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"Object manipulation on young ravens and crows: exploration and play? "

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Abstract

Play is a complex behaviour enhancing both motor and social abilities, but remains understudied. For instance, object play may be related to increased cognitive flexibility and the development of tool use. Corvids *(Corvus)* have a pronounced playfulness. The aim of this study was to investigate (social) object play behaviour in families of common ravens *(Corvus corax)* and carrion/hooded crows *(Corvus corone*, *Corvus cornix)*. I was interested if the birds show a preference for i) a specific experimental design and/or for ii) specific object properties and iii) if they include conspecifics in the interactions with these items. For this purpose, I presented birds in their family groups with two set-ups (board with fixed tubes, box with small items) and with different object categories (e.g. balls, stones, branches) that were either familiar or unfamiliar. Ravens and crows showed similar results in terms of object properties and play type. A preference for the unfamiliar items could be observed, as well as a higher engagement in solitary object play than in social object play. In addition, for the ravens, a difference in object manipulation could be found between the offspring and the parents in relation to the test week. In conclusion, the size of the test material and the level of familiarity plays a role in the play behaviour of corvids and the interest to engage in play is affected by age.

Zusammenfassung

Spielen ist ein komplexes Verhalten, das sowohl motorische als auch soziale Fähigkeiten fördert, aber noch nicht ausreichend erforscht ist. So kann beispielsweise das Spielen mit Objekten mit einer erhöhten kognitiven Flexibilität und der Entwicklung des Werkzeuggebrauchs zusammenhängen. Rabenvögel (*Corvus*) haben einen ausgeprägten Spieltrieb. Das Ziel dieser Studie war es, das (soziale) Objektspielverhalten in Familien von Kolkraben (*Corvus corax*) und Aas-/Nebelkrähen (*Corvus corone, Corvus cornix*) zu untersuchen. Mich interessierte, ob die Vögel eine Vorliebe für i) eine bestimmte Versuchsanordnung und/oder für ii) bestimmte Objekteigenschaften zeigen und iii) ob sie Artgenossen in die Interaktionen mit diesen Gegenständen einbeziehen. Zu diesem Zweck präsentierte ich den Vögeln in ihren Familiengruppen zwei Versuchsanordnungen (Brett mit festen Röhren, Box mit kleinen Gegenständen) und verschiedene Objektkategorien (z. B. Bälle, Steine, Äste), die entweder vertraut oder unbekannt waren. Raben und Krähen zeigten ähnliche Ergebnisse in Bezug auf Objekteigenschaften und Spieltyp. Es konnte eine Vorliebe für die unbekannten Objekte beobachtet werden, sowie ein höheres Engagement beim einsamen Objektspiel als beim sozialen Objektspiel. Außerdem konnte bei den Rabenvögeln ein Unterschied in der Objektmanipulation zwischen den Nachkommen und den Eltern in Bezug auf die Testwoche festgestellt werden. Zusammenfassend lässt sich sagen, dass die Größe des Testmaterials und der Grad der Vertrautheit eine Rolle für das Spielverhalten von Rabenvögeln spielen und dass das Interesse am Spiel vom Alter beeinflusst wird.

Content

Introduction

For a long time, it was assumed that play was a merely waste of time. However, in the last decades, scientific interest for this topic has grown. Most research was focused to the play behaviour of mammals (Ficken, 1977; Ortega & Bekoff, 1987; Bateson & Martin 2013). Today, play behaviour has been documented in birds, reptiles, even insects might engage in some aspects of playful activities (Burghardt, 2006; Graham & Burghardt, 2010; Bateson & Martin, 2013). Play in parrots and corvids may be on a similar level of complexity of that of primates, even if it has emerged independently in birds and mammals (Ficken, 1977; Fagen, 1981; Diamond & Bond, 2003; Emery & de Waal, 2016). The amount of displayed play behaviour differs between species but also within a species, as it tends to decline with age (Ficken, 1977; Bekoff, 1984; Bjorklund & Gardiner, 2011). Social species with a long developmental time and relatively large brains in relation to their body size are more likely to engage in play activities (Graham & Burghardt, 2010; Emery & de Waal, 2016). The most playful species like great apes, dolphins, parrots and corvids have also some complex cognitive abilities in common (Osvath et al., 2014).

