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1 **Investigating the potential for call combinations in a life-long vocal learner.**

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8

9 **ABSTRACT**

10

11 The ability for humans to create seemingly infinite meaning from a finite set of sounds has

12 likely been a critical component in our success as a species, allowing the unbounded

13 communication of information. Syntax, the combining of meaningful sounds into phrases, is

14 one of the primary features of language that enables this extensive expressivity. The

15 evolutionary history of syntax, however, remains largely debated, and it is only very recently

16 that comparative data for syntax in animals has been revealed. Here, we provide further

17 evidence for a structural basis of potential syntactic-like call combinations in the vocal

18 communication system of a group-living songbird. Acoustic analyses indicate that Western

19 Australian magpies (*Cracticus tibicen dorsalis*) structurally combine generic alarm calls with

20 acoustically distinct alert calls to produce an alarm-alert sequence. These results are distinct

21 from previous examples of call combinations as, to our knowledge, evidence for this capacity

22 is yet to be demonstrated in a non-human species that is capable of vocal learning throughout

23 life. These findings offer prospects for experimental investigation into the presence and

24 function of magpie call combinations, extending our understanding of animal vocal

25 complexity.

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Keywords: call combinations, syntax, animal vocal communication, language evolution, Western Australian magpie, Cracticus tibicen dorsalis.

1. Introduction

The immensely generative nature of language has long been thought to be a key factor distinguishing humans from other animals (Collier et al., 2014; Hurford, 2011). The property of language that enables extensive combinatorial power is known as double articulation and refers to the combining of sounds into words (phonology), and the grammatical combining of meaningful words into phrases (syntax, Hurford, 2011). While there is no doubt humans are capable of vast combinatorial power (Hurford, 2012), recent comparative research has begun to draw parallels between language’s combinatoriality and potential equivalents within non-human animal vocal communication systems (Arnold & Zuberbühler, 2006; Engesser et al., 2016; Ouattara et al., 2009; Suzuki et al., 2016; Townsend et al., 2018).

Many non-human animals, such as some cetacean and avian species for example, have been found capable of stringing sounds together into larger sequences, that, at least superficially, are reminiscent of the phonological layer of human language (Engesser et al., 2015; Hauser et al., 2002; Suzuki et al., 2006; Tyack, 1983). Moreover, a growing body of work has revealed interesting potential homologous and analogous examples of call combinations in animals which can be feasibly compared with simple syntactic structures in language (Arnold & Zuberbühler, 2006; Ouattara et al., 2009; Townsend et al., 2018).

50 The combination of context- specific calls into a meaningful sequence has been suggested in
51 two different studies in related monkey taxa (Arnold & Zuberbühler, 2006; Ouattara et al.,
52 2009). Putty-nosed monkeys (*Cercopithecus nictitans*) combine two predator-specific alert
53 calls into a larger meaningful sequence (Arnold & Zuberbühler, 2006). However, despite the
54 discrete calls each being elicited upon discovery of the presence of a specific predator, the
55 sequence evokes group movement regardless of predatory context. It is, therefore, uncertain
56 whether this call sequence is indicative of compositional or instead combinatorial syntax,
57 where the meaning of the resultant sequence (i.e. ‘Let’s go’) is not a product of the
58 combination of the alarm calls’ meanings (Collier et al., 2014; Hurford, 2012).

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60 Perhaps more convincing evidence of rudimentary compositional syntax in primates is shown
61 in a study on male Campbell’s monkeys (*Cercopithecus campbelli campbelli*), where the use
62 of an acoustically invariant suffix modifies the meaning of predator-specific alarm calls in a
63 predictable way (from more specific to more general, Ouattara et al., 2009). Specifically, this
64 has been argued to be akin to abstract meaning operators in language, such as “like”, that
65 generalises the meaning of words (“monkey” to “monkey-like”) and is therefore suggestive
66 of basic compositional syntax (Collier et al., 2014; see also Townsend et al., 2018).

67

68 Recently, additional evidence of simple syntax has been seen in more distantly related
69 species. The combining of warning and recruitment calls in the Japanese great tit (*Parus*
70 *minor*) elicits a compound response consisting of a combination of the behaviours prompted
71 by each individual call (Suzuki et al., 2016). Critically, when artificially reversing the
72 sequence, the authors find a change in behavioural response, which is argued to indicate the
73 sequence is perceived as a single meaningful unit (Suzuki et al., 2016). Similarly, alert and

74 recruitment calls in the cooperatively breeding southern pied babbler (*Turdoides bicolor*) are
75 combined into a sequence eliciting mobbing behaviour from conspecifics in the presence of a
76 territorial threat (Engesser et al., 2016). Experiments demonstrated that the individual calls
77 have an independent meaning that are distinct from, but contribute to, the meaning of the
78 mobbing sequence and thus are strongly indicative of rudimentary syntax (Engesser et al.,
79 2016; see Suzuki et al., 2018, Townsend et al., 2018 and Zuidema & de Boer, 2018). These
80 studies have laid the foundation for further research into basic syntactic abilities in non-
81 human animals.

