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Research

The scope and limits of overimitation in the transmission of artefact culture

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Children are generally masterful imitators, both rational and flexible in their reproduction of others' actions. After observing an adult operating an unfamiliar object, however, young children will frequently *overimitate*, reproducing not only the actions that were causally necessary but also those that were clearly superfluous. Why does overimitation occur? We argue that when children observe an adult intentionally acting on a novel object, they may automatically encode all of the adult's actions as causally meaningful. This process of *automatic causal encoding* (ACE) would generally guide children to accurate beliefs about even highly opaque objects. In situations where some of an adult's intentional actions were unnecessary, however, it would also lead to persistent overimitation. Here, we undertake a thorough examination of the ACE hypothesis, reviewing prior evidence and offering three new experiments to further test the theory. We show that children will persist in overimitating even when doing so is costly (underscoring the involuntary nature of the effect), but also that the effect is constrained by intentionality in a manner consistent with its posited learning function. Overimitation may illuminate not only the structure of children's causal understanding, but also the social learning processes that support our species' artefact-centric culture.

Keywords: imitation; overimitation; causal learning; cognitive development; artefacts

1. INTRODUCTION

Though we understand much about how imitation shapes the human mind, there are some aspects of imitative learning that remain mysterious. Imagine a preschool-aged child watching an adult open a simple novel object to retrieve a toy. Imagine that the adult approaches this task in a way that is clearly inefficient, for example, adjusting superfluous rods and levers on the outside of the object before opening it. How would we expect the child to later open the same object him or herself?

We know that even infants are capable of rationally selective imitation [1,2], i.e. of copying only those components of an action sequence that are appropriate given their goals and physical context. Thus, we might expect our hypothetical preschooler to 'edit' the observed actions, copying only the necessary parts of the adult's behaviour. Yet this is not always what occurs. Horner & Whiten [3] presented both children and chimpanzees with a display very much like the one described above. Both groups watched an adult opening a simple 'puzzle fruit' using a short sequence of necessary and visibly unnecessary actions, and were subsequently allowed to try and open the fruit for themselves. While chimpanzees ignored the adult's irrelevant actions, children did not; in fact, the children tended to reproduce everything that the adult had done—even the actions that were plainly superfluous.

We term this curious phenomenon *overimitation* [4]. It is not a new occurrence; many instances of overimitation-like behaviour can be found in the social learning literature of the past two decades (e.g. [5–10]). Until recently, however, the effect attracted little comment. It was generally assumed that the surface oddity of overimitation (i.e. children seeming to be outsmarted by chimpanzees) could be easily resolved by appeal to some plausible configuration of social motivations.

2. PRIOR THEORIES OF OVERIMITATION

Theorists have long argued that imitation plays a critical dual role during development, serving as an early socialization strategy as well as a learning mechanism ([11,12]; see also [8,13,14]). Thus, one common reading of overimitation has been that it simply reflects the social end of the imitative continuum. On this view, overimitation is ascribed to children's desire to 'be like' an adult model [8], and their willingness to privilege this social concern above instrumental

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efficiency. In essence, the argument is that children overimitate because they *want* to.

In a related vein, the procedural details of some prior studies may have led children to overimitate because they believed that they were *supposed* to. For example, in Horner & Whiten's experiments [3], participants watched the adult repeat the same sequence of relevant and irrelevant actions three times in succession before acting on the object themselves (see also [15,16]). Though this procedure was arguably necessary in Horner & Whiten's comparative context (i.e. to ensure that the chimpanzee participants were attending), children may have reasonably interpreted the repeated displays as a non-verbal mandate to 'do it like so . . . '.

A third theory of overimitation, what Whiten and colleagues have termed the 'copy-all, refine/correct-later' view [17, p. 2425], argues that 'we are such a thorough-going cultural species that it pays children, as a kind of default strategy, to copy willy-nilly much of the behaviour they see enacted before them. Children have the longest childhoods of any primate . . . so there is plenty of opportunity to weed out wrongly assimilated aspects of the actions observed' ([18, p. 280]; see also [10,15]). This perspective sees overimitation as a kind of cultural Pascal's wager: even if an adult's actions appear irrelevant, children reproduce them because they have little to lose (and, in our artefact-centric culture, potentially much to gain) by assuming that the actions may serve some non-obvious purpose. This is a logically appealing possibility, and one that would help to explain why older children may actually be *more* prone to overimitation than younger ones ([15,19]; see also [20] for extension to adults). That is, the copy-all/correct-later view predicts the increase of overimitation over development, as we would expect older children to be more sophisticated about withholding judgement on seemingly irrelevant actions.

3. AN ALTERNATIVE VIEW OF OVERIMITATION: AUTOMATIC CAUSAL ENCODING

The above explanations all share an important commonality. The unifying assumption is that children overimitate not because they are actually confused about the causal importance of the actions they have observed, but rather because they are *choosing* (for social or pragmatic reasons) to copy actions that appear to be unnecessary. Several years ago we began to consider an alternative theory of overimitation, one that challenges this core assumption [4]. Our motivation stemmed in part from considering the unique causal learning challenges that children face during development.

