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EPS Mid-Career Award 2013

Ways of thinking: From crows to children and back again

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This article reviews some of the recent work on the remarkable cognitive capacities of food-caching corvids. The focus will be on their ability to think about other minds and other times, and tool-using tests of physical problem solving. Research on developmental cognition suggests that young children do not pass similar tests until they are at least four years of age in the case of the social cognition experiments, and eight years of age in the case of the tasks that tap into physical cognition. This developmental trajectory seems surprising. Intuitively, one might have thought that the social and planning tasks required more complex forms of cognitive process, namely Mental Time Travel and Theory of Mind. Perhaps the fact that children pass these tasks earlier than the physical problem-solving tasks is a reflection of cultural influences. Future research will hope to identify these cognitive milestones by starting to develop tasks that might go some way towards understanding the mechanisms underlying these abilities in both children and corvids, to explore similarities and differences in their ways of thinking.

Keywords: Corvid cognition; Cognitive development; Mental time travel; Mental attribution; Tool-use.

The last few decades have seen a shift in focus within the field of comparative cognition. Formerly the province of the primates, there is now considerable evidence that a number of other animal groups also possess these cognitive abilities, including dolphins (Marino, 2002), hyaenas (Holekamp, Sakai, & Lundrigan, 2007), and canids (Hare & Tomasello, 2005; Miklosi, Topal, & Csanyi, 2004) and consequently there is increasing support for the hypothesis that cognition has evolved convergently in these and other distantly related groups that face similar physical and social challenges (Seed, Emery, & Clayton, 2009; van Horik, Clayton, & Emery, 2012). Perhaps the

most striking case is that of corvids, members of the crow family that includes ravens, jays and magpies (Emery & Clayton, 2004), because these birds are even more distantly related to primates than the mammalian examples listed above, sharing a common ancestor with the primates over 300 million years ago. These birds have been shown to be capable of feats that were thought until recently to be uniquely human, including the ability to recall specific what-where-and-when memories about the past (Clayton & Dickinson, 1998) and use such information to plan for the future (Cheke & Clayton, 2012; Correia, Dickinson, & Clayton, 2007; Raby, Alexis,

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Dickinson, & Clayton, 2007a). In addition to mental time travel (Clayton, Bussey, & Dickinson, 2003), these birds have been shown to display sophisticated social and physical cognition, such as perspective taking (Dally, Emery, & Clayton, 2006; Legg & Clayton, *in press*; Ostojić, Shaw, Cheke, & Clayton, 2013) and experience projection (Emery & Clayton, 2001), cooperative problem solving (Seed, Clayton, & Emery, 2008) and creating novel tools to solve problems (Bird & Emery, 2009a, 2009b; Weir, Chappell, & Kacelnik, 2002). Furthermore, research on developmental cognition in human children using comparable non-verbal tests of cognition (e.g., Beck, Appeley, Chappell, Guthrie, & Cutting, 2011; Cheke, Loissel, & Clayton, 2012; Teufel, Clayton, & Russell, 2013) suggests that these abilities are not trivial, emerging relatively late in a human child's cognitive development.

These findings raise a number of questions about what exactly it is that has evolved convergently. Are corvids really using human-like reasoning to carry out these behaviours and solve these tasks, and if not, what cognitive processes allow for their impressive flexibility? How do the corvids differ in their decision-making processes from those made by children? Are there a suite of similarities and differences in the ways of thinking used by corvids and by humans, and what can this tell us about the evolution of both the human and the corvid mind?

In order to address these questions, this article reviews some of the recent work on the remarkable cognitive capacities of food-caching corvids. Three sources of evidence will be discussed: social cognition, mental time travel and physical problem solving. In addition, the application of this work to research on developmental cognition in young humans will be considered, for both comparative and developmental cognition require the use of tasks that are, respectively, entirely or largely, non-verbal. The purpose is not to ask questions about whether or not corvids show cognitive performance equivalent to children of a certain age: adult corvids differ in many ways from young children that make such questions meaningless.

The aim of these comparisons between corvids and children is in fact twofold. First, to investigate two rather different kinds of mind in order to compare and contrast the mechanisms they use to solve the tasks. Of interest here is the fact that the bird brain has a strikingly different neural architecture from that of the mammalian brain with a nuclear arrangement, bereft as it is of the mammalian six-layered neuroarchitecture (Jarvis et al., 2005). This raises interesting questions about how information processing is achieved in these two kinds of mind, and specifically how the information is passed between groupings in the avian brain as opposed to between layers in the mammalian cortex. It should be noted that, despite differences in the gross structure of the brain, there are in fact a number of similarities in the way they are organized, suggesting convergence between birds and mammals in the neural correlates of cognition (Güntürkün, 2012). For example, we now know that birds have a nidopallium caudolaterale, which is thought to be equivalent to the mammalian pre-frontal cortex (Güntürkün, 2005). Furthermore, it has recently been demonstrated that the bird and mammalian brain share similar patterns of large-scale network organization (Shanahan, Bingman, Shimizu, Wild, & Güntürkün, 2013).

Second, the comparison between corvids and children allows us to combine the strengths of both research areas. The field of comparative cognition has tended to focus on two questions, namely “do animals have cognitive processes similar to humans?” and “how does cognition evolve?”, whereas developmental psychologists assume the eventual presence of human cognition in young children and ask “when does it develop?” and “how do the reasoning processes of young children differ from those of adults?” An integration of both fields may advance these questions by enabling us to ask “what is it that evolves and develops?”, focusing on the similarities and differences in performance on various experimental interventions to establish what mechanisms are used, when, and by whom.

1. SOCIAL COGNITION

1.1. Corvid cache-protection tactics

Much of the work on social cognition in corvids revolves around the tactics that these birds use to protect their caches of hidden food from being stolen by other individuals, both conspecific (same species) and heterospecific (different species) pilferers (Vander Wall & Jenkins, 2003). Many of these species tend to live in large social groups, where they are likely to compete for food, and where the likelihood is that they can be seen by onlookers both when protecting their own caches and when pilfering the caches of others. Indeed, pilferage rates can be quite high, ranging from 2 to 30% per day, at least for artificial caches (reviewed in Vander Wall & Jenkins, 2003). In corvids, the risk of pilferage by conspecifics is especially great because these birds do not just rely on random search but possess observational spatial memory and can therefore remember the locations of caches that they have seen other individuals make and return at a later date to steal the contents of those caches when the cachers are not present to defend the cache sites (Bednekoff & Balda, 1996a, 1996b; Bugnyar & Kotrschal, 2002a; Scheid & Bugnyar, 2008; Watanabe & Clayton, 2007).

It has been suggested that this observational spatial memory may have acted as a catalyst in an evolutionary arms race between cacher and pilferer, resulting in the development of a suite of sophisticated strategies for cache-protection and pilfering (Bugnyar & Kotrschal, 2002b; Grodzinski & Clayton, 2010). As Bugnyar and Kotrschal (2002a) were the first to point out, observational spatial memory markedly increases pilfering success compared to random search, for example, and this has the knock-on effect of making it more advantageous for cachers to evolve a protective countermeasure to minimize the risk of cache loss. Furthermore, once pilferers use observational memory, then the risk of pilfering becomes cache-specific, and depends upon the pilferer's knowledge of the cache, which in turn depends on whether or not the pilferer perceived the

caching event, and if so how accurately they attended and remembered. This creates the possibility for a variety of cache-protection strategies to evolve that are concerned with altering a pilferer's knowledge, e.g., hiding caches in sites that are hard for the potential pilferer to see, and minimizing auditory information when the potential pilferer can hear but cannot see. For the purposes of this argument, "knowledge" simply refers to the information that is accessible to the cache-protector and/or pilferer, without any necessary implication about the mechanisms with which they might attribute such information, through behaviour-reading or mind-reading for example. Indeed it remains an open and much-debated question as to whether or not corvids (and non-human animals in general) attribute knowledge or ignorance to others, namely whether or not they possess a "theory of mind" (see Emery & Clayton, 2009a; Heyes, 1998; Lurz, 2009; Penn & Povinelli, 2007). This is a point we shall return to when discussing behaviourist and mentalist accounts of social cognition in young children.

An added complexity is that any one individual can play the role of both the protector of their own caches and the pilferer of other birds' caches. This role-playing may have enabled shortcuts that accelerated the evolution of more complex cognitive strategies for pilfering and cache protection (Emery & Clayton, 2008). Consider the effect of pilfering experience on a western scrub-jay's propensity to re-cache in new locations in private, when the original caching event had been observed (Emery & Clayton, 2001). The striking finding was that it is only those birds who themselves have been thieves in the past that re-cache the food once the potential pilferers have left the scene. Naïve jays that had not been given the opportunity of stealing another bird's caches did not do so. A capacity to predict high pilfering risk from the presence of an observer by using their own experience as a pilferer suggests that the jays may be able to imagine another individual's point of view (Emery & Clayton, 2008). Such experience projection would create the opportunity for using many cache-protection and pilfering strategies without learning through trial and error first, or the need for innate

strategies and counter-strategies to evolve. Ravens can differentiate between knowledgeable and ignorant competitors both as storsers and as pilferers (Bugnyar & Heinrich, 2005). It would be fascinating to determine whether they can also use their experience in one role to make decisions in the other.

Corvids use a suite of cache-protection strategies, ones which limit opportunities for potential pilferers to witness caching events (Clayton, Dally, & Emery, 2007). In a series of experiments, we have investigated the caching strategies used by western scrub-jays to protect their caches when being observed by a potential pilferer, by comparing the behaviour of birds that are allowed to cache in private with those that are observed by a conspecific in a neighbouring cage. The key finding is that the birds limit opportunities for conspecifics to witness these caching events: they preferentially cache behind barriers when others are watching (Dally, Emery, & Clayton, 2005a), and use both distance (Dally et al., 2005a) and shade (Dally, Emery, & Clayton, 2004) to degrade the visual information available to observers, preferences they do not show when others cannot see what and where they cache. Their decisions are not limited to the visual domain, however, for when the potential pilferers can hear but cannot see they conceal auditory information by caching in a substrate in which the act of burying the food makes little noise, whereas when alone or when others can see and hear they prefer to cache in noisy substrates (Stulp, Emery, Verhulst, & Clayton, 2009). This may also serve as a cache protection strategy, allowing the cacher to detect a potential cache-raid should the protector be within earshot of the pilferer but unable to see.

The jays also keep track of which particular individual bird watched them cache and when (Dally et al., 2006) and take protective action accordingly, moving the high-risk caches only when the knowledgeable potential pilferer is no longer present (Dally et al., 2006; Emery & Clayton, 2001). If the pilferer is present at the time of recovery, however, they then use “confusion tactics”, in which the cacher repeatedly moves the items from one place to another, thereby sometimes making fake caches and re-caches (Dally et al., 2006),

reminiscent of the Cups and Balls Effect and Three Shells Effect that magicians use to misdirect the visual information that the onlooker sees. In deciding which cache protection tactics to use the birds take into account the dominance status of the potential pilferer in relation to their own dominance status, employing different strategies if they are dominant to the onlooker than if they are subordinate (Dally, Emery, & Clayton, 2005b, 2006). The variety of these cache protection strategies are not exclusive to western scrub-jays: similar tactics have been observed in ravens (e.g., Bugnyar & Heinrich, 2005; Bugnyar & Kotrschal, 2002a, 2002b, 2004; Bugnyar, Stöwe, & Heinrich, 2007; Heinrich & Pepper, 1998), Clark’s nutcrackers (Clary & Kelley, 2011), Florida scrub-jays (Kulahci & Bowman, 2011) and Eurasian jays (Legg & Clayton, *in press*; Shaw & Clayton, 2012, 2013, *in press*).