The more the animal's morphology deviates from the human anatomy, the more challenging it might be to recognise play as such. Because it appears in so many forms and among all types of animals, it is difficult to define it clearly and unambiguously (Fagen, 1981). To do so, Gordon Burghardt (2010) provides five criteria to distinguish play from other activities. According to that, it is voluntary and rewarding, has marginal direct effects, the displayed behaviour is repetitive and it is only shown in relaxed settings. To classify an activity as play all criteria should be met simultaneously (Burghardt, 2010). Bateson and Martin (2013) suggest a sixth criterion for play to become *playful* and that is being in a positive mood, but it is rather difficult to study empirically in non-humans (Bateson & Martin, 2013).

In general, three subcategories of play behaviour can be distinguished: social play, locomotor play and object play (Ortega & Bekoff, 1987; Burghardt, 2006; O' Hara & Auersperg, 2017). Social play includes playful interactions between conspecifics. Through that animals can train their social skills or build social relationships (Bekoff, 2001). Movements that are performed with one's own body, such as running, jumping, etc. are called locomotor play (O' Hara & Auersperg, 2017). The last category, object play, encompass any behaviour in which the individual handles an inedible object (Burghardt, 2006). This is the predominant play type in predatory species. This might be due to the possibility that young animals can train their hunting behaviour, where the object could serve as a substitution for their prey. In adults it resembles actual hunting behaviour (Hall, 1998). Moreover, object play can be divided into

primary and secondary manipulations. The former refers to the handling of a single object and the latter describes more complex interactions such as combining multiple items or including the environment (Torigoe, 1985; O' Hara & Auersperg, 2017). Beyond that, playing with objects could contribute to a greater flexibility and the development of problem-solving skills (Ortega & Bekoff, 1987; O'Hara & Auersperg, 2017). It is even discussed that tool use might have evolved from the same motor patterns that are used for object play behaviour (Graham & Burghardt, 2010; Kenward et al., 2011; Auersperg et al., 2015).

Animals only take up playful activities when they do not have to deal with immediate survival needs, i.e. an individual only plays when it is free from hunger, illness or predation (Burghardt, 2006; Bateson & Martin, 2013). It has some adaptational merit for cognitive and social abilities and it might help individuals in coping with environmental affordances (Fagen, 1981; Osvath et al., 2014). But play also carries additional costs, such as energetic and time consuming effort, as well as increased risk of injuries or predation. Beyond that, it seems to serve no immediate functions (Bateson & Martin, 2013). This raises the question of why animals play at all (Burghardt, 2006). Many researchers have addressed this issue and yet there is no unique answer to that question. In the past, it was thought that play behaviour mainly evolved to prepare the young animals for adulthood. This way they could train motor skills or social abilities under eased conditions. Making mistakes would have barely serious consequences (Bjorklund & Gardiner, 2011).

Since recently, however, it is believed that this accounts for only part of the question why animals play. If it just served to refine skills, this would not explain why adults also engage in playful activities. Furthermore, juveniles which grew up play deprived should lack these certain skills (Pellis et al., 2010). But so far, this assumption could not be confirmed in any study: Caro (1980) could not find any significant differences between play deprived and normally playing kittens *(Felis catus)* with respect to their hunting behaviour. Vincent and Bekoff (1978) came to similar results in experiments with coyotes *(Canis latrans)*. However, it seems to be the case that play behaviour can enhance the development of certain social skills (Pellis et al., 2010). Play appears to have an impact on more than one aspect. Thus, there are different theories to illustrate the possible functions of play, which are not contradictory to each other. Another assumption is that through playing in early life the animal can prepare for unexpected situations (Pellis et al., 2010; Bateson & Martin, 2013). During play activities, the young can practice a wide range of various motor patterns, sometimes even containing self-handicapping. Meaning they actively put themselves in circumstances where they do not keep full control over the situation through e.g. an unbalanced position or by running too fast, etc.