Children must contend with an environment that is dense with tools and artefacts, many of which are difficult or impossible to understand through direct inspection alone. This problem of *causal opacity* is obvious for modern devices like computers and cell phones, but it actually extends to far simpler (and far more evolutionarily salient) kinds of artefacts. Indeed, Gergely & Csibra [21–23] have argued that once cognitive innovations like inverse teleology (the ability to stably conceptualize tools in terms of the goals they enable)[1] and recursive teleology (the ability to conceptualize objects as tools for making other tools) arise, understanding the structure and usage of even 'simple' artefacts quickly becomes a daunting inferential problem. Because these teleological modes allow tool-mediated actions to occur separately from the goals they ultimately serve, it is often impossible to predict *a priori* which *features* of a tool or which *aspects* of its usage are the causally important ones to attend to (see [24] for more discussion of this issue). Since learners can no longer rely solely on physical and environmental cues to understand the artefacts around them, some form of social support becomes necessary.

We wondered whether overimitation might reflect a unique human social learning mechanism that would help children to overcome this problem of causal opacity. We hypothesized that when young children view an adult acting intentionally on a novel object, they may automatically (and in some cases mistakenly) encode all of the adult's purposeful actions as causally necessary. In other words, children 'may implicitly treat the adult's actions as highly reliable indicators of the object's "inner workings" or causal structure, revising their causal beliefs about it accordingly' [4, p. 19 751]. Such an *automatic causal encoding* (ACE) process would normally be very helpful, allowing children to extract accurate causal beliefs about complex artefacts by observing adults' intentional actions. However, in the unusual event of an adult *intentionally* performing *unnecessary* actions, this mechanism would cause children to incorrectly encode the irrelevant actions as causally important. This mistaken encoding, and the distortions in object-specific causal beliefs that it would cause, might explain why children are vulnerable to overimitating unnecessary actions that other apes more readily ignore.

To review: whereas prior theories of overimitation have assumed that children copy irrelevant actions because they *want* to (for social reasons), or because they think they are *supposed* to (owing to task demands), our hypothesis stakes out different ground. We believe that children may overimitate because, in an important sense, they *have* to: the normally adaptive ACE process blinds them to the irrelevance of the adult's unnecessary actions. Among prior theories, our view is most similar to Whiten *et al.*'s copy-all/correct-later hypothesis, as both perspectives see overimitation as an adaptive human social learning strategy. The ACE hypothesis differs, however, in its assertion that overimitation is an entirely automatic response to a specific class of stimuli (i.e. intentional action enacted on a novel object) rather than a deliberate strategy arising from experience.

In the remainder of this paper, we synthesize data from a variety of sources, including several new experiments reported here for the first time, to construct a detailed appraisal of the ACE hypothesis. We begin by briefly reviewing the studies that initially supported the ACE theory, and then progress to new evidence that more fully illustrates the scope and limits of the effect.

4. THE STORY SO FAR: INITIAL TESTS OF THE AUTOMATIC CAUSAL ENCODING HYPOTHESIS

The ACE hypothesis makes an unambiguous prediction: if children truly overimitate because they have mis-encoded adults' purposeful actions as causally meaningful, then they should be unable to avoid doing so—even in situations where copying superfluous actions would be inappropriate. We first tested this prediction in a series of experiments in which 3- to 5-year-olds were trained to identify irrelevant actions as 'silly' and unnecessary [4]. Children watched as an experimenter used sequences of relevant and irrelevant actions to remove toys from familiar, transparent household containers such as plastic food jars, clear zipper pouches, etc. The children then received effusive praise for successfully pointing out the actions that the experimenter had not needed to perform. This training made clear to children both that: (i) the experimenter was an 'unreliable' model, frequently performing actions with no bearing on his goal, and (ii) that performing irrelevant actions was not desirable.

Immediately following this training, children watched the same experimenter retrieving toys from inside simple (but now *novel*) 'puzzle objects'. As during the training phase, the adult's retrieval method was always markedly inefficient, incorporating obviously irrelevant actions (e.g. pulling out an extraneous wooden dowel on top of the object) alongside necessary ones (e.g. opening the door to a compartment containing the toy). Also as in training, each of the puzzle objects was constructed predominantly from transparent materials (e.g. Plexiglas) such that the causal significance of each of the adult's actions was plainly visible. The question of interest was whether children would overimitate on the puzzle objects, despite having just been trained to ignore irrelevant actions in a nearly identical context. We predicted that the novel puzzle objects would trigger ACE and overimitation, even among those children who had shown no difficulty filtering out irrelevant actions enacted on familiar objects.[2]

Despite their extensive contrary preparation, children did indeed show a near universal tendency to overimitate on the puzzle objects. This finding was not simply a reflection of the puzzle objects being overly complex, as participants in an age-matched baseline group seldom operated the irrelevant mechanisms when opening these objects independently. Moreover, children's tendency to overimitate was independent of the ease with which they completed the training phase; participants who easily identified the irrelevant actions on the familiar training objects were just as likely to overimitate on the novel puzzle objects as children who found the training more challenging. Consistent with the ACE theory, we found that a single observation of an adult performing purposeful but unnecessary actions on a novel object was enough to lock even 'causally precocious' children into overimitation.[3]

