Gergely and Csibra (2005, 2006) argued that children's tendency to reproduce novel actions of others reflects the functioning of an adaptive learning system, which allows for the fast transfer of relevant knowledge between individuals. In this view, imitation of behavior does not itself serve a causal role per se in learning; nevertheless, the reenactment of the novel action does provide evidence that learning has taken place and about what infants have learned. According to natural pedagogy theory, ostensive communicative signals, such as eye contact and child-directed speech (Csibra, 2010), indicate to children that the information about to be communicated provides them with the opportunity to acquire some new and relevant knowledge. From this perspective, the results of Gergely and colleagues' (2002) modified head touch study can be reinterpreted as follows. When ostensive signals are presented to infants and the model produces her subsequent actions deliberately, children interpret the demonstrated action as a manifestation of a communicative intention of the model rather than as a merely instrumental action. The ostensively induced expectation that

[1] Note that in Meltzoff's (1988) study, in the no-modeling baseline condition there was no infant who used the head to light up the lamp. This result confirms that the head action is a rather unusual means to perform on the lamp (see also Zmyj et al., 2009, for similar results with a novel lamp setup).

informative new and relevant knowledge is about to be manifested would suggest that the subsequently demonstrated action is important to acquire regardless of the fact that it seems not to be the most efficient way to achieve its apparent goal, that is, regardless of the opacity of the model's choice of the demonstrated action to bring about the effect. This account is also supported by further empirical evidence indicating that infants (Brugger, Lariviere, Mumme, & Bushnell, 2007; Nielsen, 2006) and even adults (Wang, Newport, & Hamilton, 2010) show more imitation in the presence of ostensive communicative signals such as eye contact.

When proposing that action imitation in communicative contexts often reflects learning, we do not intend to suggest that this epistemic function is limited to learning about the physical world only. In fact, when children learn about the function and manner of use of novel artifacts, they learn not only about the causal dispositional properties of the physical object world but also about relevant and shared normative dispositional properties of the social world around them. (An obvious characteristic of many, but by no means all, cultures is the use of cutlery for eating, which is the socially accepted and sanctioned normative manner of consuming food even though eating with hands is clearly much easier and is universally preferred by children. Moreover, different cultures have developed a variety of culture-specific artifacts specialized for eating as well as opaque but normative manners of using them to satisfy the need to consume food). In fact, artifacts are cultural products serving a variety of functions whose demonstrated use may manifest shared social knowledge not only of hidden dispositional affordance properties of the artifact (and its kind) but also of social norms and conventional functions that their use may involve or serve (Rakoczy, Warneken, & Tomasello, 2008; Tomasello, 1999). Note that the ostensively induced "basic epistemic trust" (Gergely, Egyed, & Király, 2007) and the social motivation to acquire shared cultural knowledge (including social conventions, manners of use, and traditions) from communicative action manifestations result in infants' spontaneous propensity to acquire *cognitively opaque* forms of actions demonstrated to them. The epistemic motivation to learn about opaque but socially shared cultural norms and conventions can easily lead to "overimitation" (the general tendency evidenced by older children to faithfully reenact relevant as well as apparently irrelevant steps of demonstrated action sequences; see Lyons, Damrosch, Lin, Macris, & Keil, 2011; Lyons, Young, & Keil, 2007). For example, a recent study of Kenward (2012) shows that preschoolers imitate actions that they already discovered to be unnecessary to achieve an outcome because they conceive them as norms.

But how do children know which elements of a demonstrated action sequence constitute instrumental and/or social norms to be acquired? We propose that communicative demonstrations elicit the presumption of relevance in their addressee (cf. Sperber & Wilson, 1986). When the model deliberately produces her instrumental actions while engaging in ostensive communication with infants despite the fact that her action is causally opaque (i.e., seemingly not the most efficient way to achieve the goal state), her demonstration activates the presumption of relevance in infant learners. This presumption guides the interpretation of the demonstration by searching for a communicative content that appears to be in some way relevant to recipients. If the action involves a novel artifact, the most relevant information for novice learners is (a) its function and (b) its mode of usage as dictated by instrumental or social norms. It is important to note that because of the opaque nature of much cultural knowledge in human societies (Gergely & Csibra, 2006), naive learners cannot expect to derive "b" from "a" by applying the rationality principle, but the principle can still be employed to disregard action elements of the observed demonstration that are justifiable by situation-specific physical constraints.

Thus, we propose the following reinterpretation of the selective imitation phenomenon demonstrated by Gergely and colleagues' (2002). Because of the ostensive signals that accompany the action demonstration, infants construe it as a communicative action rather than a purely instrumental action (Gergely & Jacob, 2012; Southgate, Chevallier, & Csibra, 2009). The fact that the action is performed on a novel artifact and produces a salient effect will suggest to infants that the relevant information to be acquired is the function and usage of the artifact. In the hands-occupied condition, they learn a final goal state (artifact function: the lamp is illuminated) and a subgoal (usage: the lamp is operated by contact) that brings about the final goal. The relation between these two goals is arbitrary because infants have no way to assess the causal mechanisms by which the subgoal produces the final goal. Infants then learn this arbitrary relation as the informative content communicated by the action manifestation. In the hands-occupied context, there is nothing more to explain about (or learn from) the demonstration because the model (in accordance with the rationality principle) performs the most efficient action available to her to produce the subgoal (to achieve the lamp being contacted). Therefore, infants who observed the head touch in the hands-occupied condition and acquired the subgoal to achieve direct contact with the lamp will touch the lamp with their hands because this is the most efficient action available to them to bring about the subgoal. In the hands-free condition, however, the rationality principle would be violated by the demonstrated head touch action if its goal state were assumed to be the same subgoal (i.e., to make contact with the lamp) performed in order to light up the lamp (the final goal). This would leave the agent's choice of performing the suboptimal head touch action as the means action unaccounted for. Thus, the observed action is reanalyzed at a finer level by the introduction of an additional finer grained arbitrary means–end relation, namely, the normative further subgoal specifying that the subgoal of contacting the lamp should be achieved by the use of the head. This second arbitrary relation is then added to the inferred informative content of the communicative demonstration, that is, to the manifested relevant new knowledge to be acquired. Therefore, when infants have an opportunity to operate the artifact in the hands-free context condition, they retrieve not one but two subgoals that they acquired and reproduce *both* of them by emulation (through the use of the most appropriate motor actions available to them). Thus, insofar as both arbitrary means–end relations are stored in and reactivated from their memory, infants will use their hands to efficiently realize the first subgoal (i.e., making contact with the lamp) but will also reenact the head action to efficiently bring about the second, more fine-grained subgoal (i.e., to realize making contact with the lamp by using the head).

