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Supplemental Information

Long-Term Memory for Affiliates in Ravens

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Supplemental Inventory

Supplemental Data

Table S1, related to Figure 2. Model Selection

We present this table so that readers of our manuscript can see the influence of the fixed factors on the predictor variable. We think this table is crucial for the reader to completely understand the paper.

Table S2, related to Figure 2. Pairwise Comparisons

We present this table so that all detailed differences are presented to the reader. This table is crucial for completeness of our results.

Supplemental Experimental Procedures

1. Animal Housing

Table S3, related to Figure 1. Background Information on Test Subjects

The complete part plus the table are important to understand the influence of kinship and keeping conditions on our data. As we separated the birds to different locations and in various pairs, it is important for the reader to understand the relation of each individual to any other in our setup.

2. Vocalizations and Recordings

It is important for the reader to understand and be able to replicate our results to see our definition of vocalizations and our recording procedures.

3. Playback Presentation and Analysis

Figure S1, related to Figure 1. Sketched View of the Playback Setup

It is important for readers to be able to replicate our results, thus we present our detailed playback presentation with a sketched view and the analysis of behaviors.

4. Acoustic Analysis

Here we include the detailed way of acoustic parameters so that the derivative parameters of our components can be understood and additionally we facilitate replication of our data.

Supplemental References

Table S1, Related to Figure 2. Model Selection

	df	F	P
component 1	AICc: 2656.152		
kinship	2	0.858	0.354
sex relation	1	7.770	**0.005**
affiliation	2	4.118	**0.003**
component 2	AICc: 3093.280		
kinship	2	0.121	0.728
sex relation	1	0.004	0.947
affiliation	2	3.505	**0.030**
component 3	AICc: 3297.639		
kinship	2	0.006	0.938
sex relation	1	2.968	0.085
affiliation	2	3.722	**0.024**
component 4	AICc: 2945.752		
kinship	2	2.191	0.139
sex relation	1	1.182	0.277
affiliation	2	4.956	**0.007**
component 5	AICc: 3387.972		
kinship	2	7.992	**0.005**
sex relation	1	5.509	**0.019**
affiliation	2	12.368	**≤0.001**
component 6	AICc:2712.115		
kinship	1	0.153	0.695
sex relation	2	5.654	**0.018**
affiliation	1	5.330	**0.005**

All components of call parameters were analyzed with the three fixed components kinship, sex relation and affiliation. In all components the full model was also the final model as AICc values were the lowest. Significant relationships are highlighted in bold letters.

Table S2, Related to Figure 2. Pairwise Comparisons

	estimated means			β	t	p
sex relation	**same sex**	**different sex**				
component 1	0.096	0.599		-0.504	-2.788	0.005
component 5	-0.404	0.278		-0.681	-2.827	0.005
component 6	-0.327	0.088		-0.416	-2.378	0.018
kinship	**kin**	**nonkin**				
component 5	0.034	-0.160		0.194	2.347	0.019
affiliation	**affiliate**	**nonaffiliate**	**unfamiliar**			
component 1	0.694	-0.063	0.412			
nonaffiliate vs. unfamilar				-0.474	-2.641	0.025
component 3	0.509	0.022	-0.179			
affiliate - unfamilar				0.688	2.703	0.021
component 4	0.125	-0.242	0.301			
nonaffiliate - unfamilar				-0.543	-3.121	0.006
component 5	0.468	-0.184	-0.474			
affiliate - nonaffiliate				0.651	2.772	0.011
affiliate - unfamilar				0.942	4.446	≤0.001
nonaffiliate - unfamilar				0.290	0.116	0.012
component 6	0.255	-0.558	-0.055			
nonaffiliate - unfamilar				-0.503	-2.821	0.015

Significant results are presented only. All pairwise comparisons were calculated using Student's *t*-test and sequential Bonferroni correction. Only significant differences are presented.