Subsequent experiments confirmed and expanded these findings, demonstrating that overimitation was not diminished by increasingly blatant countervailing information. For example, in a 'covert' follow-up immediately after the above experiment, participants were led to believe that the study was over. As the experimenter cleaned up, he asked the child for help in verifying that an assistant had correctly replaced all of the toys in the puzzle objects (the experimenter claimed that another participant was due to arrive at any moment and that he was thus pressed for time). Despite the time-sensitive nature of this task, children continued to overimitate at levels indistinguishable from the first study when opening the puzzle objects. A third experiment found that even directly *telling* children not to overimitate failed to curtail the effect.

Together these findings weigh against prior social views of overimitation, in which the effect was seen as arising from the child's desire to interact with the experimenter or to accommodate perceived task demands. The persistence of overimitation—even when situational demands strongly discourage it—is instead more consistent with the ACE hypothesis, and its contention that ACE can sometimes render children unable to avoid copying irrelevant actions.

However, while these initial studies provide a solid foothold for the ACE theory, limitations remain. Our puzzle objects were deliberately designed to be appealing to children, with colours, textures, knobs and handles used to highlight each object's mechanistic affordances. Given that these kinds of properties encourage children to manipulate and explore objects [27], might children have persisted in overimitation simply because they were curious?[4] Alternatively, returning to the copy-now/correct-later view of Whiten and colleagues [17], might the demands we used to oppose overimitation simply have been insufficient to dislodge a deliberate, productive strategy of high-fidelity copying? Having hypothesized that overimitation is essentially unavoidable, we need to be thorough in our evaluation of these voluntary alternatives.

5. USING COMPETITION TO TEST THE SCOPE OF OVERIMITATION

Though our prior experiments were designed to discourage overimitation, it is important to note that there was no actual cost to indulging in it. Thus, one way of testing the ACE hypothesis more rigorously would be to attach a salient price to the reproduction of irrelevant actions. For example, what if overimitation placed children at a disadvantage in a competition, making them less likely to win or gain an enticing prize?

Competition is an important dimension of childhood from an early age. By the time children reach preschool, informal competitions such as being the first to the toy box have become ubiquitous features of their daily routine [29]. Preschoolers spontaneously describe photos of potentially competitive situations (e.g. a girl and a boy running side-by-side) in terms of winning and losing, are able to give detailed accounts of which peers usually win in competitive contexts [29], and attach greater value to success in competitive settings [30]. Additionally, whereas older children and adults show a long-term negative relationship between competition and intrinsic motivation [31,32], competition seems to actually enhance preschoolers' interest in and motivation to master novel tasks [33–35].

Given that competition is such a highly motivating context for preschoolers' learning, it seems an ideal tool for further exploring the ACE hypothesis. In experiment 1, we thus presented children with a situation in which overimitation posed a distinct competitive disadvantage. We hypothesized that even in this highly motivating context, ACE of the adult's purposeful actions would render children unable to avoid overimitation. Contrastingly, if children in our original studies were overimitating simply out of curiosity or as part of a habitual learning strategy, then we would expect that the more acute incentive of competition would block the effect.

6. EXPERIMENT 1: DOES ASSOCIATING A COMPETITIVE COST WITH OVERIMITATION ELIMINATE THE EFFECT?

(a) *Procedure*

As in our prior work, we began with a training phase designed to oppose overimitation.[5] Children aged 4 and 5 years ($n = 64$) watched an experimenter removing toy dinosaurs from eight familiar household containers using sequences of relevant and irrelevant actions. For the first four training items, children were asked to verbally identify the experimenter's 'silly' unnecessary actions; on the final four training items, children were invited to try retrieving the dinosaur faster than the experimenter. Children who responded by correctly identifying or skipping the irrelevant steps received enthusiastic reinforcement, while those who missed or copied the unnecessary actions were verbally corrected and guided towards the correct solution (see the electronic supplementary material for full details). This action-based training procedure allowed children to practise inhibiting copying, and also helped to establish an explicit causal relationship between skipping unnecessary steps and reaching a desired goal state more quickly.

(i) *Non-competitive phase*

Immediately after training, children were introduced to the 'monkey box', a novel puzzle object consisting of two symmetrical halves separated by an opaque divider (figure 1; electronic supplementary material, figures S3 and S4). Each of the identical halves was very similar to the puzzle box used in prior studies [3,4] and incorporated analogous relevant and irrelevant mechanisms. Children watched the experimenter retrieve a toy turtle from the monkey box using a combination of irrelevant and necessary actions partially depicted in figure 1. After reassembling the object outside of the child's view, the experimenter explained that he was going to briefly step outside; he told participants: 'if you want to, you can get the turtle out while I'm gone. You can get it out however you want'. The experimenter then left the room, a step we took to minimize any perceived social pressure to copy his actions. Children were free to retrieve the turtle in whatever manner they chose.