The current experiments tested predictions derived from this proposal. In Experiment 1, we investigated whether social–communicative signals are necessary to elicit the reenactment of a teleologically unjustified action. If the account described above is correct, observation of a noncommunicative action should not induce the presumption of relevance and the acquisition of arbitrary means actions. Experiment 2 tested whether information about the overall goal state (i.e., the function of the novel artifact) is necessary to be present in the demonstration, as our proposal hypothesized, and whether the function of the learning is primarily epistemic or social.

Experiment 1

Although various alternative theories have been advanced to account for the underlying mechanisms driving imitative learning, apart from the current approach, none of them proposes that the communicative context of action demonstration plays a qualitative role in inducing selective imitation of novel means in different action contexts. One alternative account proposes that infants' observation of an action with a salient effect makes infants interpret it as a goal-directed action, and infants are motivated to imitate goals (Bekkering, Wohlschläger, & Gattis, 2000; Carpenter, Call, & Tomasello, 2005). Another approach suggests that imitation occurs as a consequence of motor resonance of previously encoded action–effect associations that are activated by the observed actions (Paulus et al., 2011a; Paulus et al., 2011b). Yet another alternative proposes that action imitation is modulated by the differential amount of attention evoked by the variable saliency of the target action performed in different contexts (Beisert et al., 2012). None of these alternatives, however, predicts a differential pattern of action imitation as a function of whether the target action is communicatively demonstrated to infants or is simply observed from a third-person perspective without communication. In contrast, if reenactment depends on the interpretation of the observed action, which in turn is modulated by ostensive communicative signals (Southgate et al., 2009), selective imitation is expected only in communicative contexts. Experiment 1 contrasted these alternative hypotheses by repeating Gergely and colleagues' (2002) study both in a communicative context (as in the original version) and in a noncommunicative third-person observation situation.

Method

Design

We investigated the effect of two independent variables on infants' tendency to imitate. The first independent variable was whether the model's action was observed when presented communicatively

Please cite this article in press as: Király, I., et al. Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations. *Journal of Experimental Child Psychology* (2013), http://dx.doi.org/10.1016/j.jecp.2012.12.003

to infants (Communicative context) or from a third-person observational perspective when it was intentionally performed in a noncommunicative context (Incidental Observation context). The second independent variable was the mode of presentation of the target action (Hands Free vs. Hands Occupied), as in Gergely and colleagues' (2002) study. These two factors were crossed in a factorial design, creating four groups of participants.

Participants

A total of 75 14-month-old infants were recruited through advertisements in local newspapers. Of these infants, 6 were excluded from the final sample because of technical error ($n = 2$), parental interference ($n = 1$), or fussiness ($n = 3$). The remaining 69 children were randomly assigned to one of the four conditions. Mean age, sex distribution, and number of infants in each condition are presented in Table 1.

Apparatus

The tool on which the target action was modeled for infants was a small, circular, translucent "magic lamp" mounted on a box ($27 \times 19 \times 4.5$ cm). The lamp reacted to a gentle push by lighting up and remained illuminated until it was released. The lamp was placed on a small table in between the model and infants during the modeling phase and was presented to infants at the same location during the test phase. The sessions were monitored and videotaped from behind a one-way mirror.

Procedure

The procedure was composed of a modeling phase and a test phase.

Modeling phase: Communicative context. The infant was seated on the parent's lap in front of the table with the magic lamp, covered with a cloth. The distance from the table was approximately 1 m, which prevented them from reaching the apparatus. The mother was instructed not to interact with the infant during the modeling phase. The experimenter sat down at the other side of the table, uncovered the magic lamp, looked at the infant, and called the child's name, making sure that the infant paid attention. Then she shuddered and told another experimenter who was present in the laboratory that she was cold and asked for a blanket. After the blanket was handed to her, she wrapped it around her shoulders. In the Hands Free condition, she left the blanket hanging on her shoulders. She then placed her visibly free hands on the table on either side of the magic lamp. In the Hands Occupied condition, she wrapped the blanket around her shoulders and held it tightly with both hands. In both conditions, the model then bent forward from the waist and lit up the lamp by touching it with her forehead. She

Table 1
Descriptive statistics, looking times to the model, and the proportion of imitators in each condition.

Experiment/condition	N	Mean age (weeks)	Sex distribution (male/female)	Looking time to the model (s) [SD]	Infants performing the head action (successful goal attainment)	
					N	Percent
Experiment 1						
Communicative						
Hands Free	17	60.94	7/10	32.0 (4.9)	11 (8)	64.7
Hands Occupied	17	61.02	8/9	36.3 (5.5)	4 (3)	23.5
Incidental Observation						
Hands Free	17	60.53	5/12	35.6 (4.9)	5 (3)	29.4
Hands Occupied	18	61.20	8/10	33.2 (4.5)	8 (5)	44.4
Experiment 2						
No Effect	14	61.41	8/8	31.0 (4.6)	1 (0)	7.1
Model Present	13	61.20	7/6	34.6 (5.4)	9 (5)	69.2
Model Absent	18	60.07	9/9	33.5 (5.5)	9 (6)	50.0

Please cite this article in press as: Király, I., et al. Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations. *Journal of Experimental Child Psychology* (2013), http://dx.doi.org/10.1016/j.jecp.2012.12.003

repeated this action three times, making eye contact with the infant in between these actions and getting the infant's attention if necessary.