Supplemental Experimental Procedures

1. Animal Housing

Experiments were conducted on adult ravens kept in male-female pairs at Alpenzoo Innsbruck, Cumberland Wildpark Grünau, Konrad Lorenz Forschungsstelle, Wildpark Wels, Wildpark Haag, Vogelpark Turnersee (all Austria), Wildlife Enclosure in the National Park Center Lusen (Germany), Wildpark Goldau (Switzerland) and at private keepers in Wolkersdorf and Weidling (all Austria). Table S3 lists the nine birds from the former nonbreeder group in Grünau, Austria, their kinship and affiliate relationships as well as their assignment as affiliates and nonaffiliates in the playback experiment. Furthermore, Table S3 lists the seven birds used as controls in the playback experiment (i.e. having no experience with the played back ravens). The remaining two pairs have been used for stimuli recording only.

In all but one case, affiliates were characterized by high loadings in value (featuring high rates of allo-preening, contact sitting and help in agonistic support) and compatibility (high tolerance to approaches and low rates of aggression and counter-intervention). The exception was the adult male H, whose relations to subadult birds in the nonbreeder group was expressed in tolerance to approach and aggression levels; thus, affiliate dyads with H had a high loading in compatibility only. The relationships of all dyads used in the experiment were stable across the entire period the birds lived together in a social group, i.e. all had high loadings in the security component.

Table S3, Related to Figure 1. Background Information on Test Subjects

Pair	ID	Sex	Current Housing	Former Housing	Kinship	Affiliation	Stimulus affiliate	Stimulus nonaffiliate
1	I	M	WP Grünau	WP Grünau	Q, T	Q; O, E	Q	L
1	O	F	WP Grünau	WP Grünau	E	E; I, Q	E	D
2	Q	M	NP Bayr. Wald	WP Grünau	I, T	I; O, E	I	P
2	E	F	NP Bayr. Wald	WP Grünau	O	O; I, Q	O	D
3	H	M	KLF	WP Grünau	-	P, Q; D*	Q	L
3	D	F	KLF	WP Grünau	L, P	L, P; T	T	E
4	L	M	Zoo Wels	WP Grünau	D, P	P; D, T	P	I
4	T	F	Zoo Wels	WP Grünau	I, Q	L, P; D	D	E
5	P	M	Wolkersdorf	WP Grünau	D, L	L; D, T	L	Q
5	Mä	F	Wolkersdorf			Control	D**	O**
6	Kä	M	WP Haag			Control		
6	Lu	F	WP Haag			Control		
7	Ru	M	Weidling			Control		
7	Ro	F	Weidling			Control		
8	Pa	M	Zoo Innsbruck			Control		
8	Fl	F	Zoo Innsbruck			Control		
9	Gm	M	WP Goldau					
9	Gf	F	WP Goldau					
10	Km	M	VP Turnersee					
10	Kf	F	VP Turnersee					

Ravens (ID, sex) are listed according to pair membership (number 1-10) and current housing. Subjects of pairs 1-5 were part of the nonbreeder group at WP Grünau, of which all kin and affiliate relations are listed. For pairs 6-10 relationships are unknown. (Note that the female Mä of pair 5 was also not part of the nonbreeder group and consequently no background information is available). The affiliate and nonaffiliate same-sex stimuli used in the playback are listed per individual. Each individual was also subjected to the respective stimuli of the pair-partner, and its responses to both sets of stimuli (own and partner) entered our statistical model. We excluded two pairings (H>T, D>Q) in our model because their affiliation to the same-sex playback of the respective partner was neutral. Thus a total of 18 affiliated and 18 nonaffiliated pairings were tested. Out of the affiliate combinations, seven were from kin and eleven from nonkin. Birds of pair 6-8 and the female Mä from pair 5 served as controls in the playbacks. Pairs 9,10 have been used for additional stimuli recording.

*As the only adult, H behaved aggressively to most of the group members; his relationship to these three birds, however, was tolerant and nonaggressive.

**Stimuli for the individual Mä were the female stumuli for P only, as the female Mä was not part of the group.

2. Vocalizations and Recordings

We differentiated between long distance calls/broadcast vocalizations (a large variety of high amplitude calls) and soft calls/proximal vocalizations (relatively low intensity signals produced in close spatial proximity of conspecifics and used in a variety of communicative and social contexts) [S1]. The seven locations of stimuli recordings were Cumberland Wildpark Grünau, Konrad Lorenz Forschungsstelle, Vogelpark Turnersee, Wildpark Wels, Wolkersdorf, all Austria; National Park Center Lusen, Germany; Wildpark Goldau, Switzerland.