1.2. Experience projection by corvids

Perhaps the most striking finding, however, and one that was discussed earlier when considering complex social cognitive skills including theory of mind, is that it is only those birds who have been thieves themselves in the past that engage in the re-caching strategies of moving food to new places once the potential pilferer has left the scene (Emery & Clayton, 2001). Naïve birds that have not stolen other birds’ caches do not do so, ruling out the possibility that such cache protection strategies are hardwired. Furthermore, the re-caching behaviour is not simply a response to the stress of being observed and subsequent memory failure (Thom & Clayton, 2013), as has been suggested recently by computational modelling work (van der Vaart, Verbrugge, & Hemelrijk, 2012). It is important to note that in these experiments the jays were neither rewarded nor punished for re-caching, and in fact they were not given the opportunity to recover their re-caches and thus discover whether or not re-caching was successful. We can therefore also rule out the possibility that the birds could have learned about the benefits of re-caching. Emery and Clayton (2001) have argued that the inference is that the experienced pilferers

engage in experience projection, predicting by analogy of their own behaviour as a pilferer, anticipating that the onlooker might do what they would do in such circumstances, and thus move their caches to new places that the potential pilferer does not know about. Moreover, the responses of these experienced birds are highly flexible. The birds only re-cache the food when a potential pilferer has observed them cache—they do not move the food to new places if the onlooker was their mate, with whom they share their caches, or if the potential thief did not witness the caching event (Dally et al., 2005b; Emery & Clayton, 2001).

In short, this finding suggests that the old adage “it takes a thief to know one” applies not only to humans, but also to these food-caching jays. This is far from a trivial capacity. Experiments we have conducted recently with young children suggest that they have great difficulty projecting their own experience to infer what others have and have not seen, and do and do not know (Teufel et al., 2013).

1.3. Experience projection by children

In the experiment reported by Teufel et al. (2013), we tested two-year-old toddlers on a game in which the children had to put stickers of particular animals onto the appropriate location on a game board. The task was based on a procedure developed by O'Neill (1996) that was designed to test young children's understanding of the relationship between visual perception and knowledge formation, namely that seeing leads to knowing and not seeing leads to not knowing. In the crucial part of O'Neill's experiment, the child sat at a table with the experimenter and a parent. Two identical opaque boxes were placed at the far end of the table beyond the child's reach. In each trial, the experimenter dropped a sticker in one of the two boxes, and the child had to request help from the parent to get the sticker. In the “seeing” condition, when Mummy's eyes were open and uncovered during the hiding event, the child should simply ask for the sticker. By contrast, in the “unseeing” condition, in which Mummy had covered her eyes with her hands during the

hiding event, then the child would need to indicate which of the boxes contained the sticker once Mummy had opened her eyes again. In the original experiment by O'Neill (1996), young children spontaneously pointed to the correct box when Mummy's eyes had been covered by her hands during the hiding event, whereas if Mummy's eyes had been uncovered they would typically say “go get it” or words to that effect. This finding could be taken to suggest that the toddlers have some understanding of the relationship between visual perception and knowledge formation, that Mummy's lack of perceptual access to a certain fact leads to ignorance about that fact and that a pointing gesture is an appropriate way of informing her about which box contains the sticker.

O'Neill (1996) argued that the results of her study did not necessarily indicate that seeing leads to knowing, and not-seeing leads to not-knowing. Perhaps the toddlers simply realized that Mummy was disengaged from the hiding event and wanted to update her about this event. This simpler explanation could be of the form “tell other people about significant happenings they did not take part in with me” O'Neill (1996, p. 674). Support for this “disengagement plus updating” account comes from a study by Dunham, Dunham, and O'Keefe (2000), who found that when Mummy first covered her eyes but then reopened them, either before or after the sticker was hidden, the younger children pointed equally as often in both conditions. Dunham et al. (2000) argued that the younger children based their judgement of whether or not Mummy was disengaged on the basis of global contextual cues of the hiding game, while for the older children, disengagement was associated with more specific behavioural cues, namely whether or not Mummy's eyes were visible during the critical hiding event. Other authors have suggested simpler behavioural accounts of the young children's behaviour (e.g., Doherty & Anderson, 1999; Perner & Ruffman, 2005). The children could be using a simple rule about the presence or absence of eyes, for example, in order to decide whether or not to point. They could also use their personal experience of playing peekaboo and therefore learning about

the effects of covering and uncovering their eyes, without having to understand the causal connection between perceptual access and knowledge transfer. That is why it was so important to contrast the experienced pilferers with the naïve jays in the original experience projection experiment on the scrub-jays—because the birds had been hand raised, it was possible to know what experiences these birds had already acquired (Emery & Clayton, 2001).

At issue, then, is whether, and to what extent, the children's success in this experiment was cognitive or behavioural. To explore this further, we added two artificial "seeing" and "unseeing" conditions, in which Mummy wore a pair of glasses that meant that her eyes could no longer be seen (Teufel et al., 2013).¹ From the perspective of the person wearing the glasses, one pair was transparent and the other was completely opaque. It was not possible to determine which pair of glasses was transparent and which one was opaque by looking at the glasses from the outside, however, because both pairs had mirrored lenses. The two pairs of glasses could be distinguished visually but not in ways that predicted whether or not they were transparent or opaque. One pair was cased within a blue mask, and the other within a yellow one, such that for half of the tests yellow glasses were transparent and for half of the tests the blue ones were transparent.

In Experiment 1, the children were given first-hand experience of wearing the glasses and therefore of learning that they could see through the transparent pair but not through the opaque pair, but importantly, they did not experience how another person's behaviour might change when wearing the glasses. On test, in the two Natural Conditions, Mummy simply had her eyes open or covered her eyes with her hands, as in the original experiment by O'Neill (1996). In the two Artificial Conditions, Mummy put on a pair of the glasses and the children were asked whether or not Mummy could see. In order to infer whether or not Mummy could see the hiding of the sticker, the children had to use their own first-hand visual experience of wearing the glasses.

If the toddlers understand that other people have visual experiences that are similar to their own then they should be able to use their first-hand experience with the glasses to infer whether or not Mummy can see. Furthermore, if the two-year-olds can understand the causal connection between perceptual access and knowledge formation, they should be more likely to use pointing gestures in the condition in which, during the hiding of the sticker, Mummy was wearing the opaque glasses compared to the condition in which Mummy wore the transparent glasses, mirroring the naturalistic "seen" (eyes open) and "unseen" (eyes covered) conditions.

In Experiment 2, the toddlers were given the reverse experiences. They were not given the opportunity to wear the glasses and therefore they could not use their own first-hand experience to infer whether or not Mummy could or could not see. Instead, they received third-hand experience, namely by observing how Mummy's behaviour changed when she was wearing the glasses. In this way, they could learn that a particular pair of glasses predicted a specific change in Mummy's behaviour, for example, that Mummy becomes clumsy or disengaged when she wears the opaque glasses but not if she wears transparent glasses. If the toddlers are using such behaviour-reading rather than an understanding of another's mental states, then they should use pointing gestures differentially in response to a knowledgeable versus an ignorant parent only in Experiment 2.

We replicated the original findings of O'Neill (1996) in the Natural Seen and Unseen Conditions, namely that when Mummy's eyes were open she could see and therefore she could locate the correct box. Whereas, when Mummy's eyes had been covered when the box had been baited, then she could not see and they needed to point to the box containing the out-of-sight sticker. By contrast, we found some striking dissociations between the "Can Mummy see?" question and the pointing task in the children's performance in the Artificial Conditions (Teufel et al., 2013).

¹The original idea was first suggested by Heyes (1998).

In Experiment 1, the toddlers were able to correctly infer whether or not Mummy could see by using their first-hand experience of wearing the glasses and thus concluded that Mummy could not see when she wore the opaque glasses, but that she could see when she wore the transparent glasses. However, they were unable to use this information about whether or not Mummy could see to point specifically in those instances in which Mummy was ignorant of the correct box location, namely when she had not witnessed the sticker being hidden because she had been wearing the opaque glasses. In the absence of seeing Mummy's eyes open, the children were much more likely to point and there was no significant difference between the two artificial conditions on the child's tendency to point. This result shows that there is a dissociation between the seeing test and the pointing test, namely that the toddlers can use their first-hand experience to pass the "Can Mummy see?" questions but not the pointing test in these Artificial Seen and Unseen Conditions. So unlike the western scrub-jays in Emery and Clayton's (2001) experience projection experiment, the toddlers cannot use their experience to infer what another individual may or may not know.

It is not that the toddlers cannot use social information and behavioural cues to decide whether or not they should point, as shown by the results of Experiment 2. Here the opposite dissociation is found in the two artificial conditions. The toddlers fail the "Can Mummy see?" question when they only have third-person experience of how Mummy behaves when she is wearing the glasses as opposed to first-hand experience of seeing through the glasses themselves. Yet they pass the pointing task, only pointing when Mummy had worn the opaque glasses during the hiding of the sticker.

The results of the two experiments show a double dissociation between the "Can Mummy see?" question and the pointing task. In each experiment, the toddlers pass one of the two conditions but not the other in the Artificial Seen and Unseen conditions, in which they cannot use the presence or absence of eyes, or their personal past experience of eyes being covered and uncovered by their hands. First-hand experience of wearing the mirrored

glasses can be used to infer whether or not Mummy can see when she is wearing the glasses. However, the young children cannot use this information to infer whether or not they need to point. By contrast, the young children can use their third-hand experience of watching Mummy's behaviour when she wears the mirrored glasses to infer whether or not they need to point, perhaps based on whether or not Mummy appears engaged or disengaged, but they fail to use this information to infer whether Mummy can or cannot see. Taken together, these findings suggest that the two-year-old child's understanding of the "seeing leads to knowing" relationship is rather limited (Teufel et al., 2013).

1.4. Cooperative interactions

So far we have considered the social cognition of corvids in terms of competitive interactions between caching and pilfering. However, their social cognition is not restricted to such competitive interactions. Rooks can solve a cooperative task in which two birds must pull the string together in order to reach food that would otherwise be out of beak reach (Seed et al., 2008). Even more impressive is the ability of the male Eurasian jay to understand what his female partner wants to eat, and share that food with her even when it is in conflict with his own desires (Ostojić et al., 2013, 2014).