Modeling phase: Incidental Observation context. In this context, the experimenter did not interact with the infant. The child and the parent were seated in a restricted playing area of the laboratory by Experimenter A, and the parent was instructed to play with the child. The restricted playing area was a blanket spread on the floor, and the parent was asked to keep the infant there. From this playing zone, the child could clearly see the table where the modeling would take place, which was approximately 2 m away. After a short delay, Experimenter B (the model) entered the room and went straight to the table without looking at or speaking to the infant. She uncovered the magic lamp and rang a buzzer to get the infant's attention. The mother was asked not to look at the model except when the infant was pointing to her. When the infant paid attention to the model, a confederate from behind a one-way mirror indicated to the model that she could perform the target action by switching on a hidden light-emitting diode (LED). Experimenter B then wrapped the blanket around her shoulders, leaving her hands free or occupied (depending on the condition), and then modeled the target action three times. The hidden LED alerted the model when the infant was watching her without needing to look at the child. If needed, the model operated the buzzer again to get the infant's attention. After performing the target action three times, the model covered the magic lamp and left the room without looking at the infant.

Test phase. The test phase followed the modeling phase by 10 min, which the child spent outside the laboratory. In the Communicative context, the model led the child and the parent to the apparatus, encouraged the infant to play with it, and stayed in the room. In the Incidental Observation context, Experimenter A (not the model) seated the child next to the apparatus, encouraged the infant to play with it, and then left the room.

Data analysis and scoring

The video records of the test phase were scored by two independent observers who were uninformed as to the conditions in which children participated. The dependent measure was whether infants attempted to perform the head-on-box action within a 20-s time window. An attempt was defined as either touching the lamp with the head or leaning forward in such a way that an infant's head approached the lamp within 10 cm or less (see Meltzoff, 1988). The two coders' evaluation of infants' performance was in 100% agreement.

Results

The overall time spent looking at the demonstration was measured to check whether infants attended to the demonstrator during the modeling phase equally in each condition. The mean looking times are presented in Table 1. An analysis of variance (ANOVA) found no significant difference among the four conditions in the time spent looking at the demonstrator, $F(3,65) = 2.476$, $p = .069$.

The number of infants imitating the target action is presented in Table 1. An overall analysis of the proportion of imitators was performed by a generalized linear model (i.e., a general logistic model for binary variables) along 2 (Presentation Condition: Hands Occupied vs. Hands Free) × 2 (Context: Communicative vs. Incidental Observation) factors. This analysis yielded no main effect of presentation condition (Wald $\chi^2 = 1.354$, $df = 1$, *ns*), and there was no effect of context either (Wald $\chi^2 = 4.564$, $df = 1$, *ns*). However, the Presentation Condition × Context interaction was significant (Wald $\chi^2 = 6.326$, $df = 1$, $p = .012$).

To explore this interaction, we performed separate Fisher exact tests in the two contexts. In the Communicative context, modeling the action in the Hands Free condition produced more imitation than in the Hands Occupied condition (Fisher's exact $p = .018$). No such effect was found in the Incidental Observation context (Fisher's exact $p = .489$).

In addition, we performed a follow-up analysis to check whether the reproduction of the novel head touch action occurred as a result of more attention to the demonstration. We compared the overall looking time at the model during the modeling phase between infants who were "imitators" and

Please cite this article in press as: Király, I., et al. Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations. *Journal of Experimental Child Psychology* (2013), http://dx.doi.org/10.1016/j.jecp.2012.12.003

those who were "nonimitators" during the test phase. We found that there was no significant difference between the looking times of these groups (imitators: $M = 34.42$ s, $SD = 4.91$; nonimitators: $M = 34.12$ s, $SD = 5.60$), $t(66) = 0.219$, $p = .827$. A closer look at the sequence of actions performed by infants revealed that, without exception, all of them used their hands first to attain the final goal of lighting up the lamp. This was true for both the Communicative and Incidental Observation contexts and for both the Hands Free and Hands Occupied presentation conditions.

Because the variability of the particular manner of reenactment of the head touch actions reflects the degree of fidelity of imitative motor responses, and hence can be indicative of the underlying mechanism that mediates social learning, the specific forms of head touches were also coded in this sample. Interestingly, 10 of 28 imitators (36%) performed two or even three different forms of head actions during the testing session. Only 3 infants (11%) produced a faithful motor copy of touching the lamp with the forehead, although 2 of them also used other parts of their head to light up the lamp (contacting it with an ear or with the face). Looking at the first instances of head touches only, there were only 3 high-fidelity imitative responses (touches with the forehead), 10 touches with the mouth (4 of them followed by other forms of head touches), 4 touches with the nose, and 3 contacts with one of the cheeks, and in 8 cases only the head approached the lamp box within 10 cm (without contacting it). This variability of the head contact actions revealed that the reenactment of head touches showed low fidelity when compared with the model's demonstrated forehead action.

We also tested the empirical validity of the assumption that the head touch action is a suboptimal means for infants to bring about the final goal. We counted the number of head touches that were successful in lighting up the lamp (see Table 1); overall, 67,8% of infants who reenacted the target act managed to attain the goal by this means, whereas goal attainment through the hand actions was always successful (100%). This clearly indicates that the novel head touch was a more awkward and less efficient means action for infants to perform than to touch the lamp by the familiar hand action.

Discussion

Our results in the Communicative context replicated the original findings of Gergely and colleagues (2002) and, thus, strengthen the interpretation that infants can adapt their reenactment behavior to the justifiability of the goal-directed actions performed by a model (see also Buttelmann et al., 2008; Király, 2009a; Schwier et al., 2006; Zmyj et al., 2009). Importantly, infants in the Hands Occupied condition did not reenact the observed means action. Rather, they achieved the same final goal by the most efficient action available to them, that is, their hands.

Our findings also show that selective imitation of the head action, and thus the reenactment of a cognitively opaque and arbitrary means, appeared only in the Communicative context. Infants in the Incidental Observation context did not perform more head touches in the Hands Free condition than in the Hands Occupied condition. Our procedure ensured that they had equal visual access to the head touch actions as infants in the Communicative context, and our measure of their looking time at the demonstrator's actions confirmed that they attended to the target actions equally in both conditions. The results demonstrate that infants learned about the affordance properties of the novel object in both conditions (as shown by their equal success in illuminating the lamp). However, there is no evidence to suggest that in the Incidental Observation context infants also acquired the obviously arbitrary head touch means action that the model chose to operate the lamp.