82

83 In this study, we build on emerging evidence of avian syntactic abilities by investigating the
84 occurrence of call combinations in the Western Australian magpie. Magpies in south-western
85 Australia are highly territorial, and cooperatively defend a year-round territory (Ashton et al.,
86 2018; Farabaugh & Brown, 1988; Hughes et al., 1996). All group members participate in
87 territorial defence behaviours throughout the year, including vocalizations, inter-group
88 fighting, and aggressive posturing (Farabaugh & Brown, 1988; Kaplan, 2004; Kaplan, 2006;
89 Kaplan et al., 2009). Both sexes have a similarly well-developed song and extensive vocal
90 repertoire (Kaplan, 2005; Suthers et al., 2011; Walsh, 2017). Males do not use song or any
91 other specific vocalization for courtship and thus share the same basic repertoire with females
92 (Kaplan, 2005).

93

94 The vocal repertoire of adult Western Australian magpies (hereafter magpies) can be
95 separated into short alarm calls, distress or alert calls, begging, feeding grunts, and carols or
96 warbling calls (Baker, 2009; Kaplan, 2004; Silvestri, 2017; Walsh, 2017). Previous research
97 has revealed the potential for context specificity in a variety of magpie vocalizations, such as

98 carols and some alarm calls (Baker, 2009; Kaplan, 2008). For example, carolling calls may
99 signal territoriality and willingness to participate in defence of the group territory (Baker,
100 2009). Furthermore, there is evidence that some alarm calls may be predator specific in
101 nature (Kaplan, 2005; Kaplan, 2006; Kaplan, 2008; Kaplan et al., 2009; Kaplan & Rogers,
102 2013). In light of the context-specific nature of magpie calls (Kaplan, 2008), and due to the
103 clear capabilities for flexibility in call structure (Kaplan, 2000), we reasoned rudimentary
104 syntactic structuring might also exist in the vocal system of magpies. While basic
105 combinatoriality in magpie vocal communication has been alluded to in past research
106 (Kaplan, 2005) to date, systematic investigations have not been conducted.

107

108 Moreover, to our knowledge, syntactic capabilities have not yet been indicated in a life-long
109 vocal learner other than humans. Magpies have been shown to be capable of flexibly
110 interspersing mimicry into their own song, indicating a high plasticity of vocal learning and
111 high retention of learned material throughout life (Brown & Farabaugh, 1991; Kaplan, 2000;
112 Kaplan, 2005). The fact that magpies can be considered as open-ended vocal learners is
113 particularly interesting because theory suggests that the transition from a non-compositional
114 system to a compositional one, relates to a constraint in the number of available calls
115 (Nowack, 2000). As this would seemingly not be a constraint for a life-long vocal learner, if
116 syntactic capability is revealed in magpies it could provide additional insight into the
117 potential evolutionary forces promoting the progression of syntax.

118

119 One instrumental first step prior to unambiguously identifying a syntactic-like combination in
120 non-human animal communication systems involves isolating naturally-occurring,
121 stereotyped, call combinations and then demonstrating that the calls comprising the

122 combination and the same calls produced alone are acoustically equivalent (*sensu* Hedwig et
123 al., 2014), such that the combination can be feasibly be considered as composed of
124 independently-occurring calls (see Hedwig et al., 2015, Engesser et al., 2016 & Suzuki et al.,
125 2016).

126

127 Observational work has indicated that magpies do indeed produce such a sequence in the
128 form of an “alarm-alert sequence” appearing to be comprised of two independently occurring
129 calls, a generic alarm call and an alert vocalisation (Figure 1), and used in a variety of threat-
130 related contexts. Furthermore, field observations suggest the call may convey information to
131 receivers with individuals responding predominantly with vigilance-type behaviours such as
132 scanning, vigilance, mobbing a predator, and movement directly following the call (Walsh,
133 2017). Regarding the individual call types, observations indicated alarm calls produced
134 predominantly during the approach of humans, dogs and general disturbance (Silvestri, 2017;
135 Walsh, 2017). The alert call, however, coincides with the presence of a potential predatory
136 threat, often eliciting response behaviours such as vigilance, scanning or carolling
137 vocalisations from other group members (Silvestri, 2017; Walsh, 2017).