(ii) *Competitive phase*

After the child retrieved the turtle, the experimenter returned to the room. Moving an opaque divider aside, the experimenter revealed a 'cabana' (electronic supplementary material, figure S1) out of which emerged a seemingly autonomous orang-utan puppet named Felix. Felix was operated by a second experimenter hidden inside the structure, who used a concealed puppetry rig to move Felix's limbs and torso; a live closed-circuit video feed allowed this experimenter to observe the child, enabling a high degree of contingent interactivity in Felix's movements and vocalizations. Once the child was comfortable, the experimenter pointed out the monkey box's symmetrical ends and explained their design: 'that's so you and Felix can have a *race*! You can both try to get the turtle out *at the same time*!' The experimenter explained that he would use a vertical tube on top of the box (electronic supplementary material, figure S5) to drop a single turtle into the centre of the object, and that whoever opened their side of the box fastest would retrieve the turtle and win. A verbal manipulation check was used to ensure that children understood these key points. See electronic supplementary material, video S1 for a complete example of this introduction procedure.

Following this set-up, the experimenter began a series of 'races' between the child and Felix. At the start of each race, the child watched the experimenter deposit a single turtle into the tube at the centre of the box; a cardboard barrier was then fitted over the box so that the child could no longer see Felix. Moving to the door of the room, the experimenter counted aloud: '1 ... 2 ... 3 ... *Go*!' On the 'go' signal the experimenter left the room, and the child (as well, purportedly, as Felix) was allowed to start opening the box. Electronic supplementary material, video S2 provides an example of this procedure.

Unbeknownst to the child, the outcome of each race was yoked to overimitation; all children 'lost' to Felix on race 1, and the outcome of race $n + 1$ was then determined by whether the child overimitated on race n (see electronic supplementary material for more details on this design). In losing races, children opened the monkey box only to find that it was empty; when the central divider was subsequently removed children saw that Felix had won and was holding the turtle. The question of interest was whether, over the course of up to three consecutive races, children would adapt to Felix's apparent expertise by beginning to omit irrelevant actions, thus enabling them to open the box more quickly.

(b) *Results and discussion*

An initial analysis confirmed that children did understand the competitive nature of the racing task. We found that all children—regardless of whether they overimitated—opened the monkey box significantly more quickly on the first competitive trial than on the non-competitive trial that preceded it (mean improvement: from 18.6 to 5.6 s); significant improvements continued to be evident across races 2 and 3 as well. While some fraction of these changes can no

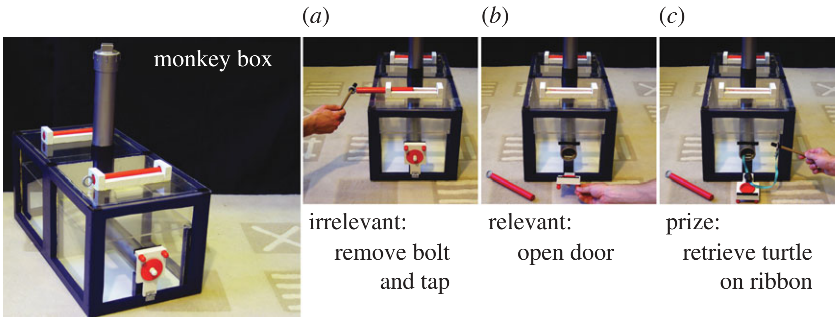

Figure 1. The experimenter retrieved the toy turtle from the monkey box by (*a*) removing the irrelevant red bolt and tapping the wand in the empty upper compartment, (*b*) opening the door to the prize compartment, and (*c*) using the wand to pull out a ribbon to which the turtle was attached. See electronic supplementary material, methods and figure S4 for full details.

doubt be attributed to a practice effect, the steep slope of the initial improvement—averaging 302 per cent faster on the first competitive trial—argues that children understood the competition and were adapting their behaviour accordingly. The fact that this large speed improvement was evident even among overimitators is important, as it shows that the continued reproduction of irrelevant actions was not caused by a failure to grasp the competitive nature of the task. Indeed, as electronic supplementary material, video S3 illustrates, Felix proved an ideal means of eliciting a full and animated competitive response from children without any of the sting that might have accompanied losing to a confederate child. As intended, overimitation imposed a large competitive cost, with overimitators needing an average of four times as long to open the monkey box as non-overimitators (7.7 versus 1.9 s, $t_{51} = 5.3, p < 0.001$).