Furthermore, infants' selective low-fidelity reenactment seems to reflect a hierarchically organized goal-emulative strategy. In fact, the results suggest that infants inferred that the relevant information that the model's communicative demonstration intended to manifest for them in the Hands Free condition consisted of two goals that are hierarchically organized. The final goal is to bring about an interesting effect (illuminate the box by exploiting its affordance properties), and the relevant subgoal is the means by which the effect should be brought about (contact the box with the head). Thus, the differential pattern of reenactment of the exact same motor behavior observed in the Communicative versus Incidental Observation context raises doubts about the resonance-based automatic motor copying account of imitative learning (Paulus et al., 2011b). These findings also seem hard to account for in terms of the assumed differential salience of the head action in the Hands Free versus Hands

Please cite this article in press as: Király, I., et al. Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations. *Journal of Experimental Child Psychology* (2013), http://dx.doi.org/10.1016/j.jecp.2012.12.003

Occupied conditions (Beisert et al., 2012) because the very same action contexts were tested in both the Communicative and Incidental Observation conditions.

Note also that even in the condition where the head action was reliably reproduced, infants' reenactments remained relatively low fidelity. The model demonstrated touching the lamp with her forehead, which infants reproduced by contacting the lamp with virtually any parts of their heads. This suggests that infants encoded the intended subgoal at a relatively abstract level (establish contact between the lamp and the head) and emulated that subgoal nonimitatively by producing a variety of alternative head actions (Csibra, 2007). This variability of low-fidelity renditions of the demonstrated head touch action is also hard to account for in terms of the direct matching-induced motor resonance approach to imitation (Paulus et al., 2011b).

Experiment 2

The results of Experiment 1 are consistent with the proposal that infants learn the head touch action as a means to achieve the final goal, but they do not constitute a proof of this assumption. Our proposal is that infants use the interpretive scheme of the teleological stance (Gergely & Csibra, 2003) to infer the related elements of an ongoing action sequence and organize them around the attainable goal state. To test this hypothesis, in Experiment 2 we violated the availability of well-formed goal state information in the modeling situation by presenting the head action so that it did not induce a perceivable effect. If the minimal interpretability of an overall goal serves as an anchor for learning (and potentially for generalization), and for hierarchically relating a subgoal to it, infants should not be able to interpret the behavior as an instrumental action without supporting information about its goal and no acquisition of the novel behavior is expected.

Another question concerns the motivation behind infants' acquisition of arbitrary means actions. In Experiment 1, we covaried the presence or absence of communicative signals during the modeling phase with the presence or absence of the experimenter during the test phase. Thus, it is possible that the differential tendency to reproduce the novel means action in the two contexts was attributable to the presence of the model during test rather than to her communication signals during demonstration. Indeed, it has been proposed that imitation serves a social function by letting infants express their affiliation to others (Nielsen & Blank, 2011; Over & Carpenter, 2012). If this is the case, infants may reenact the newly acquired means action not because they have learned a novel behavior with instrumental value but rather to demonstrate to the model that they have acquired it. We attempted to address this issue by varying the experimental setup of the test phase as follows. In one condition the model who had demonstrated the target behavior was present during testing, and in the other condition no model or communicative partner was present during testing, only the infant‘s parent. Crucially, the novel action was demonstrated in an ostensive manner in both conditions.

Method

Design

There were three experimental conditions: Model Present, Model Absent, and No Effect. In all three conditions, the head action was demonstrated to infants in the Hands Free version and in a communicative manner.

Participants

A total of 50 14-month-olds were recruited through advertisements in local newspapers. Of these infants, 5 were excluded from the final sample because of technical error ($n = 1$), parental interference ($n = 1$), or failure to come back for the test phase of the study ($n = 3$). The remaining 45 children were assigned to one of the three conditions. Mean age, sex distribution, and number of infants in each condition are presented in Table 1.

Apparatus

The same apparatus was used as in Experiment 1

Please cite this article in press as: Király, I., et al. Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations. *Journal of Experimental Child Psychology* (2013), http://dx.doi.org/10.1016/j.jecp.2012.12.003

Procedure

In the Model Present and Model Absent conditions, infants were brought to the laboratory twice, with a 1-week delay in between. The first session consisted of the modeling phase, and the second session (1 week later) was the test phase of the study. In the No Effect condition, a short (10-min) delay was used, as in Experiment 1.

Our rationale to introduce these different delay intervals was motivated by several considerations. First, we wanted to present empirical proof for the claim that the same effect of selective learning that has been demonstrated following a shorter (10-min) delay can be similarly induced after a long (1-week) delay as well. Second, a central purpose of Experiment 2 was to disentangle whether it is the epistemic function or the social-affiliative function of imitation that is the dominant determinant of infants' performance in this particular task. To compare the relative contribution of the epistemic motive (as tested by the Model Absent condition) versus the social-affiliative motive (and/or the effect on recall of the presence of the demonstrator as an additional mnemonic cue, as tested by the Model Present condition), we used the same delay interval in both conditions. Note that if imitation serves primarily the epistemic function of learning, using the longer (1-week) delay would not be expected to influence the pattern of action reenactment, whereas if one assumes the primacy of the social-affiliative function, infants' imitative performance would be more likely to be reduced after a long delay due to the possible decrease in salience of the memory of the experimenter with whom infants were interacting during the demonstration phase. For this reason, we chose to use the longer (1-week) delay to compare the Model Present and Model Absent conditions.

On the other hand, the No Effect condition was designed with the primary purpose to test whether the selective reenactment of the head action induced in the communicative demonstration condition of Experiment 1 was constrained by the interpretability of the head touch as a goal-directed instrumental action or whether it was determined solely by the facilitative influence of the ostensive demonstration context to induce imitative behavior. This required that we test for the relative degree of imitation of the two types of actions by using the same delay interval in the No Effect condition as the one we used for testing the imitation of the head action *with* an observable effect in Experiment 1, so we employed the same (10-min) delay in the No Effect condition of Experiment 2 as well.