138

139 The fact that two independently occurring calls (alarm and alert calls) are concatenated into a
140 single structure (alarm-alert sequence) is suggestive that the call might represent a syntactic-
141 like structure (Hurford, 2011), providing a solid basis for the investigation into this
142 combinatorial ability (Townsend et al., 2018). Here, we provide the first step in
143 demonstrating that magpies may be capable of producing call combinations by quantifying
144 the extent to which the calls comprising the combination are (a) acoustically distinct units
145 and (b) acoustically equivalent to those produced alone.

146

147 **2. Methods**

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149 *2.1. Study site and animals*

150

151 Fourteen groups of free-living magpies were chosen for this study. The groups were situated
152 in the urban Perth suburbs of Guildford (31°89'S, 115°96'E) and Crawley (31°98'S,
153 115°81'E), within Western Australia. Many individuals within these groups have been ringed
154 for identification and are habituated to human presence, therefore allowing observation and
155 vocal recording at a close distance (Ashton et al., 2018; Edwards et al., 2015; Mirville et al.,
156 2016).

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158 *2.2. Natural observations and acoustic recording*

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160 We recorded naturally occurring vocalizations and the context in which they were given,
161 while following groups in the field to compile a database of independent calls and potential
162 call combinations. Vocalizations were recorded at a 44.1 kHz sampling rate using a Roland
163 R-05 digital wave/mp3 recorder coupled to a Rode NTG2 directional condenser microphone
164 encased in a Rode Blimp Suspension Windshield. Data collection was conducted during
165 observations sessions (4-6 hours/session) on 27 days between June and August 2017. Data
166 was primarily collected in the morning to coincide with the higher activity levels of magpies
167 (Edwards et al., 2015). Recording focused on adult magpies, with no restriction based on sex.
168

169 We obtained over 500 recordings of distinct magpie vocalizations, which were extracted from

170 ~150 hours spent following groups in the field. The recordings we obtained were added to a
171 sound database that already contained over 2000 recordings (~12 hours of raw material)
172 collected by the University of Western Australia's (UWA) magpie research group from 2014
173 to 2017. Within the database, the independent vocalizations were categorised into the
174 following call types based primarily on auditory and observational features; begging, feeding
175 grunt, alarm, alert, carol, chorus (more than two individuals carolling at the same time), and
176 mimicry. Within each call type, calls were then further categorised into similar acoustic units
177 based on visual (spectrographic) features. The following contextual details were logged
178 where possible for each recording; caller identity and behaviour immediately prior
179 to/following vocalization, group members present, stimulus or disturbance, and group
180 response (vocal and behavioural).

181

182 Periods of silence have been used as a method of classifying boundaries between acoustic
183 units in numerous previous studies, including research on birdsong in zebra finches
184 (*Taeniopygia guttata*, Franz & Goller, 2002), killer whale (*Orcinus orca*) calls (Shapiro,
185 2011), and gorilla (*Gorilla beringei beringei* & *G. gorilla gorilla*) close calls (Hedwig et al.,
186 2014). Previous research on magpie song production indicated duration of mini-breaths
187 between song syllables to be roughly < 0.3 seconds (Suthers et al., 2011). As this study
188 focussed on alarm and alert calls rather than song production, we have slightly increased the
189 period of silence between calls to reflect the observed trend in periods of silence in call series
190 (independent calls produced consecutively) versus call combinations (two or more calls
191 produced in concatenation). As such, in this study, we defined calls as either discrete calls
192 (singular independent units separated by a period of silence equal to or greater than 0.5
193 seconds) or potential call combinations (independent units separated by a period of silence

194 less than 0.5 seconds). This is based on visual inspection of spectrograms of individual calls,
195 discrete call series, and potential call combinations.

196

197 A subset database was created focussing on the calls that, from preliminary field observation
198 and acoustic investigation, were (a) given frequently and (b) flexibly combined into a larger
199 sequence (see Figure 2 for examples). The subset database included the number of recordings
200 obtained for each call type from each individual from each group, and their respective
201 observational contexts. From the subset database, one type of alarm-alert sequence (Figure 1)
202 was chosen for acoustic analysis. This sequence was chosen based on the number of different
203 groups recorded producing this vocalization (N=11) and the high frequency of occurrence of
204 this sequence (and its comprising calls) detected during observational research.