How did this cost influence children's tendency to overimitate? As figure 2 shows, the beginning of the competition did reduce overimitation relative to the non-competitive phase of the experiment (McNemar test, $n = 60$, $p < 0.001$). Thus, we cannot rule out the possibility that at least some of the children in our initial experiments may have been overimitating out of curiosity or habit. However, though overimitation decreased on the first race, the *majority* of participants were unsuccessful at avoiding it—even when the pressure of repeatedly losing to Felix began to mount on the second and third trials. Most importantly, the rate of overimitation across all three of these contests was a significant 4.6–5.4 times greater than the rate of irrelevant action production observed among age-matched baseline participants ($n = 28$) who opened the monkey box independently (race 1: $\chi^2(1, n = 85) = 19.8$, $p < 0.001$, odds ratio = 13.6; race 2: $\chi^2(1, n = 84) = 14.8$, $p < 0.001$, odds ratio = 10.0; race 3: $\chi^2(1, n = 83) = 13.4$, $p < 0.001$, odds ratio = 9.0). Although fully 88 per cent of baseline participants ignored the irrelevant mechanism when opening the monkey box independently, children in the experimental group tended to fixate on overimitation despite (i) their increasing first-hand experience with the monkey box itself, and (ii) repeatedly discovering that Felix had apparently opened the box more quickly.

Overimitation's persistence during competition is consistent with the ACE hypothesis, but there is another possible explanation for these results. Perhaps

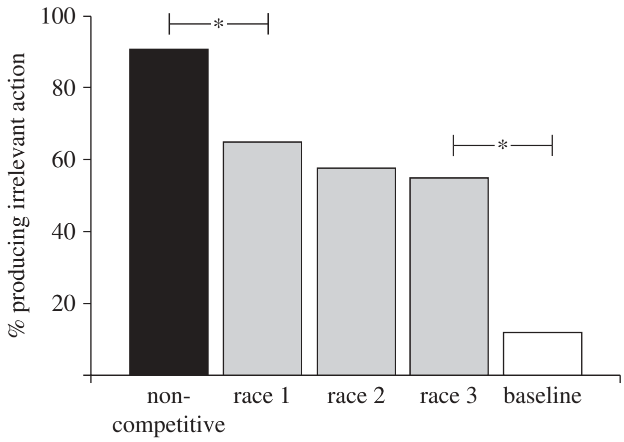

Figure 2. Children continue to overimitate even when doing so places them at a disadvantage in a time-critical race. Though the competitive cost of overimitation did dissuade some participants, most children continued to overimitate across all three races. Even after the final race, irrelevant action production remained 4.6 times more frequent than in the baseline condition.

children believed that the experimenter's irrelevant actions were intended to be *part of the race*, i.e. that performing these actions was mandated by the rules of the contest. We find this possibility unlikely (it runs strongly counter to the contrary training phase that began the experiment), but it does bear consideration. To resolve this alternative we undertook a second competitive experiment, covertly presented to participants immediately following experiment 1.

7. EXPERIMENT 2: OVERIMITATION AND 'REAL-WORLD' COMPETITION

(a) *Procedure*

After the final race in experiment 1, Felix retired to his cabana and participants were told that the game was over. The experimenter brought in a new puzzle object (figure 3; electronic supplementary material, figures S7 and S8), which he identified as a box of prizes. Indicating that he was going to retrieve a prize for the child, the experimenter proceeded to open the box using a series of relevant and irrelevant steps; a bell attached to the irrelevant mechanism caused the box to jingle noisily when the experimenter performed the unnecessary action.

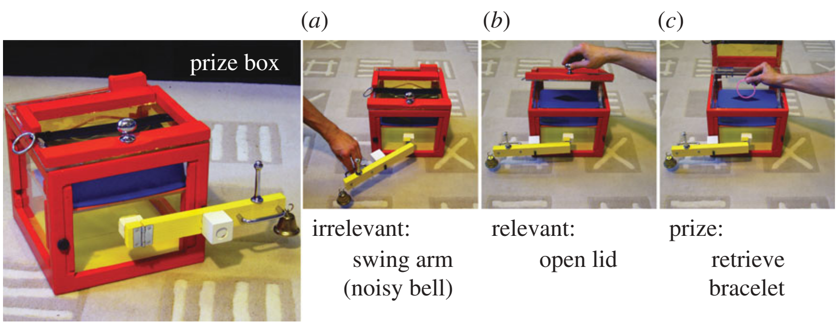

Figure 3. The experimenter retrieved the toy bracelet from the prize box by (*a*) swinging the irrelevant yellow arm from right to left (causing the bell to jingle loudly), (*b*) opening the lid to the prize compartment, and (*c*) removing the bracelet. See electronic supplementary material, methods and figure S8 for full details.

The experimenter removed a prize from the box and handed it to the child. As the child examined their reward, Felix unexpectedly re-emerged from his cabana. The experimenter interpreted as Felix gestured and vocalized: 'I think Felix wants to see your prize. Would you mind showing it to him?' Unfortunately, once the participant agreed, Felix took the prize and disappeared back into the cabana in a flurry of excited chattering. After feigning shock, the experimenter remarked that Felix must have taken the prize because of being awakened by the loud jingling bell (attached to the irrelevant mechanism).

