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BEPROC-2890; No. of Pages 8
ARTICLE IN PRESS

Behavioural Processes xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Behavioural Processes

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

Addition and subtraction in wild New Zealand robins

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
New Zealand robin
Arithmetic
Addition
Subtraction
Avian cognition

ABSTRACT

This experiment aimed to investigate proto-arithmetic ability in a wild population of New Zealand robins. We investigated numerical competence from the context of computation: behavioural responses to arithmetic operations over small numbers of prey objects (mealworms). Robins' behavioural responses (such as search time) to the simple addition and subtraction problems presented in a Violation of Expectancy (VoE) paradigm were measured. Either a congruent (expected) or incongruent (unexpected) quantity of food items were hidden in a trap door out of view of the subject. Within view of the subject, a quantity of items were added into (and in some cases subtracted from) the apparatus which was either the same as that hidden, or different. Robins were then allowed them to find a quantity that either preserved or violated addition and subtraction outcomes. Robins searched around the apparatus longer when presented with an incongruent scenario violating arithmetic rules, demonstrating potential proto-arithmetic awareness of changes in prey quantity.

This article is part of a Special Issue entitled: Cognition in the wild.

1. Introduction

Avian numerical competence, like that of many species, is something that has become increasingly understood over the last two decades; from quantity discrimination (Emmerton and Renner, 2006; Honig and Stewart, 1989, 1993; Hunt et al., 2008; Garland et al., 2012; Rugani et al., 2008, 2013a,b, 2014), summation (Boysen and Berntson, 1989; Pepperberg, 1994; Rugani et al., 2011a,b), serial ordering and cardinality (Emmerton et al., 1997; Pepperberg, 1987, 1988, 2006a,b; Rugani et al., 2007) to simple arithmetic and proto-arithmetic (Emmerton, 1998; Pepperberg, 1983, 2012; Roberts et al., 2000), and even matching number with symbols (Rugani et al., 2013c; Xia et al., 2000, 2001). What is less entirely clear is the extent to which such a number sense may have evolved independently from the cognitive skills of primates and humans (Beran, 2006, 2008; Cantlon and Brannon, 2006; Feigenson et al., 2004; Hauser and Spelke, 2004; Wynn, 1992, 1995, 1998). This study aimed to build on previous numerosity studies in New Zealand robins (Armstrong et al., 2012; Garland et al., 2012; Hunt et al., 2008) by gaining a basic understanding of wild robins' spontaneous responses to simple arithmetic operations using small quantities of insect prey, without training. As an avid caching species that are naïve to mammalian predators, the New Zealand robin is potentially a promising model system for contributing to a fuller picture of the role of evolution in numerical representation.

A variety of studies show that infants can perform basic, non-symbolic arithmetic computation, such as addition and subtraction of items (Barth et al., 2006; McCrink and Wynn, 2004; Wynn, 1992). Using the Violation of Expectancy (VoE) paradigm, where behavioural responses to possible and impossible scenarios are compared, Wynn (1992) demonstrated that 5-month-olds successfully responded to simple arithmetic operations. Infants were shown a certain number of toys as they were placed behind a screen, and in some instances the outcome was expected (e.g. 1 + 1 = 2), and in other cases the number revealed was unexpected (e.g. 1 + 1 = 1); infants looked longer at outcomes where expectation was violated. There is debate over whether infants are capable of perceptual processing of numerical information itself, or are responding to other features. Simon et al. (1995) suggested that the differences in patterns of looking-time responses could be based on knowledge of physical object behaviour rather than underlying arithmetical ability. Indeed, Simon et al. found that even though infants looked longer at mathematically incorrect outcomes, they did not look longer when the type of object hidden was switched. Cohen and Marks (2002) also insisted that the infants in Wynn's study might have been responding with familiarity preferences along with the tendency to look longer at more items. Whilst infants look longer at perceptually novel displays, either in item type (Barth et al., 2006) or number (Slater et al., 2010), it does not rule out

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http://dx.doi.org/10.1016/j.beproc.2014.08.022
0376-6357/

Please cite this article in press as: Garland, A., Low, J., Addition and subtraction in wild New Zealand robins. Behav. Process. (2014), http://dx.doi.org/10.1016/j.beproc.2014.08.022

the use of arithmetic operations such as addition or subtraction. Research also indicates that infants are capable of representation of simple arithmetic operations even when the objects of such operations are stripped of their non-numerical features (Rugani et al., 2009). Outcomes in addition/subtraction VoE experiments have been replicated even when non-numerical information is taken into account. Further evidence shows that infants appear able to add and subtract over numbers that exceed object-tracking limits (McCrink and Wynn, 2004), supporting representation of numerical computation.

A number of different animal species have also displayed the ability to perform simple addition and subtraction of small numbers, for example in rhesus monkeys, *Macaca mulatta* (using VoE in Flombaum et al., 2005; and in a choice task Sulkowski and Hauser, 2001), lemurs (*Eulemur fulvus*, *Eulemur mongos*, *Lemur catta* and *Varecia rubra*) (Santos et al., 2005, in a VoE task) and domestic dogs, *Canis familiaris* (West and Young, 2002, in a VoE task) among others. Chimpanzees (*Pan troglodytes*) have been shown as capable of summing both small numbers (Boysen and Berntson, 1989) somewhat larger quantities (such as 3 + 4 + 1 or 2 + 2 + 3) (Beran, 2001, in a choice task), but failed to choose a combined greater quantity (comprised of two smaller quantities) over a single lesser quantity (Beran et al., 2005). In Flombaum et al.'s (2005) study, rhesus monkeys also successfully recognised addition of larger numbers (such as 4 + 4 = 8) when using lemons in that VoE study.