1.5. Corvid food-sharing

During the breeding season corvids will actively provision their partners with food. In the case of Eurasian jays, it is easy to observe the amount and type of food that the birds share, as each item is transferred individually from beak to beak. This allowed us to investigate another aspect of Theory of Mind, namely desire state attribution. We tested whether the males could attribute changes in the desire state to their female partner during courtship feeding (Ostojić et al., 2013, 2014).

Desire states can be manipulated by satiating individual jays with a particular type of food. Such satiety is specific because it reduces the

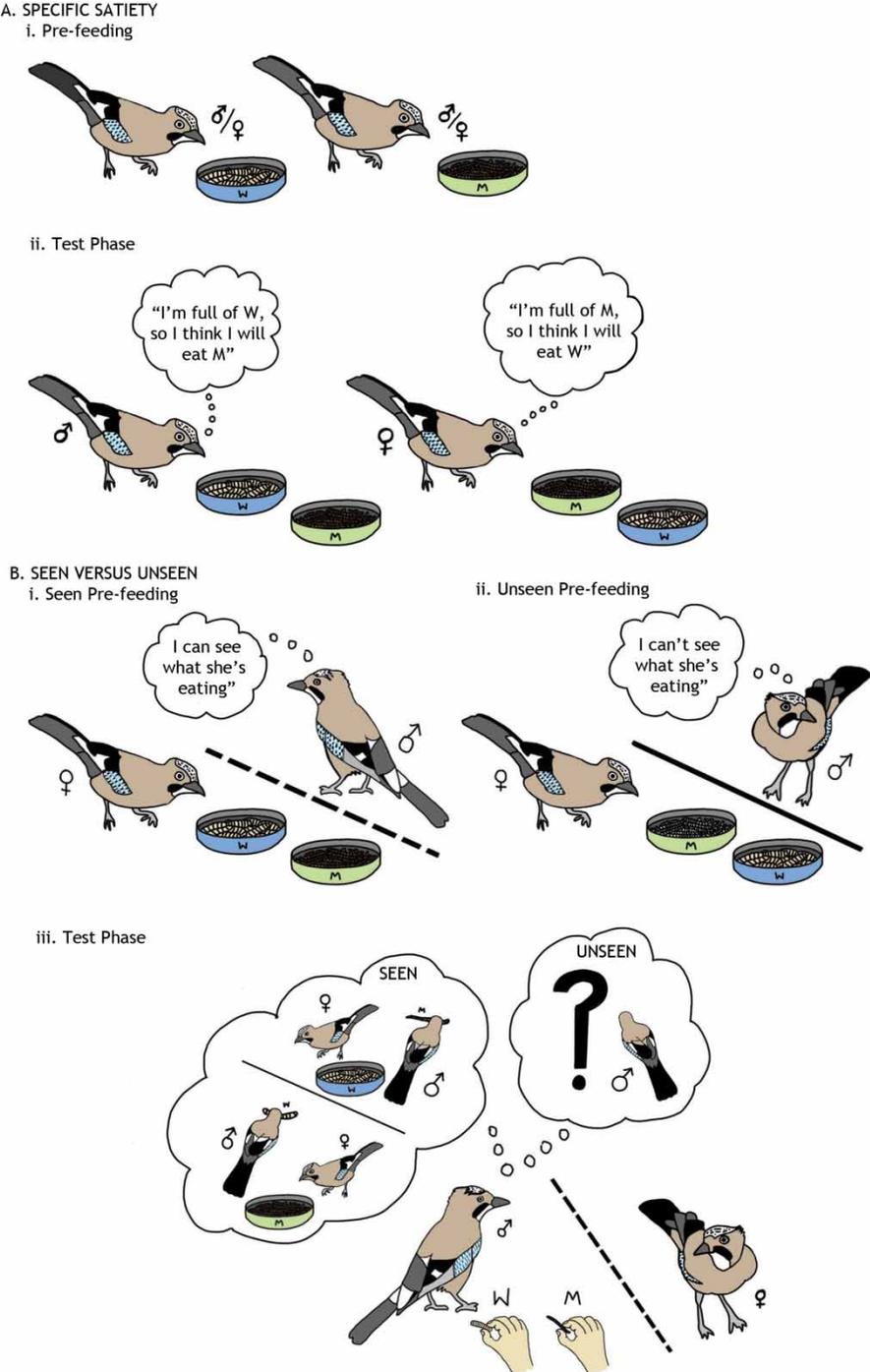
desire for that particular food without necessarily impacting on the desire for other food types. To induce specific satiety we gave the birds either wax worms (W) or mealworms (M) to eat during the pre-feeding stage and then a choice between these two foods in the test phase (see Figure 1A; Ostojić et al., 2013). All 13 jays showed specific satiety, consuming a lower proportion of the W if they had been pre-fed W than if they had been pre-fed M. As there was a large degree of variation between individuals in the amount of food eaten and in their preferences for one food over another, Ostojić et al. (2013) compared the birds' choices on the test trials with their eating pattern in a baseline condition where the birds had been pre-fed on their maintenance diet (MD), which does not include W and M.

In terms of desire state attribution, the key question is whether the male will take his partner's specific satiety into account in deciding which foods to offer her during courtship feeding. A male that does take his partner's specific satiety into account should adjust his food-sharing behaviour after observing her being pre-fed on a particular food and share less of that food relative to a baseline in which the food was not devalued for the female. In order to test this hypothesis, in the Food-Sharing Experiment the desire state of the female was manipulated by pre-feeding her either W or M or the baseline MD. The males were always fed the baseline MD to keep their desire constant over trials. There were two conditions. In the Seen Condition, the males watched their partner being pre-fed for 15 min in an adjacent compartment through a wire mesh window that was covered by a transparent screen (Figure 1Bi). In the Unseen Condition, the males could not see what the females ate during the pre-feeding phase because an opaque screen covered the mesh window (Figure 1Bii), but the males could continue to hear the female. At the end of the pre-feeding phase of both conditions, the screen was removed and each male was given 20 opportunities to choose a single W or M that he could give to his partner through the wire mesh window.

If the male's choice of what to share was influenced by what he had seen his partner eat, then his courtship feeding behaviour should differ between these two conditions. The Unseen Condition is an important control to establish whether the male's choice is guided by what he has seen her eat and thus knows about her desire state, or whether he is simply behaviour-reading, that is responding to differences in her behaviour during the food-sharing test phase. The females could, for example, have indicated their preference for a particular food type during the test phase by begging more intensely for one of the foods, or immediately after a sharing bout, the female could have indicated either acceptance or rejection of the food he had just offered her and this could then influence his subsequent choices of the two foods.

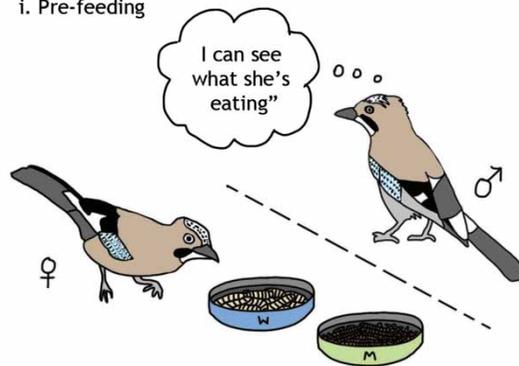
The pattern of food-sharing did differ between the Seen and Unseen conditions. It was crucial to compare the sharing patterns in the test trials in which females were pre-fed either W or M to that shown in the baseline when females were pre-fed MD because of inter-individual variation in the amount of sharing bouts and in the preference to share one food over another, just as we did for the proportion of W eaten in the Food-Sharing Experiment.

In the Seen Condition, the males responded to the current desire state of their partners by sharing a lower proportion of W when the females had been pre-fed W than when they had been pre-fed M. By contrast, in the Unseen Condition there was no difference in the proportion of W given when the female was pre-fed W or M. This pattern of results suggests that the males needed to observe what the females had eaten during the pre-feeding phase—simply observing her behaviour during the test phase did not provide them with sufficient information to ascertain which food she desired most. It is also important to note that the males never had visual access to the females during the test phase of the specific satiety experiment and consequently the decrease in the males' sharing of the pre-fed food in the Seen Condition could not be explained by



C. OBSERVATIONAL SPECIFIC SATIETY

i. Pre-feeding



ii. Test Phase

Figure 1. *Continued.*

them having had any prior experience of the females' response to pre-feeding in this context.

One possible explanation for the difference between the Seen and the Unseen conditions is that males developed specific satiety themselves from watching the females being pre-fed on a particular food and that their subsequent sharing behaviour reflected their own decreased desire for the pre-fed food, rather than an understanding of the female's decreased desire as a consequence of eating that food. To test this possibility, we ran a third experiment, which we termed the Observational Specific Satiety experiment (Figure 1C). The pre-feeding phase was identical to the pre-feeding phase in the Seen Condition of the Food-Sharing experiment. The female was then released back into the aviary after the pre-

feeding stage and then the males were given the opportunity to eat W and M just as they were in the original Specific Satiety Experiment.

If specific satiety can be induced simply by watching the female eat a particular food as opposed to actually consuming the food themselves, then the males' eating behaviour in the Observational Specific Satiety experiment should show the same pattern of results as in the original Specific Satiety experiment, namely a decrease in preference for W if they had either been pre-fed W as opposed to M or watched the female being pre-fed W as opposed to M. This was not the case. The fact that observing the female being pre-fed did not induce a decrease in the male's own desire for that food rules out the possibility that males developed observational specific satiety

through watching the female being pre-fed on the test foods during the Food-Sharing experiment.

Taken together, the results of these three experiments suggest that the jays can flexibly cater for their partner's desire state provided they have seen what she has consumed beforehand during the pre-feeding stage, even when that desire state is in conflict with the male's own motivational state (Ostojić et al., 2013). Furthermore, a subsequent experiment tested the extent to which the males' decisions are influenced by their own current desire (Ostojić et al., 2014). We found that when the male's desire matched his partner's needs, then the males correctly shared the food that was desired by both parties. Even when the female's desire differed from the male's own desire, then his decision of what to share was not driven entirely by his own desire, suggesting that the males also took their partner's desire into account. In short, male Eurasian jays can use this information to know what their partners have been sated on and thus what they will want now. In common with the research on experience projection by jays, this finding is particularly intriguing in the light of some experiments we have conducted recently on desire state attribution in young children (Legg, Ostojić, Hughes, & Clayton, 2014).

1.6. Food sharing by children

A number of experiments have been conducted to investigate when young children develop the ability to respond appropriately to another individual who directly indicates a different desire to the child's own desire (conflicting desires tasks). The importance of the conflicting desire tasks that involve inference lies in the possibility that they might be tests of whether or not children are truly representing another individual's desires as mental states. When the protagonist's desires concur with their own, then young children can simply use their own desires without having to differentiate between their own mental states and those of others. By contrast, children who cannot differentiate other individuals' mental states from their own will make errors on the conflicting desires tasks when they have to infer what the protagonist

wants because they fail to understand that someone could want something different to that which they want. They do not need to do so, of course, when they are told explicitly about the other individual's desires because they can use simple behaviour-reading cues such as verbal and facial expressions. In the case where desires must be inferred, however, in order to pass the conflicting desires task the children need to understand that mental states are subjective, that they can differ between people and even within the same individual at different times. The power of perspective taking is that it allows you to understand other minds and other times.