3. Playback Presentation and Analysis

A playback session consisted of three blocks; each presenting calls of one of the stimuli categories (i-iii). Per block, a 15-minute baseline without playback was followed by 5 calls of a given category, a 1-minute intermission interval, 5 calls of the same category, a 1-minute interval, and another 5 calls of the same category. Thus, we presented a total of 15 calls per individual, category and block, separated by 15 min pauses.

We conducted two playbacks for each raven pair; one in the morning and one in the afternoon, with either female or male stimuli and counterbalanced combinations between pairs. Two loudspeakers were set up in the vicinity of the aviary (10 m ± 3 m) behind a visual barrier. Each playback block was presented from one side, whereby each successive playback block was played back from the respective other location, so that stimulus block one and three were played back from the same location and two from the other location. The randomization of the playback order for familiarity also resulted in the randomization of familiarity and location combinations, whereby starting location was alternating between morning and afternoon playbacks and was randomized between pairs (see Figure S1).

Responses were coded during the one-minute intermission intervals and five minutes after the last playback of the session with Solomon coder (V: beta 11.01.22 see [S2]) video analysis software. All emitted calls were counted and categorized as long distance calls and soft calls. As vocal interactions between distant individuals (i.e. our simulated intruder and the focal subject) necessitate a minimum threshold sound pressure level, we focused on long distance calls for further analysis, as long distance calls are obvious response to our stimuli whereas soft-calls in this context are mainly used for within-pair communication.