With the original prize now gone, the experimenter presented the child with a new plan. The experimenter proposed that he would leave the room, thus fooling Felix into thinking that everyone had gone home. The child would then have an opportunity to stealthily open the prize box and retrieve another reward—this time without alerting Felix. After explaining this idea the experimenter left, leaving the child to determine how best to proceed (electronic supplementary material, video S4 provides an example of this procedure). Would this real-world competitive scenario push children to ignore the noisy irrelevant mechanism?

(b) *Results and discussion*

Children approached this task with great seriousness, often pausing to consider their strategy and moving with stealthy slowness (electronic supplementary material, video S5). Yet despite this caution, children were remarkably blind to the strategy of simply ignoring the noisy irrelevant mechanism. As figure 4 shows, children continued to overimitate at a rate indistinguishable from that observed in a non-competitive comparison condition. This finding was all the more striking given that none of the participants in a baseline control group ever operated the prize box's irrelevant mechanism. These results thus confirm and extend those of experiment 1, demonstrating that children will persist in overimitating even when doing so imposes a direct competitive cost. Indeed, consistent with the ACE hypothesis, children continued to reproduce observed irrelevant actions as though there was no other choice.

These competitive studies expand the scope of overimitation beyond our initial work, demonstrating that children will continue to overimitate even when doing so imposes motivationally salient costs. This degree of persistence is consistent with the proposed automaticity of the ACE process, and argues that ACE may be a better explanation for overimitation than more voluntary alternatives.

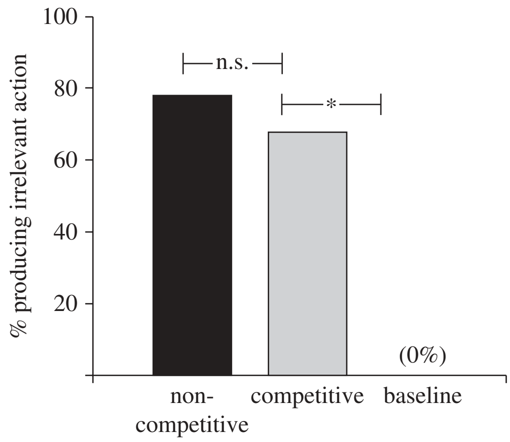

Figure 4. Experiment 2 participants continued to overimitate even when doing so directly imperilled their prospects for obtaining a desirable prize. The rate of overimitation observed during the competitive phase of the study was indistinguishable from that observed in the non-competitive phase.

8. THE LIMITS OF OVERIMITATION

Interestingly, we have now reached the point where the very robustness of overimitation begins to pose a challenge for our theory. That is, overimitation surprises us precisely because children's causal intuitions usually seem much more accurate. By the time they reach 3–5 years of age, children routinely operate (and watch others operate) devices that are much more complex than our puzzle objects without being diverted by causally irrelevant steps. At the same time though, our central claim is that children often base their understanding of new objects on a profoundly uncritical encoding of others' actions. How can both of these things be true? If children's causal understanding is as malleable to observed actions as we have suggested, then why is it not riddled with errors and inconsistencies by the end of early childhood? If ACE does occur, it must be subject to constraints that normally confine it to contexts where it will clarify children's causal understanding rather than undermining it.

(a) *Prior investigation of constraints: core knowledge*

Our previous work began to examine the issue of constraints by focusing on 'core knowledge': the set of foundational rules that infants use to structure their earliest interpretation of physical events [36]. One particularly elemental aspect of core knowledge is the contact principle, which specifies that mechanical interactions cannot occur at a distance. Infants as young as three months of age display surprise when this principle appears to be violated, such as when two balls react as though they have collided without actually touching [37]. Because the contact principle is so deeply rooted in our causal knowledge, we predicted that children would not causally encode (and thus, would not overimitate) actions that appeared to violate it.

In a test of this prediction, two groups of 3- to 5-year-old children watched an adult open a puzzle object comprising two distinct halves, performing relevant actions on one half of the object and irrelevant actions on the other. The only difference between the groups pertained to the presence or absence of a small connector tube between the halves of the object. Participants in the *connected* condition saw the experimenter performing his actions with the tube in place (hence the relevant and irrelevant actions occurred on a single continuous object), while in the *disconnected* condition the tube was removed. Despite identical experimenter actions in both cases, only children in the connected condition overimitated; children in the disconnected condition ignored the experimenter's unnecessary actions. The ACE process was blocked when the irrelevant action implied a violation of the contact principle [4].

This initial result was an important 'existence proof' for our theory, demonstrating that overimitation is indeed subject to at least some constraints consistent with its posited learning function. However, if ACE is to be a net benefit to children's causal understanding, more constraints are needed. An especially useful kind of constraint—one that has been implicit in our theory from the outset—involves intentionality.

9. EXPERIMENT 3: DOES INTENTIONALITY CONSTRAIN OVERIMITATION?

In introducing our hypothesis, we framed the ACE process as one that helps to extract causal information from *purposeful* (intentional) adult actions. Indeed, the theory depends on this assumption, as intentionality is a prime indicator that an adult's actions are likely to reflect a target object's causal structure. Conversely, the functional value of ACE breaks down when an observed adult's actions are unintentional and therefore unlikely to convey meaningful information. If our theory is correct, it follows that ACE and overimitation should shut off with a circuit-breaker-like crispness when an adult's irrelevant actions no longer appear to be intentional.