Modeling phase: Model Present and Model Absent. This phase was identical to the modeling phase of the Hands Free condition in the Communicative context of Experiment 1.

Modeling phase: No Effect condition. The demonstration was identical to the Hands Free condition in the Communicative context of Experiment 1 with the exception that, when the model bent forward, she stopped short of touching the lamp by approximately 2 cm and did not light it up. This action was repeated three times and was accompanied by the usual communicative signals.

Test phase: Model Present condition. The infant again was seated on the parent's lap in front of the table with the uncovered magic lamp, but this time at a distance that allowed the child to reach it. The model who had demonstrated the head touch action 1 week earlier sat on the other side and encouraged the infant to play with the apparatus without giving explicit instructions.

Test phase: Model Absent condition. The infant had the opportunity to play with the props in the presence of his or her parent only. The mother was asked to refrain from giving any direct instruction with respect to the modeling phase.

Test phase: No Effect condition. The model who demonstrated the head touch action 10 min earlier sat on the other side of the table and encouraged the infant to play with the apparatus without giving explicit instruction.

Data analysis and scoring

The same procedure was used to analyze the recording as in Experiment 1. Only 2 infants' performance was evaluated differently by the coders, and these cases were resolved by repeated scoring until agreement was reached.

Please cite this article in press as: Király, I., et al. Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations. *Journal of Experimental Child Psychology* (2013), http://dx.doi.org/10.1016/j.jecp.2012.12.003

Results

The overall time spent looking at the demonstration by infants is presented in Table 1. An ANOVA revealed that there was no significant difference among the three conditions in this measure, $F(2,42) = 1.726$, $p = .190$.

Number and proportion of infants who performed the target action are presented in Table 1. We compared the performance in the three conditions with each other in a chi-square test and found that they were significantly different from each other, $\chi^2(2) = 11.396$, $df = 2$, $p = .003$. We also compared the performance in the three conditions pairwise; the frequency of target actions did not differ significantly between the Model Present and Model Absent conditions (Fisher's exact $p = .462$), whereas the frequency of target action was lower in the No Effect condition than in the Model Present and Model Absent conditions (Fisher's exact *p*s = .001 and .019, respectively).

We also compared children's performance in the No Effect condition to that in the Hands Free condition presented in the Communicative context (Experiment 1) to check the potential impact of difference in delay on imitative tendencies. Here again the frequency of target action was lower in the No Effect condition than in the Hands Free condition presented in the Communicative context (Fisher's exact $p = .002$).

To directly test whether changing the delay from 10 min to 1 week had any effect on imitative reenactment tendencies, we also compared children's performance in the Model Present condition of Experiment 2 with that in the Communicative context–Hands Free condition of Experiment 1. There was no significant difference between the reenactment of target behavior in the above conditions (Fisher's exact $p = 1.000$), suggesting that learning of the opaque head action was not influenced by the different length of delays in the two experiments.

Discussion

Our findings suggest that although ostensive communicative signals are important, by themselves they are not sufficient to trigger action imitation. When the communicatively demonstrated head action was observed without a consequent visible effect being brought about, infants ceased to reenact the model's head action. This is consistent with the proposal that infants attempt to organize their interpretation of the demonstrated behavior into a hierarchical teleological structure of an instrumental goal-directed action that is anchored by the artifact function. This result is in line with the empirical findings of Paulus and colleagues (2011a), who found that the modeled action must be followed by a salient action effect in order to be imitated. Paulus and colleagues argued that the activation of the infants' own motor response can be linked to the representation of the action effect only if the latter is salient, and when this happens an association is automatically established between the activated motor program and the object producing the salient effect. However, the results of Experiment 1 are incompatible with this account because they provide no evidence that such an automatic association has been formed in the Incidental Observation condition. We believe that the role of the action effect is more likely to be that of specifying the relevant information about the function of the artifact (the final goal that can be achieved with it), which can provide an anchor that the further elements of the communicatively demonstrated action can be related to as subgoals.

Our findings are in accordance with the results of Lyons and colleagues (2007, Experiment 2B), who found that 4-year-olds do not overimitate demonstrated actions in which the contact principle was violated. The authors interpreted this finding as supporting their hypothesis that core assumptions of naive physics need to be satisfied to bring into play an automatic causal interpretation of the behavior as an instrumental act for the sake of learning (Lyons et al., 2007).

Furthermore, we found that infants tend to use a novel means action as a subgoal to attain a final goal both when the model who had demonstrated the behavior to them was present and when she was absent during the reenactment phase. This finding lends support to the claim that although it is crucial for infants to receive the novel information to be learned from a communicative partner, the subsequent reenactment of the acquired means action can be elicited without social cueing. This supports the view that the acquisition of the novel action was driven by an epistemic motive; the equal likelihood of its reenactment even in the absence of a social partner reflects the fact that the action has been learned as a culturally relevant novel instrumental means that ought to be used to operate the novel artifact. This result also confirms that the absence of head touch reproduction in the Incidental Observation context of Experiment 1 was not due to the absence of the model during the test phase.

At the same time, finding no significant difference between the proportion of reenactment of the novel means act in the Model Present versus Model Absent testing conditions seems unexpected at first glance given the results of Király (2009a), who, using a different task, found that when tested in the presence of the model, infants were more likely to attempt to reenact a previously demonstrated, rather complex tool use procedure to attain a goal (93% attempted tool use) than when they were tested without the demonstrator's presence (65% attempted tool use). This discrepancy, however, is plausibly attributable to factors stemming from the significantly higher difficulty for infants to perform the complex tool use action demonstrated in Király's (2009a) study (practically none of the imitators succeeded in achieving the goal by their attempted reproduction of the novel tool use) than to perform the head touch action in the current paradigm (67.8% of imitators were successful in lighting up the lamp through reproducing the novel head touch action). In our view, the increased proportion of imitative attempts to reenact the novel tool use in the presence of the demonstrator can also be plausibly attributed to infants' epistemic motive to learn relevant and new information from the communicative demonstrator.