(Spinka et al., 2001). Besides the training for the unexpected, the experience of play might also help to cope emotionally with it (Bateson & Martin, 2013). In addition, there is some evidence that animals without juvenile play experience are less resistant to stress (Pellis et al., 2010). For example, studies with rats *(Rattus norvegicus)* found that young animals that interacted rarely in play fighting showed less social competence and had a higher stress response as adults (Pellis & Pellis, 2007). In general, animals which had the opportunity to play as juveniles appear to have higher chances of survival as well as greater reproductive success in adulthood (Burghardt, 2006; Pellis et al., 2010; Bateson & Martin, 2013).

Although object play looks similar to exploration, these behaviours should not be confused with each other as both are used for different purposes (Pellis & Burghardt, 2017). The main motive of exploration is gathering information about the unknown entity. It could turn out to be edible or dangerous. Object play goes beyond this, the individual can find innovative ways to use the novel thing (Pellis & Burghardt, 2017). Both answer separate questions: by exploration, the subject tries to find a response to 'what can *it* do?' while object play is more related to the individual itself: 'what can *I* do with it?' (Bjorklund & Gardiner, 2011). Moreover, there are further key differences between exploration and object play: exploration aims to avoid difficulties, whereas play can rather help to get out of them. In playful interactions with a weaker companion, an animal might inhibit itself, which is not helpful in an explorative context. Unlike play, exploration occurs mainly in situations where caution is required (Fagen, 1981; Spinka, 2001). Above all, the two vary in intensity, as play behaviour is more vigorous and, in contrast to exploration, it is repeated over and over again (O' Hara & Auersperg, 2017). Since exploration is sometimes included in play, the boundaries are rather blurred (Pellis & Burghardt, 2017).

Different ecological factors determine how an animal reacts to new stimuli. Therefore, a distinction is made between two opposed ways of approaching the unknown. In combination, they enable the safe exploration of new environments (Miller et al., 2015). Neophobia describes the avoidance of a novel object just because the animal has not seen it before and neophilia is the tendency to explore unfamiliar things. Therefore, an animal's exploration behaviour depends on the costs and benefits of the environmental conditions. However, exploring an unfamiliar surrounding also brings dangers, as the vigilance is lower and it is also time demanding. In addition, the environmental background of the subjects plays a role. In a habitat where potential food may be toxic, it is best to be cautious and to explore little. The degree of neophobia is also influenced by the foraging behaviour of a species. Compared to specialists, generalists may benefit more from a neophilic approach since they discover more food resources (Greenberg &

Mettke-Hofman, 2001; Pika & Bugnyar, 2011). Another factor that shapes the exploration behaviour of an individual is the social context. There is evidence that the presence of conspecifics promote exploration which is also referred to as 'social facilitation' (Stöwe et al., 2006). In experiments with zebra finches (*Taeniopygia guttata*) individuals tested in groups tend to be less neophobic than tested alone (Coleman & Mellgran, 1994). In ravens, some individuals are more likely to approach an unfamiliar object if a conspecific has previously touched it (Marzluff & Heinrich, 1991). They spent more time with the objects, particularly in the presence of their siblings (Schwab et al., 2008). However, there are also studies in corvids where the opposite effect, the so called 'socially induced neophobia' was observed (Miller et al., 2015). In these experiments, individuals approached an unknown object more slowly when conspecifics were nearby, probably because they rather wait till someone else takes the possible risk. Experimental studies confirmed that the emotional state of certain group members can be transmitted to others (Stöwe et al., 2006; Wenig et al., 2021). Furthermore, the relationship to others plays a relevant role when dealing with novelty. Besides kinship and group size, other factors like sex or rank can have an impact on the exploration behaviour of others (Stöwe et al., 2006; Schwab et al., 2008; Miller et al., 2015). For instance, mainly males were more likely to investigate new stimuli especially in the presence of a female (Range et al., 2006; Stöwe et al., 2006). When looking at the rank, there were again ambivalent results: in some studies, dominant subjects were the fastest to reach unfamiliar stimuli; in other experiments, lower-ranking subjects were the first to inspect them (Greenberg, 2003; Chiarati et al., 2012).