At first sight the results of the studies themselves appear conflicting: in some studies, toddlers of about 18 months of age can pass such tasks (Repacholi & Gopnik, 1997), whereas other studies suggest that children under five years old struggle to inhibit their own desire when predicting another individual's desire (Moore et al., 1995). One difference between the two studies was whether or not the children received explicit information about what their parents wanted. In Repacholi and Gopnik's (1997) study the toddlers received direct and explicit information about what their parents wanted in the form of a verbal and facial expression. By contrast, in the experiment by Moore et al. (1995) the young children were provided with rather limited information, namely a story about the protagonist being frightened by an animal, and from that they had to infer what the other individual desired.

Cassidy et al. (2005) directly tested whether or not performance on conflicting desire tasks is influenced by how the children are informed of the other individual's desires. In their study, three-year-old children were asked to predict a protagonist's action in a range of scenarios in which the children's own desires either concurred or conflicted with the protagonists' desires. In some cases, the protagonist's desire was explicitly mentioned and in other cases it had to be inferred, for example by watching them eat and thus become sated on a particular food. Cassidy et al. (2005) found that the three-year-olds were able to infer the other individual's desires. They could also attribute

conflicting desires. However, when the task required the children to do both things, namely to infer what the protagonist wanted when that desire was in conflict with their own, then the three-year-olds performed at chance. Taken together, these findings might be taken to suggest that although the very young children are able to pass the task under some circumstances, they do so without truly representing the protagonist's desires. In line with studies on young children's understanding of the relationship between visual perception and knowledge formation, a behaviour-reading account seems more likely than a cognitive one. The children may have relied on rules of thumb and past experience just as they may have done in the "seeing leads to knowing" studies. For example, the items the children chose to share with the protagonist may have been informed by their past experience of contingencies between the protagonist's positive and negative expressions and their future actions.

It should be noted, however, that failure in the conflicting desires task does not distinguish between children who lack an understanding of the subjectivity of mental states and those with an inability to inhibit control by their own mental state (Hughes & Russell, 1993; Perner, Lang, & Kloo, 2002). We have just begun to investigate children's ability to comprehend the subjectivity of desires in a scenario where there was no need to inhibit their own desires (Legg et al., 2014). Conflicting desires tasks require children to represent that their own desire is different from another individual's. By contrast, in our current study (Legg et al., 2014), the children were required to understand that another individual's desire may change over time. Consequently, subjectivity in this task was expressed through changes to a third person's desires.

We asked children of four to six years of age to pack a lunch box with food to give to another individual after observing them eating different foods to satiety once per day across three consecutive days (Legg et al., 2014). The protagonist's desires were manipulated by pre-feeding them one of two foods, just as we did for the jays. Over the three days of testing, the children watched each of three

4-minute-long video clips depicting the same protagonist (male for the boys, female for the girls) becoming satiated in three different conditions: on their dinner (Eats Baseline); on crackers (Eats Crackers) or on slices of apple (Eats Apples). The Eats Baseline acted to assess the children's baseline preference for sharing apples and crackers in the same way as the pre-fed MD baseline for the jays. Consequently, each child was always shown the Eats Baseline video first, and then the order in which the children saw the Eats Apples and Eats Crackers videos was counterbalanced. Each 4-minute-long video was followed immediately by a 10-second clip in which the protagonist sat in front of a bowl filled with crackers and a bowl filled with slices of apples. In the Eats Baseline trial the protagonist remained silent and made no indication of their preference for apples or crackers, whereas in the Eats Apples and the Eats Crackers trials the protagonist indicated their preference for one food over the other (see below). The food-sharing phase followed immediately afterwards. The children were given 50 slices of apple and 50 crackers and two lunch boxes, a blue-labelled container to give to the protagonist and a transparent container for themselves. We introduced the additional condition (Choose for Self) because previous research has found that giving children the opportunity to choose some for themselves improves their ability to respond to others' desire states by reducing the salience of their own desire (Atance, Bernstein, & Meltzoff, 2010). The children were asked to choose food for the protagonist first before choosing their own food.

If children understand that another individual's desires can change over time, then the type of food they choose to share with that other person should depend upon which food the protagonist is currently satiated on, just as the male jays' decision of what to feed his partner depended on what he had seen her eat. In the first experiment, we tested whether or not children are able to change their choice of which food to give to the protagonist in response to what that person directly indicated that they would like to eat. In the second experiment, children were tested using the same paradigm but this time they saw either the

protagonist indicating which food they were “full of” or the children had to infer which food the protagonist was sated on based on which food they had seen the protagonist eat during the pre-feeding phase. In this way, we could compare the children’s changes in sharing behaviour when the protagonist’s different desires were directly indicated through verbal comments (Experiment 1: “I’d like some of that”; Experiment 2: “I’m full of that”) and when these different desires had to be inferred from observing which food the protagonist had eaten to satiety (Experiment 2: Infer group). The latter is analogous to the Seen Condition in the Food-Sharing experiment of Ostojić et al. 2013.

We found that the four- and five-year-old children responded correctly when they were directly informed of the protagonist’s desires (Legg et al., 2014), in line with the previous studies (e.g., Cassidy et al., 2005). Unlike the jays in the Seen condition of Ostojić et al. (2013), however, the four- and five-year-old children failed to respond correctly when they had to infer the protagonist’s desires based on what they had seen them eat. It was only the six-year-olds who could respond appropriately regardless of how the protagonist’s desire was indicated. The results of our desire task confirm previous studies by showing that young children struggle to infer desires that conflict with their own based on what they have seen them eat, but do not struggle when the protagonist has directly indicated their desire in the conflicting desire situation. Our findings add to the previous work by demonstrating that the children’s difficulty with inferring desires is not limited to cases where their own desire is in conflict with a protagonist’s but is also present when a single individual changes their desire over time. In short, we suggest that young children below the age of six struggle to infer desires whenever they have to represent the subjective nature of a desire state. This requires them to engage in perspective taking, to understand that other minds may differ from their own, but also that these minds, own and other, may change over time and thus differ from the present self. It is this topic of temporal perspective taking to which we shall now turn.

2. MENTAL TIME TRAVEL

Although physical time travel remains within the realm of fiction, mental time travel is something which adult humans engage in much of the time, travelling backwards in the mind’s eye to remember the past (episodic memory) and forwards to plan for the future (episodic future thinking). Temporal perspective taking allows us humans to possess an ever present awareness of the passage of time, to acknowledge that what was once the future will rapidly become the past and that what happened in the past can be recreated in the ever-changing yet persistent present to question which version is correct—just one, or all, or none. As Mark Twain assiduously remarked, “I have been through some terrible things in my life, some of which actually happened”.

According to the Prospective Brain hypothesis proposed by Schacter and colleagues, the brain’s crucial function is to use our past experiences that have been acquired by the episodic memory system in order to ponder, plan and predict future possibilities (Schacter, Addis, & Buckner, 2007; Schacter et al., 2012). In other words, the function of episodic memory lies primarily in its constructive rather than its reconstructive ability—the system evolved in order to mentally simulate multiple future scenarios by flexibly recombining details of the events that have happened to us in the past without having to physically engage in the actual behaviour. There is a trade-off between flexibility and stability, however, and therefore the cost of using the episodic memory system is that it is much more vulnerable than the semantic knowledge system to errors such as misattribution and false recognition because of its creative nature. This is the reason why our episodic memories are surprisingly inaccurate compared to our semantic knowledge-based memories, and why they are more fragile and more labile—for each time we revisit these memories using our episodic system we recreate them. This does not happen with semantic system, devoid as it is of a creative time-travelling self (see Schacter, Addis, & Buckner, 2008 for an excellent and relatively recent review).

There has been considerable debate as to whether mental time travel is a uniquely human ability (e.g., Suddendorf & Corballis, 1997; Tulving, 2005), or whether we share this cognitive feat with some other animals (e.g., Clayton, Bussey, & Dickinson, 2003; Corballis, 2013). Part of the difficulty is that mental time travel has typically been characterized in terms of its phenomenological consciousness. This episodic system has two key features that the semantic knowledge system does not. The first is an awareness of the subjective sense of time, of re-experiencing now in the mind's eye an event that happened in the past (chronesthesia; Tulving, 2002). The second is an awareness of being the owner and author of these memories and forethoughts (autonoesis; Wheeler, 2000). As William James so aptly wrote, "[m]emory requires more than the mere dating of a fact in the past. It must be dated in *my* past" (James, 1890, p. 6509).

In the absence of any agreed behavioural markers of consciousness in non-linguistic animals and preverbal children it is not possible to evaluate empirically whether or not mental time travel is unique to humans, nor precisely when it develops in young humans (Griffiths, Dickinson, & Clayton, 1999). This dilemma can be resolved to some degree, however, by differentiating between the phenomenological and behavioural criteria for episodic cognition. The latter is referred to as episodic-like cognition in acknowledgement that these criteria explicitly ignore the involvement of phenomenological consciousness.

My colleagues and I have argued that episodic-like memory, the retrospective component of mental time travel in animals, needs to fulfil three criteria to meet the behavioural properties of episodic memory as defined for humans: content, structure and flexibility (Clayton, Bussey, & Dickinson, 2003). In terms of the content of an episodic-like memory, the subject must remember what happened, where and when on the basis of a single past experience, and in a way that cannot be explained in terms of relative familiarity. Second, the what-where-and-when components form an integrated structure which allow the subject to discriminate between similar episodes that occurred at different times and places.

Finally the information must be capable of flexible deployment, and thus be updated and generalized across situations.

2.1. Episodic-like memory in corvids

We tested whether western scrub-jays can episodically recall specific past caching episodes in terms of what happened where and when (Clayton & Dickinson, 1998). To do so we capitalized on the fact that these birds will readily cache perishable items such as worms that degrade over time as well as non-perishable nuts, and as they do not eat rotten worms, recovering the perishable food caches is only valuable when the food is still fresh. To investigate whether or not jays can remember which foods they have hidden where and how long ago, they were given the opportunity to cache worms and peanuts and then recover these caches of food either after a short delay of 4 hours or a long delay of 124 hours (i.e., 5 days plus 4 hours). This procedure ensured that the birds were tested at the same time of day in both conditions so that they could not use a circadian rhythm to discriminate between short and long delays but instead had to remember how long ago the caching event had occurred.

Although the jays had no cue to predict whether or not the worms had perished other than the passage of time between caching and recovery, the birds rapidly learned that the highly preferred worms were still fresh when recovered 4 hours after caching, whereas they were rotten and tasted unpleasant after 124 hours. Consequently, the jays avoided the wax worm caches if they had been cached 124 hours earlier, and instead only recovered and ate the peanuts, which do not perish. After the birds had received this experience of caching and recovering worms and peanuts after the short and long delays, we introduced test trials in which the food was removed prior to recovery to ensure that the birds relied on memory rather than olfactory cues emanating directly from the food (Clayton & Dickinson, 1998). Subsequent tests have revealed that the jays also remember which perishable foods they have hidden where and how long ago, irrespective of whether the foods

decayed or ripened (Clayton, Yu, & Dickinson, 2001; de Kort, Dickinson, & Clayton, 2005). The jays also discriminate between similar episodes that occurred at different times and places, demonstrating that they form integrated what-where-and-when components (Clayton et al., 2001).