Recently, Nielsen and Blank (2011) reported a study in which children showed an increased likelihood of imitating previously observed opaque and arbitrary parts of an action sequence to achieve a goal when tested in their demonstrator's presence as compared with the presence of another model who had demonstrated to them a more efficient—and simpler—version of the goal approach that did not include the unnecessary target actions in question. The 4-year-old participants in that study produced irrelevant actions at a significantly *lower rate* when given the apparatus by the efficient adult demonstrator than when the apparatus was handed over to them by the adult who had demonstrated the irrelevant actions to them in the first place. We accept the authors' interpretation that this finding demonstrates that social affiliative motives can indeed influence and increase imitation of others, at least in 4-year-olds. However, it should be noted that the results also provide positive evidence for the influence of the epistemic motive underlying children's imitation of the demonstrated opaque means actions; after all, they did reenact the demonstrated irrelevant actions *even when* interacting with the efficient demonstrator, although they admittedly (and quite understandably) did so with lower frequency than when tested by the inefficient model.

These findings, together with the current results, suggest that although the presence of a social model can in some circumstances increase the rate of imitation, it is not a necessary condition for the learning and imitative reenactment of novel means actions from communicative demonstrations by others.

General discussion

We have offered a reinterpretation of the phenomenon known as rational imitation in the literature and tested predictions drawn from this interpretation in two experiments. Under our proposal, the mechanism behind this phenomenon is not imitation (in the sense of motor copying actions), nor does it reflect the application of the principle of rationality (in the sense of optimal instrumental action selection). Rather, our account explains this phenomenon as an interplay among (a) specific forms of human communication, (b) the learning of hierarchical teleological structures of artifact function and use, and (c) emulative manifestation of acquired knowledge. The results of the experiments presented in this article confirmed the predictions drawn from this account.

Ostensive communication has been proposed to induce expectation of the opportunity to acquire new and relevant knowledge from the source of communication in human children (Csibra & Gergely, 2009). We believe that many earlier studies that ostensibly investigated the mechanisms of imitation actually studied how children interpret communicative action demonstrations. So far, not many experiments have contrasted communicative versus noncommunicative demonstrations, but the ones that have done so found different patterns of imitation in these conditions (Brugger et al., 2007;

Nielsen, 2006; Southgate et al., 2009). Our results confirm these findings. However, unlike Nielsen (2006) and Brugger and colleagues (2007), who emphasized the role of the "social" nature of demonstrations in general, the proposal we defend points to the role of *child-directed communication* as the crucial factor influencing reenactment and learning of novel skills and means actions demonstrated. Because human social interaction is normally communicative in nature, these two kinds of account predict action reproduction in similar situations. However, the absence of reenactment in the absence of obvious artifact function and the undiminished tendency to reproduce a novel means action in the absence of a social partner in Experiment 2 are more consistent with the primarily epistemic than social function of observational action learning.

Our results also speak against proposals that (a) consider only the motor aspects of action demonstrations in explaining imitative behaviors (Paulus et al., 2011a; Paulus et al., 2011b) and (b) try to interpret the findings of the original head touch study in terms of varying attentional distractiveness of the different modes of presentation (Beisert et al., 2012) because both the motor components and the relative salience and distractiveness of the demonstrations were similar across contexts and conditions in Experiment 1.

We have proposed that when children observe an object-directed instrumental action in the context of ostensive communication, they interpret the action in a different manner. If the manifested new behavior is a goal-directed action resulting in a well-defined outcome state (effecting a change of state in the world), infants try to interpret it in terms of their teleological representational schema, but they "suspend" the rationality requirement that the action needs to be the most efficient means available in the situation (cf. Gergely & Jacob, 2012). They do so because they expect relevant information (Sperber & Wilson, 1986), and one way that the content of the communication could be relevant for them is if it reveals arbitrary means–end relations about the novel artifact that infants could not have discovered on their own (lacking relevant causal knowledge). Thus, when children observe, in a communicative context, a goal-directed action that cannot be justified by invoking the principle of rationality, they interpret it as an arbitrary subgoal to be fulfilled in the service of attaining the final goal. Indeed, when children have already acquired means–end knowledge about an artifact (which, therefore, is no longer novel), they do not learn a nonefficient means action performed on it even in an ostensive communicative context (Pinkham & Jaswal, 2011). Similarly, they do not learn such an action when it is not addressed to them (i.e., in an Incidental Observation context) because this action does not carry much expected relevance for them.

It is important to emphasize that communication does not make infants learn just any arbitrary action. As Experiment 2 demonstrated, children must be able to assign to the action a well-formed teleological interpretation (Gergely & Csibra, 2003) in order to acquire it. Although the action may be arbitrary, it is not an arbitrary goal in itself but rather an arbitrary *means* toward some final goal. If some observations (e.g., turning on a light by a head action when hands are available) do not fit in this model, the explanatory attempt fails. However, the ostensive communicative context induces a search for a finer grained action explanation that extends the hierarchical representation of the teleological schema by sanctioning the inclusion of a more specific subgoal.[2]

Finally, when infants are given the opportunity to handle the novel artifact, they retrieve this hierarchical representation and perform actions that reproduce the goals and subgoals stored in their memory. Such a process is essentially a kind of emulation driven by the motivation to achieve and learn (sub)goals rather than to reenact actions (cf. Csibra, 2007; on the notion of goal-directed imitation, see Bekkering et al., 2000; Carpenter et al., 2005). This is consistent with the claim that in other contexts, imitative action reproduction may serve social functions (Over & Carpenter, 2012), and it is also possible that the primacy of social-affiliative function of imitation emerges later in development (see Nielsen & Blank, 2011).