Corvids as test species

Next to parrots, corvids are the most playful birds with a wide repertoire of complex play patterns. They are one of the few animal species that engage in all three play types (Burghardt, 2010; Emery & de Waal, 2016; O'Hara & Auersperg, 2017; Miller et al., 2022). Ravens and crows are closely related members of the crow family (Miller et al., 2015). Carrion crows and hooded crows were long considered subspecies of one species, but are now viewed as two distinct species (Glandt, 2012). Looking at the life history of crows and ravens, they tend to benefit from exploratory behaviour: they are generalists, have a wide range of habitats and live in social groups with flexible structures (Miller et al., 2015). Although corvids are very cautious, they show high levels of neophilia (Greenberg, 2003). Notably young birds frequently explore and interact with unfamiliar objects, but as they get older, their curiosity may become weaker. In the course of development, a transition from neophilia towards neophobia takes

place (Heinrich, 1995, Greenberg, 2003). Within their first year, shortly before the young animals leave their parents, they exhibit highest rates of exploration and the most play behaviour (Greenberg, 2003; Miller et al., 2015). The degree of attraction varies from certain object characteristics. Although it seems that the more the objects stand out from their usual environment, the more interesting they appear to be for corvids. Heinrich (1995) observed that ravens showed a preference for spherical, smooth and also shiny things (Rheingold & Hess, 1957; Heinrich, 1995). Long, thin objects, on the other hand, hardly evoked their interest. Possibly, they could benefit more from round objects than from thin ones when foraging. The former could turn out to be fruits or eggs, the latter twigs or even snakes. This could be one of the reasons why corvids approach round objects faster than other shapes. Another cause could be that they are generally more suspicious of large objects than small ones (Heinrich, 1995; Heinrich & Smolker, 1998).

Beyond that, ravens were observed to apply object-orientated behaviour as a communicative tool in social interactions. They use object-oriented behaviour to initiate or strengthen social bonds (Pika & Bugnyar, 2011). A commonly distributed activity in almost all corvids which can be considered as object play is the caching of inedible things (Bugnyar et al., 2007b). Caching refers to burying items or hiding them by laying material on it with the purpose to store it (Emery & de Waal, 2016). Object caching might represent a playful practise of caching behaviour since the loss of a cached item is not quite as costly as that of an edible one. Caching requires some complex cognitive skills (Bugnyar et al., 2007b; O'Hara & Auersperg, 2017). For instance, to reduce the risk of pilfering, ravens need to make sure that no one is watching. Moreover, they may learn about the caching habits of others and relate this to their own pilfering (Bugnyar et al., 2007a, b).

To my knowledge, several studies on corvid play behaviour have focused on hand-raised birds kept in groups of same-aged peers. Little is known about young corvids growing up in their family groups, i.e. at the time of development they can be expected to play most.

Questions, Hypotheses, and Predictions

I here focus on young ravens and crows raised by their parents, when their parents are still present. I provide birds with two experimental set-ups, a board with four tubes and a box in which small objects are placed that are switched each trial. The apparatus offers opportunities to manipulate moveable parts and to stick small items into tubes, i.e. practise caching. The

box containing items allows birds to take items out and transport them to other places. The items in the box are either familiar or unfamiliar to the offspring.

i) Question: Do the test subjects have a preference for one of the two set-ups?