We also found that the jays could update and generalize across situations, and therefore that these episodic-like memories also met the flexible deployment criterion (Clayton, Yu, & Dickinson, 2003). We tested this by allowing the birds to cache and recover perishable and non-perishable food items using an interleaved procedure in which the birds cached in different trays on three subsequent days, and only once they had completed the caching trials did they get the opportunity to recover their caches from each tray. We reasoned that, if the birds were capable of flexible deployment, then they should be able to update their knowledge about the rate of perishability of the food and change their search behaviour at recovery accordingly, even though the episodic information about what they cached where and when was encoded prior to the acquisition of the new knowledge about the decay rates, i.e., prior to any opportunity to recover the caches. When the jays cached perishable and non-perishable items in different locations in one tray and then subsequently discovered that the perishable items from another tray had degraded more quickly than they expected, the birds immediately switched their search preference in favour of the non-perishable nuts when given the original tray back. The birds continued to search for the perishable food if it had been cached recently, thereby showing that they had not simply developed a general aversion to searching for food that might rot. To our knowledge, this is the only published demonstration of the declarative flexibility with which animals can update their information after the time of encoding (Clayton, Yu, & Dickinson, 2003).

Since our initial studies, a number of other laboratories have investigated whether or not animals have episodic-like memory using paradigms analogous to those employed with the jays. There is now good evidence that a diverse range of animals can remember the what-where-and-when of past

events, including rats (Babb & Crystal, 2006a, 2006b), mice (Dere, Huston, & De Souza Silva, 2005), magpies (Zinkivskay, Nazir, & Smilders, 2009), chickadees (Feeney, Roberts, & Sherry, 2009), chimpanzees (Martin-Ordas, Haun, Colmenares, & Call, 2010) and cuttlefish (Jozet-Alves, Bertin, & Clayton, 2013). The extent to which these what-where-and-when memories of animals involve mental time travel remains an open question, given that there is no way of knowing whether or not animals possess autonoesis and chronesthesia. What we can investigate, however, is the developmental trajectories of these cognitive abilities by determining whether or not children pass what-where-and-when tasks at around the same age as they pass other tests of mental time travel. Much of this work has focused on the prospective component, namely episodic future thinking, rather than the mnemonic retrospective component.

2.2. Episodic-like memory and cognition by children

In the tests of episodic future thinking, the typical developmental trajectory is as follows: young children fail at three years of age, they show a transitional state of performance at four years of age, and they pass at five years of age (Atance & Meltzoff, 2005, 2006; Busby & Suddendorf, 2005; Lemon & Moore, 2007; Moore, Barresi, & Thompson, 1998; Russell, Alexis, & Clayton, 2009; Suddendorf & Busby, 2005; but see Suddendorf, Nielsen, & von Gehlen, 2011, for a case in which children do pass at four years of age). Recent studies in developmental cognition have also adopted the what-where-and-when paradigm to track the emergence of the retrospective component, episodic-like memory, in young children. For example, Hayne and Imuta (2011) developed a hide-and-seek paradigm akin to the scrub-jay caching paradigm to test the ability of three- and four-year-old children to remember specific past caching events, and Bauer et al. (2012) investigated the age at which children could bind the “where” component of a personally experienced event with the other details of the event. In line with the

results of other tests of episodic cognition in children of three to five years of age, these what-where-and-when memories also show the typical developmental trajectory outlined above, although rudimentary episodic-like memory skills do appear even in three-year-old children (Hayne & Imuta, 2011). Work by Scarf, Gross, & Columbo (2013) suggests that three-year-olds can remember these episodic-like memories over short but not long delays, so perhaps it is the ability to retain episodic memories, as opposed to the ability to encode the details of the event, that develops across this time window (Mullally & Maguire, 2014).

My colleagues and I (Russell, Cheke, Clayton, & Meltzoff, 2011) also tested three-, four- and five-year-old children on a what-where-and-when task inspired by the Clayton and Dickinson (1998) scrub-jay paradigm. In our current what-where-and-when task the young children were required to bind what (the type of food), where (the location of the boxes in which the food had been placed) and when (how long ago), just as the jays were required to do. By contrast, however, the children were given a prospective task rather than a retrospective one. So rather than being given a choice between the foods in the two boxes after either a short or long delay, which would have been analogous to the scrub-jay what-where-and-when *memory* procedure, in fact the children were asked at the time of “caching” (i.e., baiting) to *anticipate* which box they would visit to get something to eat when they came back later, either after a short or a long delay.

The issue is whether or not children show the same developmental trajectory on our what-where-and-when task as they do on the other tests of episodic foresight. The assumption is that a similar developmental trajectory would suggest that our what-where-and-when task taps into something similar to what the other tests of episodic cognition measure, a finding that would provide support for the hypothesis that episodic-like cognition really is like episodic cognition. By contrast, if the developmental trajectory for the what-where-and-when tasks were faster, such that even children of three years of age passed the task, then this finding would suggest that the scrub-jay-inspired paradigm taps into a simpler process.

In our what-where-and-when task, the children were given two types of food to choose from, just as the jays were. Here the preferred food is a chocolate teddy bear and the less preferred food is a rich tea finger biscuit, analogous to the wax worms and peanuts in the Clayton and Dickinson (1998) study, respectively. In one location (a hot box), but not in the other (a cold box), the chocolate teddy bear melts after the long interval but not after the short interval, and the children are told that they will not be allowed to eat the melted chocolate because it will make too much mess. The melting chocolate scenario parallels the degradation of the wax worms in the Clayton and Dickinson study. By contrast the biscuits do not change over time, to parallel the peanuts in the scrub-jay study. So if children can remember what-where-and-when, then they should choose the hot box that contains the chocolate after the short delay because the chocolate teddy bear will still be intact, but they should switch to choosing the cold box containing the finger biscuit after the long delay because by then the chocolate will have melted and therefore they will not be able to eat it.

As with the jays, the children were first given the opportunity to learn that food in the hot box melts, whereas that in the cold box does not. First they were shown both boxes and requested to place their hand in both boxes so that they could feel the difference in temperature between the two boxes. The children were then told that items placed in the hot box melt after the long delay but not after the short delay and shown photos of a melted snow man and a melted bar of chocolate that had been placed in the hot box after a long delay. They were also told “food keeps cool and fresh in the cold box”.

Following this familiarization phase, the children were given direct experience of the effects of the delay on the foods in the boxes. First they were shown two saucers, one containing a milk chocolate teddy bear and the other containing a rich tea finger biscuit. The children were then asked to place one saucer in each box. Each child received experience with both delays, and the order was counterbalanced. For the short delay

condition they were told “Let’s see what happens if we leave the things for a short time” before being escorted into an adjoining room for 3–5 minutes. On their return they found that all the items remained intact. For the long delay condition the instruction was “let’s see what happens when we leave the things for a long time”, and then went to play for 30–45 minutes. On their return the children discovered that although the biscuit was still intact, the chocolate had melted and had made a terrible mess, and therefore they could not eat it. Having experienced the effects of both delays on the foods “cached” in the boxes, the children were allowed to choose either a chocolate teddy bear or a finger biscuit to eat now. Only those children that chose the chocolate were invited to take part in the test trials, since a strong preference for the unmelted chocolate was an essential pre-requisite of this design, in much the same way as the strong preference for wax worms in the scrub-jay studies of Clayton and Dickinson (1998).

The test trial was administered the following day, and the children were divided into two groups, with half the children in each group receiving either the long or the short delay conditions. Unlike the jays, the children in each condition were only tested on one of the two delays, because children often just repeat the response to the first delay they are tested on. In the Future-Self Group, the children saw the chocolate teddy bear being placed in the hot box and the finger biscuit in the cold box. They were then asked to anticipate which box they would visit to get something to eat when they came back later, which would either be after a short (3–5 min) or a long (30–45 min) delay. In the Self-Caching Group the children were only shown the hot box (they were told that the cold box was not working today) and had to choose which food they would “cache” in it, to be retrieved either after a short or a long delay. In this latter case, the children were not asked to imagine what they would do in the future, but only to reason about the future palatability of the food which could be done using semantic knowledge-based future thinking as opposed to projecting one’s self into the future (i.e., episodic future thinking).

In terms of the proportion of correct responses, all the children were highly accurate with the short delay, having no problem selecting the box containing the chocolate teddy bear at a time when the chocolate would not have melted. What the children found difficult was the long delay condition. Indeed we found that the three-year-olds failed the long delay condition, performing no better than chance in both the Self-Caching and Future-Self groups, whereas the four- and five-year-olds had a greater proportion of correct responses. In the Self-Caching Group, both the four- and five-year-olds passed and there was no difference between the two age classes in the proportion of correct responses. In the Future-Self Group their performance did not reach statistical significance, although there was a trend ($p = .074$ for both age classes). Perhaps this difference reflects the fact that it is easier to solve the task using the semantic knowledge-based system as opposed to episodic future thinking, as discussed in the original paper (Russell et al., 2011).

Why did the children in the Future-Self Group have such difficulty with the long delay condition? One possibility is that they found it hard to inhibit their current desire for chocolate (Atance & Meltzoff, 2006), which was in conflict with their knowledge of what they should choose for the future (biscuit). A second possibility is that although the children knew that the chocolate would be melted after the long delay there was an overwhelming temptation to choose the chocolate simply because it was their favourite food.

In order to explore these possibilities, we tested four-year-old children on the equivalent of the ripening food scrub-jay paradigm, in which the preferred food is inedible after the short delay and delicious after the long delay, whereas the less preferred food is always edible (Russell et al., 2011). Again the less preferred food was a finger biscuit placed in the fridge to keep it fresh but now the favourite food was cake. After the short delay the cake was still in the form of a cake mix (inedible) that turned into delicious cake in the oven after the long delay. Familiarization, training and testing were conducted in the same way as for the previous experiment. If the children’s performance

in the previous experiment was affected by the executive challenge of having to inhibit their preference for the food type they currently prefer, then they should perform poorly on this second experiment, choosing for their current desire, the biscuit. If, however, their choices were masked by the overwhelming preference for the favourite food then they should choose the cake after the long delay as the currently less preferred cake mix will have become a baked cake.

We found that the four-year-olds in the Future-Self group performed poorly on the long delay, as they did in the previous experiment. This suggests that they struggled with the challenge of inhibiting reference to the currently preferred/edible food, namely the chocolate teddy bear in experiment 1 and the finger biscuit in experiment 2. Taken together, the results of these two experiments suggest that the poor performance of the four- and five-year-old children was affected by the executive challenge of having to inhibit their reference to the item they currently preferred, irrespective of whether or not that was their favourite food.

