New Caledonian crows' planning behaviour: A reply to de Mahy, Don *et al.*

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In our recent paper [1] we presented a novel test to show that New Caledonian crows can select tools in preparation for specific future events. The test consisted of a temporal sequence where the crows were: (a) shown a baited apparatus that varied in the test condition between two tool-apparatus combinations, (b) 5 minutes later given a choice between five objects and (c) 10 minutes later given access to the apparatus. Crows were able to choose the right tool for each specific apparatus they had seen 5 minutes earlier. This experimental design allowed us to empirically evaluate the hypothesis that the amount of past reinforcement associated with different objects affects the choice of functional tools when subjects solve variants of the spoon test [2]. We argue that our results demonstrate that New Caledonian crows are an excellent candidate for testing the conservative criteria for mental time travel [3].

In their comment, de Mahy *et al.* [4] argue that the crows in our study were able to solve the experiment irrespective of whether they had a "concept of the future" or not. However, they do not capture all of the details of our experiment and interpretation accurately. The argument they make, as outlined in Table 1 of their critique, substantially reduces actual task complexity by ignoring key aspects of the cognitive process required in our experiment. In Conditions 3 and 4, subjects have to note the apparatus identity, and then recall this 5 minutes later, despite recall for these specific apparatuses having not been rewarded in the past. Subjects then have to make the choice between one object that has been highly (and most recently) associated with a reward, the stick, and one of the two other functional tools (depending on the apparatus they observed 5 minutes before). The key question is whether the memory of an apparatus viewed 5 minutes before would be sufficient to motivate subjects to choose the correct tool over the more highly rewarded stick purely because of a past learnt association between a specific tool-apparatus combination, as de Mahy *et al.* argue. We believe this is a highly improbable possibility.

Simply seeing a specific object in the environment should not then lead to an animal preferring an option that has been linked to less reinforcement over one that has been linked to more (the stone and hooks had been associated less with reward than the stick). This suggests that the future value of these tools drove the crows to ignore choosing the object associated with more reward in favour of one that had been previously associated with less reward - but would lead to a certain reward in the near future. Note how difficult this choice becomes on the second trial that the crows receive of our test conditions. At this point, they observe an apparatus, and then they are presented with: 1. a stick, which has been associated with food more than the other objects, 2. a second tool that they have just been rewarded for using, and finally 3. a third tool that they have never been rewarded for choosing after seeing an apparatus 5 minutes before. It

seems highly unlikely that, at this point, our subjects would be motivated by their memory of the apparatus to choose the third, correct tool, rather than tools that had been associated more with reward, both generally (the stick), and in the immediate past (the second tool) *unless* they were aware of the utility of these tools for the upcoming situation.

Mahy *et al.* also mis-characterise our interpretation of the study, claiming that we contrast associative explanations with the birds relying on a "higher order concept of future planning". Though their commentary repeatedly refers to "higher-order" representations, we actually make no reference to such ideas in our paper, nor do we make claims about "the concept of the future". The study was not aimed at testing for higher-order concepts of the future in NC crows. Instead, it was a pre-registered adversarial collaboration aimed at overcoming one of the key shortcomings of earlier studies on planning in animals. That shortcoming was that when animals could repeatedly select the same tool [5] simple associative accounts could explain their choices [6, 7]. It had been suggested that one way to make a stronger case that animals can prepare for a specific future situation, would be to present distinct future problems and give them a choice between objects that function as a solution in one condition and as distractors in another [8]]. Our study did just that. We found that NC crows can indeed solve such a task, demonstrating sufficient flexibility in their choices to pick the right tool for the right future task, despite the presence of other tools that had been highly associated with food.

In our paper, we did not, however, develop or defend a specific theory as to what cognitive processes drive this planning behaviour or make a case, much more broadly, about the relationship between associative processes and more complex cognition, or between richer and leaner accounts of observed behaviour. Several of us have written extensively on such issues [9-11] but resolving these fundamental questions of comparative psychology was not an aim of our collaboration and it is not the objective of this response either. Instead, we would like to remind the commentators that we explicitly acknowledged in our original publication that more work is required to determine what cognitive processes underpin this behaviour. Our study provides strong evidence against one specific alternative explanation of previous experiments using variants of the spoon test. Our experimental design goes well beyond simple observations of tool use or nest building in the wild, where the previous reinforcement histories of the birds are unknown and innate tendencies cannot be excluded. Nevertheless, evidence against one specific associative account does not mean we can jump to conclusions about specific cognitive mechanisms, as the authors appear to assume we did. Furthermore, we stated clearly in our paper that "we cannot completely rule out that crows chose the correct tool because of some kind of associative learning". This caution reflects the nature of our

adversarial, pre-registered collaboration: our study makes clear progress in this field but does not over-reach in its conclusions. We believe that such collaborations offer a highly promising avenue for resolving the many antagonistic debates within comparative psychology, and trust that, on this point, we can find agreement with Mahy and colleagues.

Ethics
This article does not present research with ethical considerations

Data accessibility
The paper is a commentary and not based on data.

Authors' contributions
This paper has multiple authors, and the individual contributions are shown below
Writing: M.B., R.M., T.S., A.H.T., N.S.C.
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Competing interests
All authors declare that they have no conflict of interests.

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