I hypothesize that the corvids would differ in their approach depending on the experience and the size of the experimental material. In the beginning of the experiments, they are expected to take the small objects out of the box in order to move away from the larger set-ups. Later, when they have overcome their fear, the birds may start to scrutinise the board, having encounters with the board on a regular basis.

I also predict adults to have a higher playing time in the first week of testing, while their offspring would play more in the second week. The logic behind this prediction is that the parents may lose interest over time and the offspring may gain interest and/or learn to cope with neophobia over time.

ii) Question: Which type of objects do the corvids prefer?

I hypothesize that young birds are attracted by novel objects, due to their neophilia. They thus should have a preference for the unfamiliar objects, while their interest in the familiar ones is likely to remain rather modest, resulting in a longer playing time in the unfamiliar condition.

iii) Question: Which type of play do they show?

I hypothesize that the type of play behaviour depends on the respective set-up. With the box, the birds should interact more in social object play, whereas in combination to the board, it is more likely that they would engage in solitary object play. Moreover, they should combine multiple objects at once when interacting with the board. The tubes of the board could also be used for caching activities, preventing other birds from taking the objects.

Methods

Subjects and housing

I worked with 30 captive corvids, 20 common ravens *(Corvus corax)* and 10 crows *(Corvus corone and Corvus cornix)*. They were housed in 7 family groups, consisting of 14 adults and 16 chicks (Table 1). The individuals were distributed among three research facilities in Austria: one raven family was housed at the Tiergarten Schönbrunn (Vienna), another raven group at the Konrad Lorenz Research Center in Grünau im Almtal (Upper Austria) and the other five families were kept at the Haidlhof, near Bad Vöslau (Lower Austria). According to the location the aviaries differed in size and design. The ground was either covered with grass or gravel. All locations were intended to reflect their natural surroundings as closely as possible with additional enrichments.

Due to the loss of their only chick, one pair of crows had to be excluded for the second week of testing, so 27 birds remained. In order to prevent potential confusion, the original number of crows is maintained in the following text. Family size ranged from three to six individuals. Age of the parents was between four and ten years. Hatching date of the raven chicks was in March 2022 and the crow chicks hatched in June the same year. All chicks were raised by their parents and all adults (except Heidi) were hand-raised by humans. Every subject was marked with a coloured leg band for identification (with three exceptions: Munia, Joey and Peppi had no leg ring). The birds were fed twice a day with a mixture of meat, eggs, fruits and dairy products. Water was available ad libitum.

Table 1 | All 30 study subjects.

Location	Adults	Juveniles	
		Ravens	**n=20**
Schönbrunn	Rufus (m) - Munia (f)	Rhaegal - Smaug	
KLF	Tom (m) - Heidi (f)	Indigo - Cobalt - Navy	
Haidlhof	Janis (m) - Kai (f)	Chowder - Miso - Gazpacho - Pho	
Haidlhof	Rocky (m) - Joey (f)	Bristle - Plume - Downey	
		Crows	**n=10**
Haidlhof	Corbie (m) - Rainer (f)	Dude - Krainer	
Haidlhof	Signore (m) - Daisy (f)	Ancalagon	
Haidlhof	Saul (m) - Peppi (f)	Piccolo (†)	*

* The last group was only included in the first week of testing since Piccolo had passed away.

Experimental apparatus

The experimental setting was composed of several components. In each trial two different set-ups were presented. This involved a white plastic box (34 x 24 cm) and a wooden board (40 x 40 cm) with four moveable plastic tubes on each corner (Figure 1). Both were placed close after the entrance door with a distance of about 50 cm from each other. In addition to that, small objects were put in the box, which were exchanged for each session. Every day there were two separate test conditions for the items: familiar and unfamiliar. The familiar objects included natural objects to which the animals were used to from their aviary anyway. In contrast, items in the unfamiliar condition were of anthropogenic origin which they were unlikely to know. Further, every testing day had a separate category, clustered by shape and size.