205

206 2.3. *Acoustic analysis*

207

208 Calls were assessed for quality (where high quality = high signal to background noise ratio),
209 and the percentage of the call demonstrating clear, tonal structures using Audacity 2.1.2
210 (Audacity Team, 2016). Due to a limitation in the number of good-quality recordings of each
211 discrete call type in all test groups, only 26 recordings of the alarm, 9 recordings of the alert
212 and 19 recordings of the alert-alarm sequence, were used for analysis (our study site is
213 located within an urban matrix and so many recordings were compromised by background
214 noise). Spectrographic cross-correlation (SPCC) analyses were run to compare the recordings
215 within each call-type to determine if the calls were correlated. Analyses were then undertaken
216 to determine if the two calls are distinct in structure, and to compare the recordings of
217 discrete calls with the respective sequence component to determine similarity in structure.

218 SPCC compares the structural features in time-frequency spectrograms of two calls or
219 sounds, taking a peak correlation value as a measure of similarity and generating a matrix of
220 similarity values for each pair of calls in the analysis (Cortopassi & Bradbury, 2012).

221

222 To verify that alarm and alert calls are independent units that are structurally distinct from
223 each other, both the discrete calls and their respective sequence components were cross-
224 correlated with the other call type using SPCC. A procedure based on the Mantel test was
225 then used to test the null hypothesis that the calls grouped into the alarm or alert categories
226 were no more similar to other calls within their own group than to calls within the other call-
227 type group. As such, the SPCC matrix was compared with a second ‘hypothesis’ matrix
228 which contained a binary code, whereby ‘1’ represented same-group comparisons and ‘0’
229 represented different-group comparisons in equivalent positions (‘group’ is defined as the
230 recording being either an alarm or alert call, Schnell et al., 1985). A p-value less than the
231 alpha (set at 0.05) indicates the two calls are structurally distinct.

232

233 SPCC and Mantel testing were then used to test the null hypothesis that the discrete calls
234 were no more similar to each other than to their respective component in the call sequence,
235 using the same protocol as described above (Schnell et al., 1985). A p-value > 0.05 indicates
236 the structure of the discrete call is similar to the structure of its respective sequence
237 component, therefore confirming the two discrete calls are structurally combined into a
238 sequence.

239

240 All SPCC analyses were conducted using Batch Correlation Analysis in Raven (Bioacoustics
241 Research Program, Cornell University, Ithaca, 2017) using normalized Hamming window

242 spectrographic correlation analysis on peak values, with a band pass filter from 500Hz to 22,
243 000Hz.

244

245

246 **3. Results**

247

248 Spectrographic cross-correlation analyses revealed distinct call structure, with calls correlated
249 within each call-type. The mean correlation coefficient was consistent across cross-
250 comparisons of alarm calls (SPCC: $\bar{x} = 0.30$, $n = 325$), alert calls (SPCC: $\bar{x} = 0.34$, $n = 36$),
251 and alarm-alert sequences (SPCC: $\bar{x} = 0.34$, $n = 171$).

252

253 Mantel tests comparing correlation coefficients for alarm and alert call-type comparisons
254 were highly significant (10,000 permutations, $r = 0.284$, $p < 0.0001$), indicating the two calls
255 (alert and alarm) are structurally distinct from one another (Table 1).

256

257 Pairwise comparison analysis indicated the two discrete calls were correlated with their
258 respective sequence counter-parts. Mantel tests comparing correlation coefficients from
259 pairwise comparisons of each of the discrete calls with their respective cut-sequence
260 components were non-significant for both alarm (10,000 permutations, $r = 0.022$, $p = 0.488$)
261 and alert calls (10,000 permutations, $r = 0.019$, $p = 0.706$) (Figure 3, Table 1). Therefore,
262 recordings of the discrete calls were no more similar to one another than to their respective
263 component cut from the sequence.

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265 **4. Discussion**

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Using acoustic analyses, we investigated a potential call combination in the Western Australian magpie. Our results indicate that the alarm and alert calls are both acoustically distinct from one another but similar in structure to their respective sequence counterparts. Furthermore, spectrographic correlation analyses revealed similarity across recordings from multiple individuals, of the alarm, alert and sequence calls. These results provide evidence that the alarm and alert calls are distinct, highly repeatable calls that occur across all study groups and, at least at the structural level, are combined into an alarm-alert sequence.

The extent to which the detected combination of alarm and alert calls in the Western Australian magpie represents a syntactic-like structure, however, requires follow up experimental verification. Such experiments are key to unpacking the function of the independent calls and the combination via assessing receiver response in the absence of the stimuli that naturally elicit the vocalisations (*see* Suzuki et al., 2016 & Engesser et al., 2016).