Interestingly, the four-year-olds in the Self-Caching Group showed a different pattern of results in experiment 2. They performed poorly on the short delay and well on the long delay question. Perhaps this was because it taps into a natural prepotent response to put a cake into the oven, whereas putting a biscuit into the fridge is not something most children will have had experience of. In other words, it seems likely that the four-year-olds “gained a kind of illegitimate success on the long-delay condition of Self-Caching ... basing their choice on semantic association rather than the logic of the task” (Russell et al., 2011, p. 367).

2.3. Other tests of episodic-like cognition

So far we have focused our attention on the what-where-and-when component of mental time travel, and the extent to which the performance of three-, four-, and five-year-old children on the what-where-and-when tasks shows the same sort of developmental trajectory as that found in

episodic future-thinking tasks. Although there is good evidence that a number of animals can remember the what-where-and-when of past events, the results for the children on the what-where-and-when prospective task are mixed. On the one hand the performance of the Self-Caching Group suggests an improvement over the same developmental period as other tests of episodic cognition—what we failed to detect in the episodic-like memory task was a developmental transition at age four, or clear success on the tasks for the five-year-old children in the Future-Self Group. As discussed earlier, one possible reason for this is that the children’s performance was compromised by the executive challenge of inhibiting reference to the currently referred item. This is particularly intriguing in the light of the recent studies we have conducted on the ability of corvids to dissociate current and future motivational states.

2.4. Dissociation of future and present motivational states in corvids

It was Suddendorf and Corballis (1997) who first argued that the ability to dissociate current from future motivational states is a critical feature of episodic future planning. Mental time travel provides a profound challenge to the motivational system because the subject has to suppress thoughts about their own current motivational state in order to allow them to imagine future needs, and to dissociate them from current desires. Indeed, this is probably why the young children have so much difficulty passing these tests of episodic cognition discussed above. The hypothesis was inspired by a comparative and developmental perspective, and indeed it has led to a number of tests of whether animals can dissociate current from future motivational needs. For example, Naqshbandi and Roberts (2006) provided squirrel monkeys with the opportunity to choose between eating one versus four dates. Eating dates makes monkeys thirsty, and the monkeys were then given some water after a long or a short delay. In fact the monkeys received water after a shorter delay if they had chosen the one date rather than

the four dates. The monkeys gradually reversed their natural preference to choose four dates over one date, suggesting that they could anticipate their future thirst. The problem is that one can give a simple alternative associative explanation in terms of reinforcement of the anticipatory act because the monkeys had received repeated trials in which they had the opportunity to learn about the consequences of their choices.

More convincing evidence for a dissociation between current and future motivational states comes from a study by Correia et al. (2007) on the food-caching choices of western scrub-jays. Here we capitalized on the specific satiety effect we first discussed in the context of food-sharing to test whether the jays would choose to cache the food they want now or whether they would choose the food they think they will want when they come to recover their caches at a later date. At the start of the experiment the birds cached the food they desired at the time, but the birds rapidly switched to caching the food they would want at the time of recovery, despite continuing to eat the food they desired at the time. This result suggests that the jays can plan future actions based on what they anticipate they will desire in the future as opposed to what they need now. Subsequent studies (Cheke & Clayton, 2012) show that Eurasian jays can also dissociate future from current motivational needs, and that they can differentiate between two distinct future desires and plan for each one appropriately, despite experiencing a conflicting current motivation.

It should be noted, however, that the bird does not need to imagine a future situation to solve such tasks. Clayton, Russell, & Dickinson (2009) argued that the act of recovering a particular food might trigger the memory of the time the bird cached that food. If the bird is hungry for that particular food then recovering that food type will be rewarding, thereby directly reinforcing the act of caching that particular food type through the memory of doing so. Such memory-mediated reinforcement does not require the jay to imagine what its future motivational state will be. Indeed, it may be for this very reason that the jays are

better at dissociating current and future motivational states than young children.

2.5. Tulving's Spoon Test

Tulving has argued that it is possible to test whether or not animals are capable of such episodic future thinking. He devised the "Spoon Test", based on an Estonian children's story tale, which he argues is a "future-based test of auto-noetic consciousness that does not rely on and need not be expressed through language" (Tulving, 2005, p. 43). In the original story, a young girl dreams about going to a birthday party. All of her friends are eating her favourite desert, a delicious chocolate mousse. All she can do is watch, however, because the rules of the game are that no one is allowed to eat it without their own spoon, and she has not brought one with her. As soon as she is back home, she goes to the kitchen to find a spoon which she caches under her pillow for safekeeping, knowing she will have one to hand in the future—be it for real birthday parties or even dreams of future birthday parties.

To pass the Spoon Test, the subject must act analogously to the little girl, using past experience to take action now for a future event, caching the spoon and then carrying it to a new party. Tulving (2005) pointed out that it is important that the spoon that has been obtained in another place and at another time, in a distinctly separate event and not just a continuation of the current episode. At issue then is whether there is any evidence that animals and young children can pass this Spoon Test.

Mulcahy and Call (2006) were the first to devise a Spoon Test for animals. They trained bonobos and orang-utans to use a tool to obtain a food reward that would otherwise have been out of reach, and then gave the apes the opportunity to choose one of the tools from the experimental room, which they could carry into their sleeping quarters to be used the following morning. Although most of them sometimes chose the correct tool, the individual pattern of success for each subject was not consistent across subsequent trials, as one would expect if the apes had a

proper understanding of the task. Furthermore, a simpler explanation in terms of reinforcement of the anticipatory act cannot be ruled out because the apes received a number of training trials (Raby et al., 2007a; Shettleworth, 2007; Suddendorf, 2006). A more convincing case of future planning was provided by Osvath and Osvath (2008), who showed that chimpanzees and orang-utans are capable of overriding immediate drives in favour of future needs when selecting a tool for use in the future.

Food-caching scrub-jays also pass the Spoon Test, spontaneously planning for tomorrow's breakfast without reference to their current motivational state (Raby et al., 2007a). The birds were given the opportunity to learn across six days that they received no food for breakfast in one end compartment (the hungry room), and that they received food for breakfast in the other end compartment (the breakfast room). For the rest of the day the birds had free access to both compartments and also to a central arena. During this time the birds were maintained on powdered food, which they could eat but not cache. This was to ensure that the birds were neither rewarded nor punished for caching, and therefore one could not invoke a reinforcement of the anticipatory act to explain the results. Having been confined to each end compartment at breakfast time for an equal number of times, the birds were unexpectedly provided with the opportunity to cache food in both compartments one evening, at a time when there was plenty of food for them to eat and therefore no reason for them to be hungry, by placing a bowl of whole food items in the central arena and two caching trays, one in each end compartment. If the jays can plan for the future then they should cache food in the hungry room, given that they did not know which compartment they would find themselves in at breakfast the following morning and therefore whether or not breakfast would be provided.

That is precisely what the birds did, suggesting that the jays could anticipate their future need for breakfast tomorrow, at a time when they would be hungry, and even though they were not hungry at the time when they had the opportunity to cache. Furthermore, as mentioned above, we can

rule out an explanation in terms of mediated reinforcement of the anticipatory act because the birds had not been given the opportunity to cache during training. Indeed, Shettleworth has argued that

two requirements for genuine future planning are that the behaviour involved should be a novel action or combination of actions ... and that it should be appropriate to a motivational state other than the one the animal is in at that moment ... Raby et al. describe the first observations that unambiguously fulfil both requirements. (Shettleworth, 2007, p. 825)

Taken together these results suggest that the scrub-jays and chimpanzees can pass the Spoon Test. Furthermore, in an analogous task with young children, in which they were given the opportunity to plan for tomorrow's playtime as opposed to breakfast, we found that the children did not pass the task until they were four years of age (Atance, Louw, & Clayton, in press). At issue, however, is whether or not these tasks require the use of episodic future thinking in the first place. In the absence of language there is no way of knowing whether the jays' ability to plan for future breakfasts is based on a projection of the self in time, which is what would be required to satisfy an episodic future-thinking account. The same reasoning applies to the apes' ability to choose tools and the children's ability to plan whether or not to hide a toy to play with in the future. It is entirely possible that the jays, apes and children rely on a semantic knowledge-based sense of the future, in which they take prospective action but without any personal mental time travel into the future (Raby et al., 2007a; Raby, Alexis, Dickinson, & Clayton, 2007b). To solve the Spoon Test, all the subject has to do is to decide what has to be done to ensure that the implement will be at hand, be it a spoon, another tool, or a food cache, without the need to imagine one's self in possible future episodes or scenarios. What these studies do demonstrate, however, is the capacity of non-linguistic animals and young children to plan for a future motivational state that stretches over a timescale of at least tomorrow. The results on corvids therefore challenge the assumption that the ability to anticipate and act for future needs evolved only in the ape lineage (Raby et al., 2007a).

3. PHYSICAL PROBLEM SOLVING

The third, and final, source of evidence for the cognitive capacities of corvids comes from studies of physical problem solving, and in particular their ability to manufacture tools and use them to reach food that would otherwise be out of beak reach. Although a number of species of corvids occasionally use tools in the wild (Lefebvre, Nicolakakis, & Boire, 2002), the New Caledonian crow is by far the most prolific tool-user (Hunt, 2000). This species makes two types of tools, which are used for obtaining insect larvae from holes in living and dead wood, from leaf litter, and from the base of plants (Hunt, 1996; Hunt & Gray, 2004a). They make stick tools, which often have a hook sculpted at one end, and stepped-cut tools, which are fashioned from Pandanus and fern leaves, resulting in a tool that has a thick base and tapers through one or more steps into a narrow tip (Hunt & Gray, 2004b).

A number of researchers have discussed whether or not the tool-using skills of corvids are a reflection of physical cognition, as they are thought to be for primates (e.g., Emery & Clayton, 2009b; McGrew, 2013). Support for this claim comes from the finding that there is a strong positive correlation between the frequency of tool-use and brain size in birds (Lefebvre et al., 2002) and in primates (Reader & Laland, 2002). Furthermore, young chimpanzees require years of observing expert tool-makers to learn how to use their tools efficiently: it takes five-and-a-half years to learn how to fish for termites (Lonsdorf, 2006) and three to five years to learn how to crack nuts using hammers and anvils (Biro et al., 2003). Although New Caledonian crows spontaneously insert sticks into crevices irrespective of whether they have had the opportunity to observe a tool-user (Kenward, Weir, Rutz, & Kacelnik, 2005), subsequent studies have shown that social learning is essential for the transmission of tool-manufacturing techniques (Holzhaider, Hunt, & Gray, 2010; Kenward, Weir, Rutz, & Kacelnik, 2006).