Figure 1 | Both set-ups: on the left the wooden board and on the right the box with four bottle caps inside.

Procedure

A month before the experiments, the ravens were habituated to the box but not to the board. Due to time constraints, no habituation of the crows to the box occurred. Data collection was held from early May 2022 to mid-July 2022 (Figure 2). Testing took place from Monday to Friday. The experiments for each group were conducted over two weeks with a break of two weeks in between. The procedure of the first week was maintained in the second week. Tests were conducted in the family groups. Each group was tested twice a day, once in the morning and again at noon. Every session lasted 30 minutes and was recorded with a video camera (Canon Legria HF S10, Canon Legria HF S30 or Sony FDR-AX33) which was placed in front of the aviary. In addition, the experimenter, took voice recordings whenever a bird interacted with an object outside the camera view.

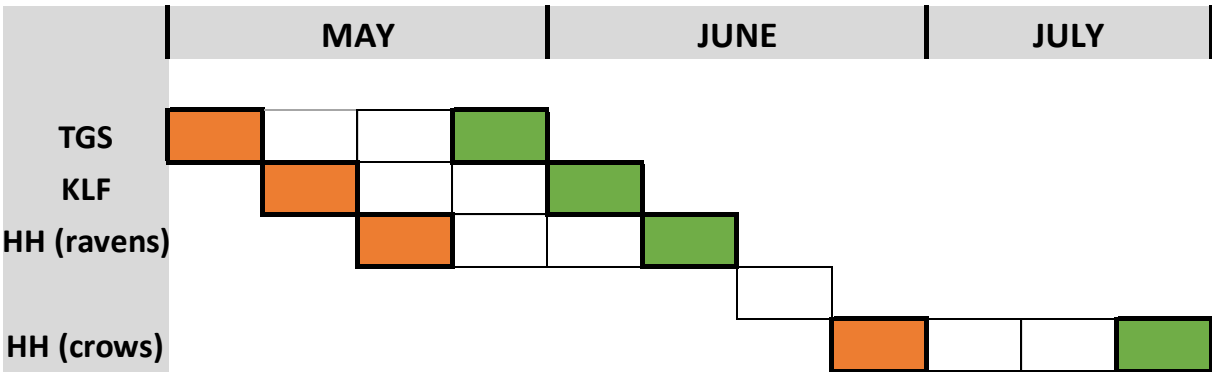

Figure 2 | Time table in weeks. In orange the first week of testing and in green the second week. Each white rectangle represents a break of one week.

To enable an even distribution, the number of items corresponded to the number of family members. Items that were used for the two trials on the same day resembled in shape and size, while differing in their degree of familiarity. The following object pairs were included in the experiment: pine cones and bottle caps, straws and twigs, pebbles and table tennis balls, clothes-pegs and pine twigs and the last couple encompassed small rocks and Kinder Surprise Egg-toys® (Figure 3). After each trial the box and the board were removed but the objects were left in the aviary. The schedule was the same for both testing weeks.