Furthermore, although initial evidence is provided here for one potential call combination, preliminary observational data indicate magpies may be capable of flexibly creating combinations larger than a two-call construction, which has, to our knowledge, yet to be demonstrated in a non-human animal communication system (see Figure 2 e-h for potential examples, Russell & Townsend, 2017). Hence, follow up work is critical to assess the extent to which (a) magpies use call combinations, (b) whether these combinations are functionally relevant and meaningful to receivers, and (c) whether these combinations are indeed indicative of compositional syntax, or rather combinatoriality.

290 Our finding of a candidate call combination in magpies (if validated under future
291 experimental investigation), in addition to previous research indicating similar rudimentary
292 compositionality in primates (Ouattara et al., 2009) and other bird species (Engesser et al.,
293 2016; Suzuki et al., 2016), further suggests that the capability for syntactic-like structuring in
294 vocal communication is not confined to humans, and may instead be phylogenetically
295 widespread (Collier et al., 2014). Such research can aid in bridging the gap between human
296 and animal communication, and potentially shed light on the evolutionary development of
297 complex vocal communication systems (Russell & Townsend, 2017).

298

299 It has been hypothesized that a transition to syntax may have evolved as a result of natural
300 selection favouring the combining of meaningful calls when the number of relevant events
301 needing to be communicated exceeds the number of calls available (Nowack et al., 2000).
302 Thereafter, simple two-word or sign combinations may have occurred as a means of
303 increasing lexicon size (Russell & Townsend, 2017). Interestingly, previous and ongoing
304 work suggests magpies' already have an extensive vocal repertoire facilitated in part by their
305 capacity to vocally imitate (Brown & Farabaugh, 1997; Kaplan, 2005; Suthers et al., 2011).
306 Why magpies would need to combine calls to communicate new events if they could instead
307 incorporate a new call/sound into their repertoire is therefore unclear. A bias towards
308 combinatoriality could, in principle, be driven by working memory constraints on the part of
309 the receiver: deriving meaning compositionally places less load on working memory than
310 learning and storing a new call type (Nowack et al., 2000). Further work investigating the
311 processing of calls will help shed light on the pressures driving combinatoriality in magpies,
312 which in turn has the potential to shed light on the evolution of human syntax given that
313 humans are also open-ended vocal production learners.

314

315 Investigating the presence of combinatoriality in animals is a critical first step to
316 understanding the origins and phylogenetic spread of this key linguistic ability. Our results
317 demonstrating combinatorial structures in Western Australian magpies contributes to recent
318 work showing that avian species are capable of producing and processing call combinations
319 (Engesser et al., 2016; Suzuki et al., 2016), in turn indicating that the phylogenetic spread of
320 this capacity is greater than previously thought. Critically, our research provides important
321 initial evidence of the presence of call combinations in a vocal learning species (excluding
322 *Homo sapiens*), which has interesting implications for theories explaining the evolution of
323 combinatoriality more generally. These results set the foundation for further experimental
324 investigations into syntactic-like structures in this species – a vital step in furthering our
325 understanding of this largely enigmatic field (Suzuki et al., 2018; Townsend et al., 2018).

326

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488 **TABLE**

489

490 **Table 1. Comparisons of different calls types using Mantel test.**

Comparison	Mean Correlation	r	P
Alarm vs Sequence-Cut Alarm	0.315	0.022	0.488
Alert vs Sequence-Cut Alert	0.355	0.019	0.706
Alarm vs Alert	0.269	0.284	<0.0001*

491 Mantel tests were based on correlation coefficients obtained from SPCC on discrete calls versus respective
492 sequence components and alarm call versus alert call. 18 recordings of each sequence-cut call, 26 recordings of
493 alarm calls, and 9 recordings of alert calls were used in analysis. Asterisks indicates significant difference in call
494 comparison whereby $p < 0.05$.

495

496 **FIGURE LEGENDS**

497

498 **Figure 1.** Spectrograms of the independent (a) alarm and (b) alert calls, and the (c) sequence
499 they comprise which was used for acoustic analysis. Calls are separated into independent
500 units (indicated by black lines) based on their occurrence with a period of at least 0.5 second
501 of silence in between calls.

502

503 **Figure 2.** Spectrograms of magpie alarm (a & b), alert (c & d) calls and potential call
504 combinations (e-h). Calls are separated into independent units (indicated by black lines)
505 based on their occurrence with a period of at least 0.5 second of silence in between calls.

506

507 **Figure 3.** Distribution of correlation coefficients obtained from SPCC on pairwise
508 comparison of each alarm and alert call-types. Calls were correlated within each call-type.
509 Boxes show the medians and interquartile ranges, and whiskers show the ranges (n = number
510 of comparisons).