An increasing body of research has continued to show that humans and other species tend to represent the fundamentals of number essentially the same way (Dehaene et al., 1998; Feigenson et al., 2004), but there has been debate as to whether the relationship between subjective and objective magnitude is linear or logarithmic (e.g. Brannon et al., 2001; Dehaene, 2003; Feigenson et al., 2004). In a study by Brannon et al. (2001), pigeons' responses to subtraction events were used to examine which was the case for numbers when time was removed as a confound. In this multi-phase study, in one phase for example, pigeons were shown between 1 and 7 flashes (*T*), and then required either to peck a 'standard' number of pecks (4) irrespective of the flashes on one key when it was lit, or solve by subtracting the number of flashes from 8 and pecking the number solved when a different key was lit. In the following phase they were given a choice between these two keys, effectively forcing them to choose whether to peck 4 times for a reward or to peck 8 – *T* times for a reward. Evidence from this study suggests that subjective number increases linearly as a function of objective magnitude. Pigeons have demonstrated numerical abilities on par with those of primates, in that both are able acquire abstract ordinal rules and apply it to numbers outside a familiar range (Brannon and Terrace, 1998; Scarf et al., 2011).

Addition and subtraction of items has been recognised in newborn chicks (*Gallus gallus*) (Rugani et al., 2009). The chicks were first imprinted on a group of 5 plastic balls, and then exposed to a brief training session in which the chick was familiarised with the experimental arena and trained to follow the same type of plastic ball after being moved behind an occluding screen. For objects similar to the imprinting object, chicks chose the larger set of objects irrespective of the number they were reared with (Rugani et al., 2010a,b). In the testing phase of the final experiment, after two initial sets of five balls (e.g. 2 and 3, or 4 and 1) were hidden behind two screens, some elements were visibly transferred from behind one screen to behind the other; for example, creating a 4 – 2 and 1 + 2 condition, where the screens began with 4 and 1. Chicks successfully selected the larger set of objects after the addition/subtraction event regardless of directional cues due to initial or final movement of the objects. Such pronounced results in chicks only several days old provides compelling evidence for representation of simple arithmetic operations as part of system of number representation in vertebrates.

In another example of avian representation of arithmetic operations, a study examining addition of numbers up to 6 arose spontaneously when Alex, a grey parrot (*Psittacus erithacus*) (Pepperberg, 2006a,b), spontaneously answered numerical identification questions posed by an experimenter to another bird by tallying and verbally announcing the number of clicks (from a training clicker) after each repeated enquiry. The resultant study revealed Alex was successfully able to sum auditory cues of up to six (e.g. 5 + 1, 2 + 4, 3 + 2, etc.) by responding verbally with the correct total number when briefly shown two sets of items each covered with cups.

While the rhesus monkeys presented with a choice task in Sulkowski and Hauser's (2001) and Flombaum et al.'s (2005) studies were free-ranging, very little experimentation focusing specifically on arithmetic operations has been done with wild populations. This study presented a population of wild New Zealand North Island robins (*Petroica longipes*) with a Violation of Expectancy (VoE) task in two separate experiments. Experiment 1 presented robins with trials that were in some cases numerically congruent, and in other cases numerically incongruent. Experiment 2 presented robins with trials that were categorically incongruent or categorically congruent. The data from these experiments were then analysed in order to examine whether robins responded with different search times to the addition or subtraction of small numbers of prey items.

2. Methods

2.1. Subjects

A total of 17 individual robins participated in this study, of the 20 birds targeted; 7 birds in the first experiment (6 males and 1 female; 3 individuals targeted began nesting and did not participate) and 10 birds (8 males and 2 females) in the second experiment. Known banded birds in a section of the northeastern portion of the sanctuary, within proximity of paths, were targeted for this study, and all subjects had prior experimental history with a quantity choice task (Garland et al., 2012, 2014), but no prior exposure to a Violation of Expectancy task. No single subject participated in more than one of the two experiments described below. Each subject was identified with the unique combination of coloured bands on the bird's legs. This study was conducted in a 225 ha fenced, predator-controlled section of native, regenerating New Zealand forest within the Zealandia Sanctuary. The sanctuary is located on the southern tip of the North Island of New Zealand (41°18′ S, 174°44′ E) in Karori, Wellington. Although birds within the sanctuary are free to disperse beyond the fence (and return), the fence is designed to prevent introduced mammals (e.g. mice, rats, cats, stoats) that threaten breeding populations of native species, which are monitored and pest-controlled within the sanctuary. As of 2008, it housed a population of approximately 150 colour-banded birds, and a total population estimated to be roughly 600 birds (McGavin, 2009).

Robins are non-migratory songbirds that live in mated pairs on established territories, raising 2–3 clutches in a season, which then disperse (Menzies and Burns, 2008). In addition to hunting and caching insects, pairs also frequently pilfer prey from mates (Burns and Van Horik, 2007; Van Horik and Burns, 2007). Robins used in trials were located auditorily and visually along a series of footpaths or transects traversing the sanctuary, and found and tested within their identified territorial boundaries.

2.2. Apparatus

Trials were performed by presenting subjects with mealworms (*Tenebrio molitor* larvae) or waxworms (*Galleria mellonella* larvae)