(a) *Procedure*

To test this prediction, a new group of 3- to 5-year-olds ($n = 27$) underwent training as in experiment 1, and then observed the experimenter opening one of the previously described puzzle objects using relevant and irrelevant actions.

In the case of the monkey box, the experimenter's actions began with waving a wooden paddle left, right and left again over the box's irrelevant red bolt, which now had a vertical 'wing' component attached perpendicularly to its left end (electronic supplementary material, figure S11). When the experimenter waved the paddle back to the left for the final time, he did so along a lower trajectory that caused the face of the paddle to strike the bolt's wing and knock the bolt out of its bracket. Upon completing this irrelevant sequence, the experimenter opened the relevant door mechanism using one of the same techniques used in experiment 1 (electronic supplementary material, figure S11 illustrates the complete action sequence).

The experimenter's actions on the prize box followed a similar structure. He began by waving a red wooden wand left, right and left again over the end of the irrelevant arm. When waving the wand back to the left for the final time the experimenter lowered it slightly, thus hitting the vertical metal rod on the arm's end and causing it to swing from right to left. After these unnecessary steps, the experimenter finished opening the object using the same relevant actions as in experiment 2 (electronic supplementary material, figure S12).

All children saw the experimenter performing these same actions, but different participants saw them embedded in different contexts. For each puzzle object, half of the children saw the adult's irrelevant actions presented as *intentional*, while half saw the same irrelevant actions presented as *unintentional*. The intentional case was exactly analogous to prior experiments, with the experimenter performing all of the irrelevant actions—including the back-and-forth waving of the paddle or wand—in a purposeful, intent manner (electronic supplementary material, video S6). In the unintentional case, however, a new procedural wrinkle was used to suggest that the experimenter's irrelevant actions were actually accidental in nature. Specifically, just as the experimenter was about to begin his action sequence, he received a call on his cellular phone, purportedly from his mother.

The experimenter answered the phone, listened for a moment, and said: 'oh, really? You can't find it?' He then looked up thoughtfully (away from the object) and continued: 'let's see . . . Did you try looking on the side of the yard over by the dog house?' While saying this, the experimenter began his action sequence by waving the wand/paddle to the left, an action that now appeared to represent gesturing towards a point in imagined space. 'No, it's not there?' he continued. 'Well, did you look on the other side of the yard, over by the tree?' The experimenter now waved the paddle back to the right, again appearing to gesture at an imagined landmark. 'It's not there either?' he said. 'Well, you know, I really feel like I saw it over by the dog house'. During this last phrase, the experimenter waved the wand/paddle back towards the left for the final time, striking and actuating the irrelevant mechanism in the process. Critically though, the operation of this mechanism now appeared to be *accidental*: an unintended by-product of gesturing during his conversation (electronic supplementary material, video S7).

After striking the irrelevant mechanism, the experimenter ended his phone conversation and (without comment) proceeded to complete the relevant portion of the action sequence. The experimenter then left the room, and children were evaluated for overimitation in the same manner as in prior studies.

(b) *Results and discussion*

Children showed a strong propensity for overimitation when the adult's irrelevant actions appeared to be intentional, copying the unnecessary actions 69 per cent of the time on both objects. However, when the very same irrelevant actions were contextualized as being unintentional, overimitation rates declined significantly (figure 5; monkey box: $\chi^2(1,\ n = 27) = 11.1,\ p = 0.001$, odds ratio = 29.3; prize box: $\chi^2(1,\ n = 25) = 9.6,\ p = 0.002$, odds ratio = 24.8). In fact, children in the unintentional condition were no more likely to operate the irrelevant mechanisms than participants in the baseline group who opened the objects independently. The same pattern held in between-subjects analyses as well, where we found that individual participants were significantly less likely to overimitate on the unintentional object than they were to do so on the intentional object (McNemar test, $n = 25,\ p < 0.001$).

Importantly, data from a separate age-matched control experiment (see electronic supplementary material for full details) argue that the absence of overimitation in the unintentional condition was not simply a by-product of reduced attention. Children in this control experiment saw exactly the same display as those in the unintentional group, but afterwards they were *asked to copy* what the experimenter had done rather than simply being given the opportunity to open the puzzle box. In this circumstance, we found that 81 and 78 per cent of children were able to reproduce the experimenter's unintentional irrelevant actions on the monkey box and prize box, respectively. Thus, we can infer that in the unintentional condition children's memories of the adult's actions were, in principle, detailed enough for overimitation to have matched the level observed in the intentional case. The steep decline of overimitation thus supports our theory's proposal that ACE is constrained by intentionality.

Although future work will likely reveal more boundary conditions on overimitation, these experiments demonstrate that the effect is not indiscriminate. Instead, overimitation is bounded in a manner consistent with the learning function we have ascribed to it.