3.1. Innovative tool-use

The final source of evidence to support the argument that tool-users are intelligent comes from studies of innovative tool-use. For example, Weir et al. (2002) observed one captive New Caledonian crow called Betty spontaneously modifying a piece of wire to make a hook-shaped tool, which she then used to pull up a small bucket containing meat. Even more striking is the finding that hand-raised rooks, which do not use tools in the wild, will spontaneously craft these hooked shape tools in the laboratory and use them to obtain food (Bird & Emery, 2009a). This is far from trivial, as recent studies investigating the hook-making abilities of young children suggest that it is not until children are about eight years of age that they can solve such tasks reliably (Beck et al., 2011; Chappell, Cutting, Apperley, & Beck, 2013; Cutting, Apperley, & Beck, 2011; Tecwyn, Thorpe, & Chappell, 2014). For example, in the study by Beck et al. (2011), the five- to seven-year-old children performed between 30 and 50% correct, whereas the eight-year-olds were 80% correct. Subsequent studies on four- and six-year-old children suggest that one of the difficulties lies in the ill-structured nature of these tool innovation problems, in which the various components of a solution need to be retrieved and coordinated (Cutting, Apperley, Chappell, & Beck, *in press*). The four-year-old children could not coordinate the actions required to solve the task, even when explicit instructions were provided. Although the six-year-olds could do so, they struggled to bring to mind the components of the solution.

Innovative tool-use is not restricted to captivity, however. Wild rooks have been observed at the Membury service station on the UK's M4 motorway pulling up the bin liners of rubbish bins in order to obtain food.² Interestingly it takes about 20 pulls to reach the food. Similar behaviour has been observed in the Tower of London ravens.³

A classic case of innovative tool-use in apes is the floating peanut task of Mendes, Hanus, and Call

²First shown on BBC1 in *Britain's Smartest Animals*, July 2003, and repeated on BBC1 in *Super Smart Animals*, Feb 2012.

³BBC1, *The One Show: Bird Brains*, May 2013.

(2007). In the original experiment, orang-utans were provided with a peanut that was out of reach at the bottom of a transparent vertical tube, and the challenge was to develop a method for raising the peanut within their reach. All five orang-utans solved the task on the very first trial, by collecting water and spitting it into the tube. It took about three mouthfuls of water to raise the water to a level at which the peanut could be reached. Mendes et al. (2007, p. 2637) argued that both the spontaneous development and the timing of the action “make this behaviour a likely candidate for insightful problem solving”. A sceptic would argue however that in the absence of knowing about the precise reinforcement history of the animals, it is not clear that this was the first instance of this behaviour, thereby questioning whether this example is a true case of innovation. The very same argument could be used to question the behaviour of the wild rooks and Tower of London ravens.

Subsequent studies have shown that while chimps also solve the task either by spitting water or urinating into the tube to raise the floating peanut to a level at which it can be reached by hand, young children had surprising difficulty on the floating peanut task, even though they were given a watering can containing water which they could use to raise the water level (Hanus, Mendes, Tennie, & Call, 2011). Of the twenty-four four-year-olds tested, only two were successful, whereas ten of the twenty-four six-year-olds passed the task, and fourteen of the twenty-four eight-year-olds passed.

3.2. The Aesop’s fable task

Although the trap-tube task (Visalberghi & Trinca, 1989) has been traditionally used as the benchmark test to investigate what animals understand about the tools that they use (e.g., Limongelli, Boysen, & Visalberghi, 1995; Martin-Ordas, Call, & Colmenares, 2008; Povinelli, 2000; Seed, Call, Emery, & Clayton, 2009; Seed, Tebbich, Emery, & Clayton, 2006; Taylor, Hunt, Medina, & Gray, 2009; Teschke & Tebbich, 2011; Visalberghi & Limongelli, 1994), considerable progress has been made in recent years using a variant

of Mendes’ floating peanut task, inspired by the Aesop’s fable “The Crow and The Pitcher”. In Aesop’s 2000-year-old tale, a crow drops stones into a half-full pitcher of water to raise the level within beak reach so that it can quench its thirst.

Bird & Emery (2009b) first developed this Aesop’s Fable paradigm to test physical cognition in rooks. Rather than making the birds thirsty, the birds were tempted with a worm that was floating on the top of a vertical transparent tube half-filled with water. Next to the tube was a pile of stones. Rather than having to collect water and pour, spit or urinate into the tube, the birds had to use the stones to raise the water level. Bird and Emery found that rooks that had experience of dropping stones, but not in the context of water, would spontaneously put the stones into the tube to raise the water level within beak reach and thereby obtain the worm. Furthermore when the water level was varied, the birds matched the number of stones required to increase the water level to within beak reach. The birds were also selective in their choice of stones, using those that would most efficiently raise the water level.

A strength of both the floating peanut test and the Aesop’s Fable task lies in their ability to examine how animals respond to novel problems that are not related to the animal’s typical tool-use behaviour. This means that the ability to understand the affordances of the task can easily be separated from exposure to technology and fine motor capacity and thus makes it appropriate for investigating physical cognition in animals that do not regularly use tools in the wild, as well as in young children who may not yet have developed such fine motor skills. Furthermore, because the paradigms are simple, it is easy to manipulate a number of variables systematically in order to investigate what subjects do and do not understand about the physics of the task. For example, we can test whether or not the subject will only use stones when the tube contains a liquid, as opposed to a solid substrate such as wood chips or sand, and whether the subjects will be selective in the type of tool that they use to raise the water level, preferentially choosing objects that sink as opposed to those that float. These issues were

explored by testing the performance of other corvids that do not use tools in the wild, namely Eurasian jays (Cheke, Bird, & Clayton, 2011), and subsequently comparing their performance to that of the habitual tool-using New Caledonian crows (Jelbert, Taylor, Cheke, Clayton, & Gray, *in press*; Taylor et al., 2011), as well as young children of four to ten years of age (Cheke et al., 2012).

3.3. Testing corvids' understanding of the Aesop's Fable task

The basic paradigm was as follows. After learning to drop stones into an air-filled tube to receive a worm reward from the bottom of the tube, the subjects were presented with a choice between a tube half-filled with woodchips or air and a tube half-filled with water, both containing a worm that was resting on the top of the substrate, either naturally in the case of the liquid and solid substrate, or thanks to blue tack in the case of the air-filled tube (Experiment 1). The reward was a worm that was out of beak reach. Having been hand-raised, we can be sure that they have had no experience of water in this form or discovering the consequences of dropping stones into water.

Of the four Eurasian jays that were tested, two of them learned to drop significantly more stones into the water than into the sawdust tube over the course of Experiment 1 (the other two birds were uninterested in the task). These two birds quickly learned across five trials to drop significantly more sinking objects into the water than floating ones in Experiment 2, suggesting that they were selective in the type of tool that they used. The jays' behaviour could be explained in terms of instrumental learning, however—dropping a sinkable object into the water tube leads to the increased probability of obtaining a worm and therefore learning which tube (water versus wood chips) and which object (sinking versus floatable) was more likely to be rewarded. For example, dropping a stone into the water tube would lead to the worm being within beak reach on about 20% of trials, whereas dropping a stone into the sawdust tube would never result in the bird receiving a worm reward. On any given stone drop, placing a sinking object

into water would also lead to the worm moving slightly closer, which may also be rewarding, while placing a sinking object into sawdust leads to no movement of the reward. The same argument applies to the choice of whether or not to drop a sinking or floating object into the water tube.

To investigate whether the jays' performance could be explained exclusively by instrumental learning we conducted a further series of tests. We found that the birds failed to learn when the colour of the substrate arbitrarily indicated which tube would be rewarded (Experiment 3) yet their behaviour was clearly goal directed, for the birds selectively placed the stones in the tube that was baited with a worm as opposed to a tube in which the worm was not floating on the surface of the water (Experiment 4). The birds were able to learn a mechanized version of the task, in which stone-dropping resulted in the approach of a worm yet they were unable to learn if the reward probabilities remained the same, but the reward did not move (Experiment 5). Perhaps the birds learned the relationship between stone drops and movement rather than the causal mechanism of the Aesop's Fable task.

In the final control test of non-causal cues (Experiment 6), we presented the birds with an apparatus that contained three tubes, two wide tubes on either side that were large enough for stones to be inserted and a central narrow tube that contained the worm but was too small for stones to be inserted. The apparatus consisted of a "U-tube" on one side and a single tube on the other, but the bases were hidden beneath an opaque box so that the birds could not see which tubes were connected to one another. As the U-tube contained a single body of water, a stone inserted into the wide arm would raise the level of water in both arms, while a stone inserted into the single, wide tube would only raise the water level in that particular tube. This task was designed to provide the same movement cues as the original task (i.e., stone insertion into one tube caused the approach of food, stone insertion into the other tube did not) but with counter-intuitive mechanism cues. We found that the jays were unable to learn this "U-tube" task even when they received twice

as many trials as on the original task. So, while instrumental learning involving movement cues was both necessary and sufficient for the jays to learn the task, the presence of cues suggesting a “possible” or “impossible” causal mechanism were able to enhance or retard learning respectively (Cheke, Bird, & Clayton, 2011).

Subsequent studies on the New Caledonian crows (Jelbert et al., *in press*; Taylor et al., 2011) suggested a comparable pattern of results. The crows preferentially dropped stones into a water-filled tube instead of a sand-filled tube; they were highly selective in which objects they dropped into the water tube, choosing sinking and solid ones rather than floating and hollow ones; and adding more objects into a tube with a high water level rather than a low one (Taylor et al., 2011). Like the jays, the New Caledonian crows failed the more challenging task that required them to attend to the counter-intuitive causal cues in a U-shaped apparatus. These results suggest that the jays and New Caledonian crows possess a sophisticated, but incomplete, understanding of the causal properties of displacement.⁴

3.4. Testing children’s understanding of the Aesop’s Fable task

We also tested children between four and ten years of age on the Aesop’s Fable task (Cheke et al., 2012). The children were trained to drop stones into tubes in a similar manner to the Eurasian jays, and presented with three of the same tasks, namely a tube containing water and one containing sawdust, a water tube and a choice of sinking and floatable objects, and the three tube apparatus consisting of a U-tube and a single tube. In all of these tasks the children were given five 2-minute trials in which to attempt to retrieve a floating token that could be exchanged for a sticker.

Overall the performance of the children showed a clear developmental trajectory. Although children from four years of age were able to learn over the course of five trials to drop marbles into the tube containing water rather than the one containing

substrate in order to raise the level of a token, this task was only solved reliably at the outset by children over eight years of age. Children from five years or age were able to learn over the course of five trials to drop marbles, rather than cork balls, into the water tube to raise the level in order to reach the token but, in common with the first task, it was only children of eight years of age and above that spontaneously solved this task. A similar developmental trajectory was also found for the U-tube task in which dropping a stone into one tube of water apparently caused a rise in the level of the token floating in an adjacent tube of water.

3.5. Comparing corvids and children on the Aesop’s Fable task

How do these results compare with the performance of the corvids? Taken together, the findings suggest that rooks (Bird & Emery, 2009a, 2009b), Eurasian jays (Cheke, Bird, & Clayton, 2011) and New Caledonian crows (Taylor et al., 2011) were all able to learn to drop stones into water rather than substrate within about five trials, a performance that equates roughly with four- to seven-year-old children (Cheke et al. 2012). Furthermore, Eurasian jays (Cheke, Bird, & Clayton, 2011) and New Caledonian crows (Taylor et al., 2011) were also able to learn to drop sinking items into water rather than floating items within five trials, and again this is a performance that equates roughly with five- to seven-year-old children (Cheke et al., 2012). These comparisons are useful only to the extent to which they allow us to investigate the possible presence of some common mechanism by which the children and corvids might solve such tasks. Consequently, an interesting and important difference between the performance of the corvids and the children emerges in the U-tube task. On this task the Eurasian jays (Cheke, Bird, & Clayton, 2011) and the New Caledonian crows (Jelbert et al., *in press*) performed substantially worse than the children, and much worse than they did on the other two tasks. Unlike the

⁴Note that the rooks in Bird & Emery’s (2009b) experiments were not presented with the U-tube task.

corvids, the children's performance on the U-tube task was not affected by counter-intuitive mechanism cues.