We are aware of the potential limitations of the fact that our theoretical proposals are based on studies with infants of a limited age range and from the detailed examination of the conditions inducing selective imitation, which, however, relies predominantly on using one specific task only—the

[2] For a recent logical formalization of the action interpretation mechanism that children employ, see Varga and van Lambalgen's (2011) model, which conceptualizes this system as a "closed world" reasoning process that involves both action interpretation and action planning.

head touch paradigm. Although this fact represents a challenge for the generalizability of our findings, there is increasing new evidence indicating that the phenomena we have uncovered can be successfully demonstrated and further investigated by using a variety of other tasks as well (see Brugger et al., 2007; Schwier et al., 2006; Southgate et al., 2009). As an example, Nielsen (2006) found that 12-month-olds copied a specific novel tool use when its relevance for goal attainment was made explicit to them by providing negative evidence about the applicability of the alternative prepotent action available in their motor repertoire. However, when no such additional evidence was made accessible to them and the tool use was demonstrated in isolation, they did not learn and imitate the novel means action. Such results underline the need for further research to explore and better understand the effects of demonstrating different types of target actions and their informative contribution in modulating infants' reenactment tendencies in different contexts. Furthermore, some recent imitation studies with 2- and 3-year-olds now clearly indicate that selective imitation is not an isolated and transient developmental phenomenon that is restricted only to an early phase of infant cognitive development and social learning (e.g., Király, 2009b; Williamson, Meltzoff, & Markman, 2008). Such results make us confident that future research using a larger variety of task domains as well as a wider range of age groups will lead us to a fuller understanding and appreciation of the central role that ostensive communication and demonstrative manifestations play in making the efficient cultural transmission and stabilization of relevant and shared cultural knowledge, even if cognitively opaque, possible in human social groups.

Indeed, our reinterpretation of action reproduction in communicative contexts explains a host of findings in the literature but raises a question about the ultimate purpose of this learning process. Why do infants and children learn nonefficient instrumental actions from communicative demonstrations when they could discover such actions themselves and may even find more efficient means to the same goals (Pinkham & Jaswal, 2011)? We think that the answer to this question lies in the inherent opacity of culturally accumulated means–end knowledge, which is often embodied in human artifacts (Gergely & Csibra, 2006). Such knowledge is difficult to acquire by individual learning or by observational social learning, but benevolent adults could facilitate such learning by communicatively demonstrating it to children.

Together with other findings, our results show that infants do expect to learn from child-directed communication. If they do so, they are rational in the evolutionary sense; they learn more efficiently than they would without relying on adults' communication. Nevertheless, as the current results attest, the mechanisms of such learning cannot be explained solely by reliance on the principle of rationality of instrumental actions alone (cf. Gergely & Jacob, 2012).

Acknowledgments

This research was partly funded by an Advanced Research Grant from the European Research Council (OSTREFCOM). The European Union and the European Social Fund provided financial support to the project under the Grant agreement (TÁMOP 4.2.1/B-09/1/KMR-2010-0003). The authors thank the infants and their parents for their participation as well as Kata Egyed, Kata Krekó, and Krisztina Kupán for their help in data collection.

References

Beisert, M., Zmyj, N., Liepelt, R., Jung, F., Prinz, W., & Daum, M. M. (2012). Rethinking "rational imitation" in 14-month-old infants: A perceptual distraction approach. *PLoS One, 7*, e32563.

Bekkering, H., Wohlschläger, A., & Gattis, M. (2000). Imitation of gestures in children is goal-directed. *Quarterly Journal of Experimental Psychology A, 53*, 153–164.

Biro, S., Csibra, G., & Gergely, G. (2007). The role of behavioural cues in understanding goal-directed actions in infancy. *Progress in Brain Research, 164*, 303–322.

Biro, S., Verschoor, S., & Coenen, L. (2011). Evidence for a unitary goal-concept in 12 month old infants. *Developmental Science, 14*, 1255–1260.

Brugger, A., Lariviere, L. A., Mumme, D. L., & Bushnell, E. W. (2007). Doing the right thing: Infants' selection of actions to imitate from observed event sequences. *Child Development, 78*, 806–824.

Buttelmann, D., Carpenter, M., Call, J., & Tomasello, M. (2008). Rational tool use and tool choice in human infants and great apes. *Child Development, 79*, 609–626.