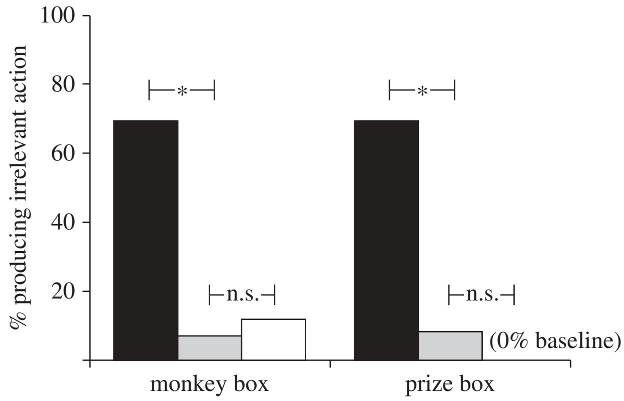

Figure 5. Overimitation is firmly constrained by intentionality. Children will ignore irrelevant actions that appear unintentional, even though the same actions presented in an intentional context trigger high levels of overimitation. Black bars, intentional; grey bars, unintentional; white bar, baseline.

10. CONCLUSIONS AND FUTURE DIRECTIONS

As adults we often use social information to guide our causal learning, looking to the ways that others manipulate novel artefacts in order to infer causally important operations. Here, we have argued that children engage in a very similar process, but that they do so in a way that is often surprisingly automatic. When children observe an adult performing intentional actions on a novel object, they have a strong tendency to encode those actions as causally meaningful—even when there is clear visible evidence to the contrary. This ACE process gives children a powerful boost in understanding our species' artefact-rich cultural environment, but it can also lead to vivid errors. In particular: in the rare case of an adult intentionally performing *unnecessary* actions, children are extremely susceptible to encoding those actions as causally meaningful. We argue that the resulting distortions in children's causal beliefs are the true cause of overimitation.

Because overimitation is rooted in a highly automatic learning process, it is an effect that is remarkably difficult to extinguish. In our previous work, we showed that opposing task demands and even direct contrary instruction were insufficient to block overimitation. Here, we have expanded the scope of these findings, demonstrating that children will continue to overimitate even when doing so imposes a direct and motivationally significant cost.

At the same time though, overimitation is not indiscriminate; the effect is subject to boundary conditions that are coherent in light of its posited learning function. In particular, our studies are the first to show that intentionality imposes a significant boundary on overimitation, just as the ACE hypothesis predicts. Combined with our prior demonstration of core knowledge constraints [4], these results begin to suggest the first contours of what is certain to be a rich and interesting landscape of overimitation boundary conditions.

Looking to the future, one of the interesting underexplored dimensions of overimitation is its potential human universality. The ACE hypothesis predicts that all humans, regardless of their cultural background or exposure to sophisticated modern devices like computers and remote controls, should exhibit overimitation. Because the effect is posited to arise from the evolutionarily ancient advances of inverse and recursive teleology [21–24], one should not need to grow up in a highly technological culture to show the effect. In fact, Nielsen & Tomaselli [16] have recently contributed the first evidence that this prediction may be accurate, demonstrating that Kalahari Bushman children are just as likely to overimitate as the urban American children we have studied. While firm conclusions on the issue will require additional data and replication, these findings present an intriguing first piece of evidence that overimitation may indeed be a universal feature of human learning in the way that the ACE hypothesis predicts.

In the laboratory, overimitation often looks like an error—an unfortunate suggestibility that leads children into mistakes other primates do not make. However, we believe that in more naturalistic settings, overimitation actually represents a profound learning advantage, one that helps to support and propagate our species' artefact-centric culture. The ACE process, operating in tandem with the kinds of powerful constraints we have begun to describe here, affords us a uniquely human perspective for understanding one another's contributions to the designed world.

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ENDNOTES

[1]Gergely & Csibra [22] contrast this with the 'simple teleology' of chimpanzees, who appear to see objects as tools only transiently, and only when prompted by the immediate presence of a desirable goal state.

[2]Recall that our hypothesis frames ACE as a learning mechanism triggered by observing intentional action on an unfamiliar object. The familiar nature of the training items was thus an important aspect of our design, as otherwise children would have been expected to overimitate during both phases of the experiment.

[3]It is interesting to compare these results to tasks in which preschoolers are asked to evaluate their trust of adults. Children will report less trust for adults who have proven unreliable in prior situations [25,26]—not unlike the experimenter's unreliable modelling during the training phase of our study—yet overimitation is not diminished by similar circumstances. In this respect, the ACE process seems to bind children more strongly than conversational inferences.

[4]Although it is true that children in our baseline control conditions were not sufficiently curious about the irrelevant mechanisms to explore them, the experimental conditions introduced further elements of stimulus enhancement (i.e. the adult actually acting on the irrelevant mechanisms). Given that similar kinds of action-based 'highlighting' have been shown to influence preschoolers' behaviour [28], the curiosity alternative needs to be taken seriously.

[5]More detailed procedures, results and discussion for each of the experiments reported in this paper can be found in the electronic supplementary material.

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