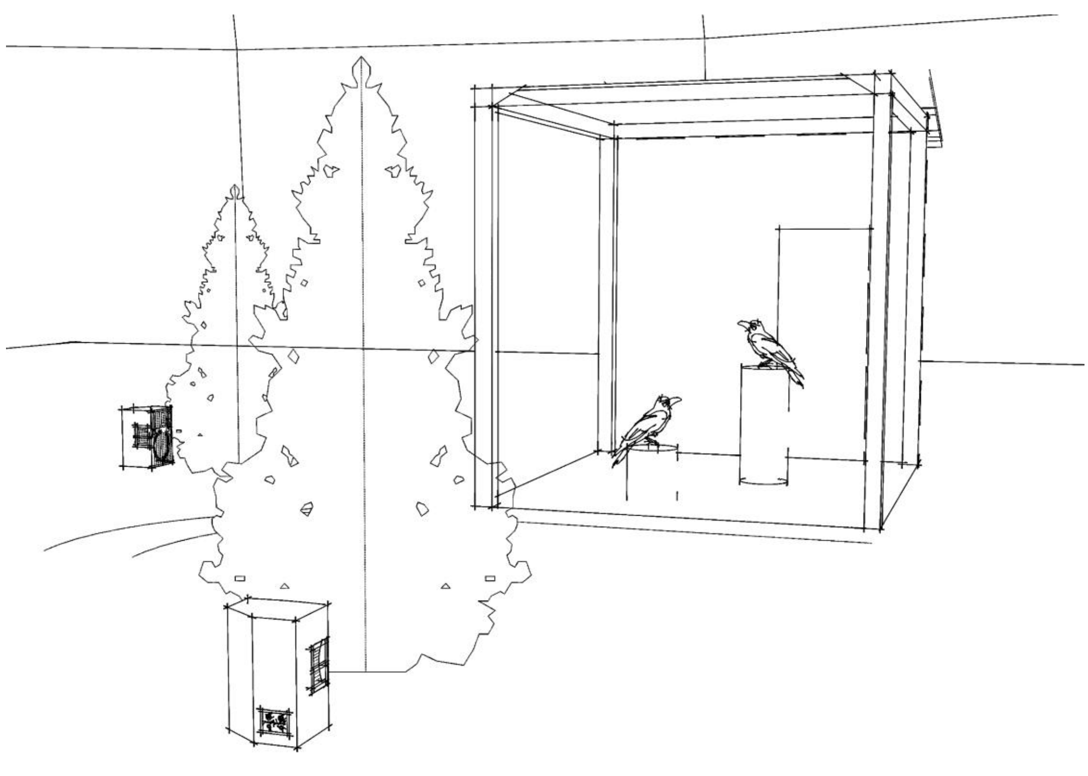

Figure S1, Related to Figure 1. Sketched View of the Playback Setup

4. Acoustic Analysis

The acoustic analysis was performed with PRAAT DSP package 5.2.10 [47]. We used dominant frequency, formants, harmonicity, call length, alpha ratios and frequencies of amplitude modulation as parameters to describe long distance calls of ravens.

To measure call length we extracted the F0 contour of calls using the ‘To pitch (cc)’ command (time step = 0.01 s; minimum and maximum F0 = 300 and 900 Hz). Time-varying numerical representations of the F0 contour were compared with the F0 as visualized on a spectrogram to test if F0 was tracked correctly. In case of incorrect software tracking the F0 was adjusted using the ‘Edit’ function. Call length was calculated with begin- and end times of the pitch contour. Due to the considerable influence of amplitude modulation on the perceived and calculated pitch was not employed as measurement value for raven calls.

To quantify the harmonic parts in relation to the chaotic parts of the call, we measured the harmonics-to-noise ratio (HNR), which calculates the relation of the energy in harmonics to the energy in noise in dB (low levels represent main energy in the periodic part). HNR was measured using the ‘To Harmonicity (cc)’ command in PRAAT (time step = 0.01; minimum pitch (Hz) = 300; silence threshold = 0.1 and periods per window = 1) and Minimum HNR, Maximum HNR and the standard deviation of HNR were obtained.

Dominant frequency was measured of the complete call and the first to third part. As all raven call frequencies were above 100 Hz we applied a stop Hann band filter from 0 Hz to 100 Hz with a 150 Hz smoothing to reduce influences of wind noise on dominant frequency measurements. In a long-term average spectrogram with a 50 Hz bandwidth we extracted frequency values with the ‘Get frequency of maximum’ command (Minimum and maximum frequency = 100 and 6000).

For the alpha ratios we used the equivalent Hann band filter and applied a long-term average filter (for alpha 1000: bandwidth = 1000 Hz; for alpha 2000: bandwidth = 200). We extracted dB measurements for the first two columns representing the sound pressure level for 0-1000 and 1000-2000 in alpha 1000 and 0-2000 and 2000-4000 in alpha 2000, respectively. Subsequently we calculated the difference between the first and the second frequency range and thus retrieved a relative dB value of the lower frequency in relation to the upper frequency level for both alpha 1000 and alpha 2000.

To obtain amplitude modulation an intensity object was extracted with the ‘To Intensity’ command (Minimum pitch = 200 Hz; time step = 0.001 s), the dc offset was removed from intensity data by subtracting the mean energy. We used the ‘Down to Matrix’ command to retrieve numerical representations of the intensity change and created a sound slice on the basis of this matrix. A sine wave with the same length as the original phonated call (0.5+0.5*sinus (2*pi*x/length of the call + 3* pi/2) was created. The sine wave and the original amplitude were multiplied with the ‘Formula’ command and a long-term averaged spectrum on the basis of the created sound was conducted. In order to retrieve the frequencies of the amplitude modulation we measured frequencies of the first three peaks.

For formant measurements we used the ‘To Formant (burg)’ command (time step = 0.025 s; Maximum number of formants = 5; Maximum formant = 6000 Hz; window length = 0.03 s; Pre emphasis = 10 Hz) and extracted mean formant values for f1 to f5. Formant dispersal was calculated applying the equation: formant dispersal = (f4-f1)/3.

Supplemental References

S1. Taglialatela, J.P., Russell, J.L., Schaeffer, J.A., and Hopkins, W.D. (2011). Chimpanzee Vocal Signaling Points to a Multimodal Origin of Human Language. PLoS ONE *6*, e18852.

S2. Péter, A. (2011). Solomon Coder (version beta 11.01.22): A simple solution for behavior coding, http://solomoncoder.com/ (last viewed 08/2011).