It seems likely that the corvids possess a rudimentary concept of the causal mechanism underlying the relationship between their stone dropping and the movement of the food reward, and the causal relationship in the U-tube task violated the assumptions of what was possible according to this mechanism. By contrast it is interesting to note that the children's performance was equivalent on this task to the other tasks, even in those individuals that did not infer the presence of the U-tube. The children who were successful on the U-tube task were those that were able to notice and describe the causal relationships between putting a stone in a particular place and the approach of the food. These children could be said to be learning using the rule "Do the action that causes the movement of the reward" whereas the corvids' performance was more in line with the rule "Do the action that causes the movement of the reward, where the choice of action is affected by, but not reliant on, some concept of mechanism".

Furthermore, the fact that children were not impaired on the U-tube task relative to the other tasks may indicate that they did not interpret the event as "impossible" because they did not understand that insertion of an item into one body of water cannot raise the level of another body of water, and this is what allows them to solve the U-tube task in a way that the corvids cannot. It seems quite likely that the children ignored the "impossible" causal cues. Interestingly, children as old as eleven years of age prioritize contingency and contiguity as evidence of causality above information about mechanism, and may ignore information about mechanism altogether if this conflicts with apparent contingency information (Koslowski, Okagaki, Lorenz, & Umbach, 1989; Schlottmann, 1999, 2001). So unlike the corvids, the children's willingness to believe their actions to be causal was not affected by the presence of cues indicating that the reward was not in the same body of water as the stones.

It may be that children with no comprehension of the mechanism did not explicitly attribute causation, but simply allowed co-variation information to guide their actions. That a bias to prioritize co-variation above mechanism information exists in children is extremely intriguing and warrants further investigation. It may be that it is a useful developmental stage that exists to allow children to learn about causation unfettered by ideas of what is and is not "possible". Equally intriguing is the idea that such a bias could conceivably come about as a product of extensive technological enculturation: children have considerable experience of devices with hidden mechanisms that make apparently impossible events happen (e.g., phones, computers, and light switches, to name but a few) and for which children are not encouraged to investigate mechanism (indeed, many of us do not understand anything about the mechanism even as adults!) but simply learn to use relying on co-variation between action and outcome. One possibility is that for children growing up in heavily mechanized and electrically powered societies, an understanding of causal mechanisms has become somewhat separated from the development of causal judgements. To disentangle these two points, it would be interesting to investigate the performance of children and adults from both mechanized and non-mechanized cultures to discover in which populations this bias exists.

3.6. Wrapping up and moving on

What can we conclude about "ways of thinking" from the comparisons of the performance of corvids and children on these cognitive tests? To address this question I shall first consider what the research on developmental cognition tells us about how a young child's understanding of social cognition, mental time travel and physical problem solving develops. The findings reviewed here suggest that young children do not pass these tests until relatively late in development, generally between four and six years of age in the case of most of the experiments on social cognition and mental time travel, but it is not until they reach eight years of age that they spontaneously and

reliably solve the tasks that tap into physical problem solving.⁵

At first sight this pattern of results seems surprising: intuitively one might have thought that the tests on desire state attribution, what-where-and-when memory and future planning would require a more complex form of cognitive process than the physical problem-solving tasks, namely the ability to engage in perspective taking, to project one's self into other times (mental time travel) and other minds (mental attribution). In tests of episodic and social cognition the typical developmental trajectory is between three and five years of age, such that three-year-olds fail, four-year-olds show a transitional state of performance, and it is not until they reach five years of age that children pass. The work reviewed here however suggests that this developmental trajectory extends to six years of age in those cases where the child's current self-desires are in conflict with what needs to be chosen for one's future self (e.g., Russell et al., 2011) or for another self (e.g., Legg et al., 2014). Young children struggle to infer desires whenever they have to represent the subjective nature of these desire states as opposed to directly experiencing them. It is particularly challenging when this desire state is in direct conflict with their current desire because this creates the additional challenge of having to inhibit reference to their present self.

Perhaps the fact that children pass these perspective-taking tasks earlier than the water tasks (e.g., Cheke et al., 2012 for the Aesop's Fable paradigm and Hanus et al., 2011 for the floating peanut experiment) and the hook-tool tasks (e.g., Beck et al., 2011; Cutting et al., 2011, *in press*) is a reflection of the effects of extensive technological enculturation on cognitive development in general, and physical problem solving in particular. It seems plausible that for children growing up in heavily mechanized and electrically powered societies, an understanding of causal mechanisms has become somewhat separated from the development of causal judgements. Indeed, in the previous

section on physical problem solving I argued that children show a bias to prioritize co-variation (contingency and contiguity) above mechanistic information, unfettered by ideas of what is and is not "possible". It would be fascinating to conduct cross-cultural studies to investigate these issues further. In Western mechanistic societies children gain considerable experience of devices with hidden mechanisms that make apparently impossible events happen, such as turning on a smart phone, computer, or light. Often, children are not encouraged to investigate the mechanism but simply learn to rely on co-variation between action and outcome, thereby learning how to press the on-button but not how the on-button works. There is a reliance on being the consumers of existing technology as opposed to the creators of new devices, which may be problematic for the development of some aspects of physical problem solving. As Gerver Tully argued in his TED talk entitled "Five dangerous things you should let your kids do", learning to manipulate as well as to articulate provides the foundation for the development of what he termed "real life intelligence", an idea eloquently expressed by Bronowski's famous phrase, "the hand is the cutting edge of the mind" (Bronowski, 1974, p. 116).

As alluded to in the previous section, it would be fascinating to carry out ethnographic studies of when these abilities develop in children from both mechanized and non-mechanized cultures to discover in which populations this bias exists and the extent to which it is a product of technical enculturation or a universal feature of the human mind. These comparisons would allow us to investigate whether, and to what extent, a child's understanding of the physical world is developmentally delayed compared to that of perspective taking (mental time travel and mental attribution) and whether or not this applies specifically to children that have been raised in mechanized cultures. Such comparative studies would also us to gain a better understanding of the mechanisms controlling the various behavioural decisions that children make in these and

⁵Of course, in the case of our experiments on experience projection it is not established when these abilities develop, as we were only able to test two-year-olds.

related physical problem-solving tasks, including how they bring to mind and coordinate the various actions required of the more complex physical tasks involved in the hook manufacture tests (Cutting et al., [in press](#)).

This research also has a number of implications for the corvids. The work on comparative cognition suggests that these birds have a rather sophisticated understanding of social cognition, mental time travel and physical problem solving. The fact that only a select few groups of animals possess these complex cognitive abilities suggests that these abilities have not evolved by common descent, otherwise they should be prevalent in most, if not all, birds and mammals. Consequently it is argued that the cognitive similarities between corvids and children must be a case of convergent evolution resulting in similar psychological functions, despite striking differences in their brain architecture and overall morphology (e.g., Emery & Clayton, [2004](#); van Horik et al., [2012](#)).

What can this tell us about the evolution of both the human and the corvid mind? By investigating two distantly related kinds of mind, ones that have very different neural architectures (Jarvis et al., [2005](#)) yet similar patterns of large-scale network organization (Shanahan et al., [2013](#)), we can address the question “what exactly is it that has evolved convergently?” How can these two kinds of mind, the nucleated bird brain that corvids possess and the laminar brain of children (and other mammals for that matter), produce the same (or similar) psychological functions? Furthermore, by integrating the fields of comparative cognition and developmental cognition we can ask questions about “what it is that evolves and develops”, focusing on both the similarities and the differences in the performance of corvids and children on various experimental interventions in the hope of establishing what mechanisms are being used, when, and by whom.

One issue is whether these corvids really are solving the problems using human-like reasoning abilities or whether their decision-making processes

are in fact fundamentally different from those used by children. The comparisons on the Aesop’s Fable task suggest there are some important differences. The children are more ready than the birds “to believe in magic”, namely to accept contingency as evidence for causality because of their interactions with mysterious hidden mechanisms. For the corvids, however, seeing is believing; their causal reasoning abilities are constrained to the realm of the observable.⁶ This is likely to explain their failure on the “U-tube task” despite their impressive performance on the other physical problem-solving tasks and their spontaneous ability to manufacture novel tools, even in those species that have not been under strong evolutionary selection pressure to do so in the wild.

Furthermore the comparisons of performance on the future planning and desire state attribution tasks suggest that birds are more able to disengage from the current motivation state to make rational choices about a future desire for themselves or for that of another individual in the present. One possible reason for this is that the birds employ a different mechanism to the children, perhaps using rule-based knowledge (semantic associations) to think about other minds and other times rather than relying on the episodic cognition system (e.g., Cheke, Thom, & Clayton, [2011](#)), which is by definition subjective and therefore more susceptible to errors that arise from overvaluing the current self (Gilbert, [2006](#)).

A second issue relates to the relationship between intelligence and encephalization. The corvid brain is small in absolute size, about the size of a walnut. Yet when expressed in relation to body size, the corvid brain is as large as that found in the great apes, and much larger than that of birds of similar body size such as pigeons (Emery & Clayton, [2004](#)). As with apes, the enlargement occurs largely in the prefrontal cortex, which in the avian brain is now called the nidopallium caudale, as mentioned in the introduction (Jarvis et al., [2005](#)). Recent findings suggest that patterns of neuronal connectivity may be key, and

⁶See Povinelli ([2000](#)) for a more detailed elaboration of the difference between the human and animal mind in reasoning about observable and unobservable causes.

that the avian forebrain shows a similar large-scale network organization to that of mammals, despite the differences in the neural architecture of nucleated avian brains and laminar mammalian ones (Shanahan et al., 2013). Here, then, the notion is that there is convergence in cognition, with similarities in terms of psychological function and network organization (see also Güntürkün, 2012), despite divergence in neuronal architecture and morphology, and differences in the decision processes these two kinds of mind make when solving these cognitive tasks. One could make an analogy here with Apple and PC computers—at one level of analysis they do the same things in a similar way, but viewed from another perspective their operating systems are indeed different.

In order to further explore these hypotheses about what exactly has converged in the cognitive abilities of corvids and children, future research will aim to identify the cognitive milestones faced by both corvids and children, by developing tasks that allow us to unravel the mechanisms that operate in these two kinds of minds with apparently similar psychological functions. The quest is to search for both similarities and differences, which is a key principle in convergent evolution. Understanding such patterns lies at the very heart of humanity, facilitating new ways of seeing and triggering new ways of thinking.

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