Carpenter, M., Call, J., & Tomasello, M. (2005). Twelve- and 18-month-olds copy actions in terms of goals. *Developmental Science, 8*, F13–F20.
Csibra, G. (2007). Action mirroring and action interpretation: An alternative account. In P. Haggard, Y. Rosetti, & M. Kawato (Eds.), *Sensorimotor foundations of higher cognition: Attention and performance XXII* (pp. 435–459). Oxford, UK: Oxford University Press.
Csibra, G. (2010). Recognizing communicative intentions in infancy. *Mind & Language, 25*, 141–168.
Csibra, G., Bíró, S., Koós, O., & Gergely, G. (2003). One-year-old infants use teleological representations of actions productively. *Cognitive Science, 27*, 111–133.
Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences, 13*, 148–153.
Csibra, G., & Gergely, G. (2011). Natural pedagogy as evolutionary adaptation. *Philosophical Transactions of the Royal Society B, 366*, 1149–1157.
Csibra, G., Gergely, G., Bíró, S., Koós, O., & Brockbank, M. (1999). Goal attribution without agency cues: The perception of "pure reason" in infancy. *Cognition, 72*, 237–267.
Gergely, G., Bekkering, H., & Király, I. (2002). Rational imitation in preverbal infants. *Nature, 415*, 755.
Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naive theory of rational action. *Trends in Cognitive Sciences, 7*, 287–292.
Gergely, G., & Csibra, G. (2005). The social construction of the cultural mind: Imitative learning as a mechanism of human pedagogy. *Interaction Studies, 6*, 463–481.
Gergely, G., & Csibra, G. (2006). Sylvia's recipe: The role of imitation and pedagogy in the transmission of human culture. In N. J. Enfield & S. C. Levinson (Eds.), *Roots of human sociality: Culture, cognition, and human interaction* (pp. 229–255). Oxford, UK: Berg.
Gergely, G., Egyed, K., & Király, I. (2007). On pedagogy. *Developmental Science, 10*, 139–146.
Gergely, G., & Jacob, P. (2012). Reasoning about instrumental and communicative agency in human infancy. In: J.B. Benson, (Series Ed.) & F. Xu, & T. Kushnir (Vol. Eds.), Rational constructivism in cognitive development (pp. 59–94). San Diego: Elsevier.
Gergely, G., Nadasdy, Z., Csibra, G., & Biro, S. (1995). Taking the intentional stance at 12 months of age. *Cognition, 56*, 165–193.
Gredebäck, G., & Melinder, A. (2010). Infants' understanding of everyday social interactions: A dual process account. *Cognition, 114*, 197–206.
Gredebäck, G., & Melinder, A. (2011). Teleological reasoning in 4-month-old infants: Pupil dilation and contextual constraints. *PLoS One, 6*, e26487.
Hernik, M., & Southgate, V. (2012). Nine-month-old infants do not need to know what the agent prefers in order to reason about its goals: On the role of preference and persistence in infants' goal-attribution. *Developmental Science, 15*, 714–722.
Kamewari, K., Kato, M., Kanda, T., Ishiguro, H., & Hiraki, K. (2005). Six-and-a-half-month-old children positively attribute goals to human action and to humanoid–robot motion. *Cognitive Development, 20*, 303–320.
Kenward, B. (2012). Over-imitating preschoolers believe unnecessary actions are normative and enforce their performance by a third party. *Journal of Experimental Child Psychology, 2*, 195–227.
Király, I. (2009a). The effect of the model's presence and of negative evidence on infants' selective imitation. *Journal of Experimental Child Psychology, 102*, 14–25.
Király, I. (2009b). Memories for events in infants: Goal relevant action coding. In T. Striano & V. Reid (Eds.), *Social cognition: Development, neuroscience, and autism* (pp. 113–128). Oxford, UK: Wiley–Blackwell.
Lyons, D. E., Damrosch, D. H., Lin, J. K., Macris, D. M., & Keil, F. C. (2011). The scope and limits of overimitation in the transmission of artefact culture. *Philosophical Transactions of the Royal Society B, 366*, 1158–1167.
Lyons, D., Young, A., & Keil, F. (2007). The hidden structure of overimitation. *Proceedings of the National Academy of Sciences of the United States of America, 104*, 19751–19756.
Meltzoff, A. N. (1988). Infant imitation and memory: Nine-month-olds in immediate and deferred tests. *Child Development, 59*, 217–225.
Newell, A. (1982). The knowledge level. *Artificial Intelligence, 18*, 87–127.
Nielsen, M. (2006). Copying actions and copying outcomes: Social learning through the second year. *Developmental Psychology, 42*, 555–565.
Nielsen, M., & Blank, C. (2011). Imitation in young children: When who gets copied is more important than what gets copied. *Developmental Psychology, 47*, 1050–1053.
Over, H., & Carpenter, M. (2012). Putting the social into social learning: Explaining both selectivity and fidelity in children's copying behavior. *Journal of Comparative Psychology, 126*, 182–192.
Paulus, M., Hunnius, S., Vissers, M., & Bekkering, H. (2011a). Bridging the gap between the other and me: The functional role of motor resonance and action effects in infants' imitation. *Developmental Science, 14*, 901–910.
Paulus, M., Hunnius, S., Vissers, M., & Bekkering, H. (2011b). Imitation in infancy: Rational or motor resonance? *Child Development, 82*, 1047–1057.
Pinkham, A. M., & Jaswal, V. K. (2011). Watch and learn? Infants privilege efficiency over pedagogy during imitative learning. *Infancy, 16*, 535–544.
Rakoczy, H., Warneken, F., & Tomasello, M. (2008). The sources of normativity: Young children's awareness of the normative structure of games. *Developmental Psychology, 44*, 875–881.
Schwier, C., van Maanen, C., Carpenter, M., & Tomasello, M. (2006). Rational imitation in 12-month-old infants. *Infancy, 10*, 303–311.
Sodian, B. T., Schoeppner, B., & Metz, U. (2004). Do infants apply the principle of rational action to human agents? *Infant Behavior and Development, 27*, 31–41.
Southgate, V., Chevallier, C., & Csibra, G. (2009). Sensitivity to communicative relevance tells young children what to imitate. *Developmental Science, 12*, 1013–1019.
Southgate, V., & Csibra, G. (2009). Inferring the outcome of an ongoing novel action at 13 months. *Developmental Psychology, 45*, 1794–1798.
Sperber, D., & Wilson, D. (1986). *Relevance: Communication and cognition*. Oxford, UK: Blackwell.

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge, MA: Harvard University Press.

Varga, A., & van Lambalgen, M. (2011). Infants' flexible closed world reasoning and imitation-for-learning. In F. Guerin, J. Alexander, D. Kazakov, & G. Tsoulas (Eds.), *Computational models of cognitive development: Proceedings of AISB 2011* (pp. 13–23). London: Society for the Study of Artificial Intelligence and the Simulation of Behaviour.

Verschoor, S., & Biro, S. (2012). The primacy of means selection information over outcome selection information in infants' goal attribution. *Cognitive Science, 36*, 714–725.

Wagner, L., & Carey, S. (2005). 12-month-olds represent probable endings of motion events. *Infancy, 7*, 73–83.

Wang, Y., Newport, R., Hamilton, A. F., & de, C. (2010). Eye contact enhances mimicry of intransitive hand movements. *Biology Letters, 7*, 7–10.

Williamson, R. A., Meltzoff, A. N., & Markman, E. M. (2008). Prior experiences and perceived efficacy influence 3-year-olds' imitation. *Developmental Psychology, 44*, 275–285.

Woodward, A. L., & Sommerville, J. A. (2000). Twelve-month-old infants interpret action in context. *Psychological Science, 11*, 73–77.

Zmyj, N., Daum, M. M., & Aschersleben, G. (2009). The development of rational imitation in 9- and 12-month-old infants. *Infancy, 14*, 131–141.

Please cite this article in press as: Király, I., et al. Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations. *Journal of Experimental Child Psychology* (2013), http://dx.doi.org/10.1016/j.jecp.2012.12.003