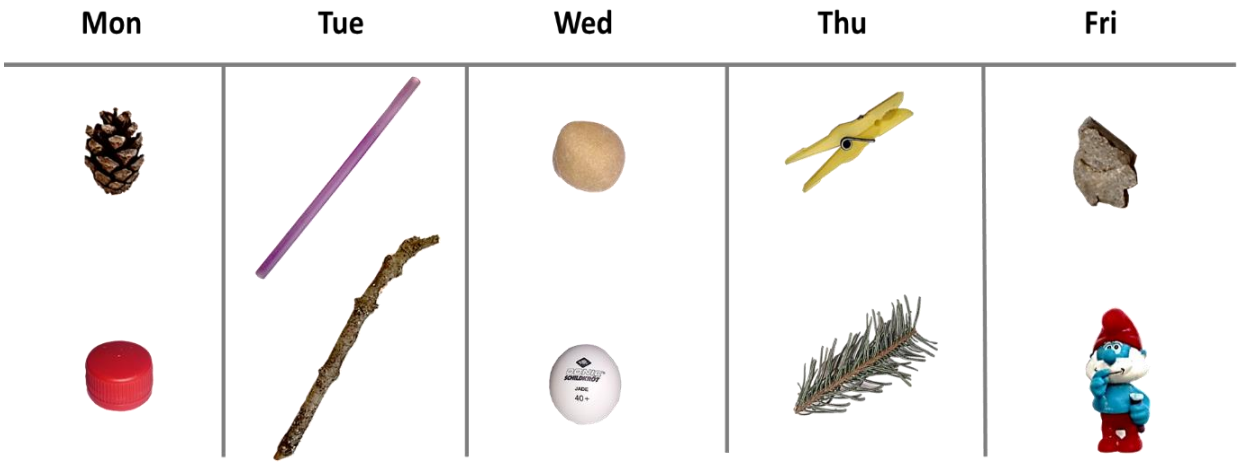

Figure 3 | Object pairs that were used for each day.

Data analysis

The program Solomon Coder (Péter, 2011) was used for the analysis of the videos and the audio recordings. Data was acquired through behaviour sampling techniques focused on the two play categories object play and social object play. Object play involved manipulating an item (with the beak or the claw), this included as well interactions with the board or box, the transport of items and caching them. Social object play contained the following behaviour: co-manipulating (several birds handling an object at the same time), transfer, discriminating hereby between donated (the item was offered to another bird) and requested (another subject tried to steal it), pilfering of another's cache, wait and watch while another corvid was playing (which was determined on the basis of their body orientation).

Statistical analysis

The statistical analysis was conducted with the program R Studio (version 4.2.1; R Core Team, 2022). Different general linear mixed models using the package 'glmmTMB' (version 1.1.4; Brooks et al., 2017) were run examining the duration (in seconds) using a gaussian distribution and frequency of interactions with the experimental material using a Poisson distribution, each time for ravens and crows separately. In addition, each species was split into the age categories adults and chicks. There was one exception for which we could not find a fitting model, so we performed a Wilcoxon rank sum test.

For the model selection in R, it was necessary to include a zero inflation formula in each model since the data confirmed to be zero inflated. We tried to incorporate random slopes, but this led to convergence issues so we had to exclude them altogether. The function 'vif' from the 'car' package (version 3.1-0) was used to check for multicollinearity using variance inflation factors. For model diagnostics the 'DHARMa' package (version 0.4.6; Hartig, 2022) was applied for checking the model assumptions. All but one frequency model had a significant outlier test, which, according to the creator, could not be avoided for such large data sets (Hartig, 2022). There were some cases in which we could not include all test predictors due to convergence issues, so we had to run several models for one (sub)group. This is stated in the following section, otherwise there is only one model with all three predictors. With every fitted model a full-null model comparison was conducted to ensure the test predictor contributes to the improvement of the model by using a likelihood ratio test.

Starting point of the statistical analysis was the following formula, which resulted in a maximal model that was reduced by removing one predictor at a time until model complexity was low enough to avoid convergence issues: duration respectively frequency ~ site + test condition + play type + week number + family size + age + (1|item) + (1|individual) with the following as test predictors: site (box and board), test condition (familiar and unfamiliar objects) and play type (object play and social object play). As fixed effects we included: week number (first and second week of testing), family size (from three to six subjects), age (chicks or adults). And when possible, we added these random factors: items (ten different objects) and individuals (all 30 subjects).

Results

Descriptive statistics

Which set-up was contacted first? Which object type was contacted most and in what way?

Out of 130 trials, in 93 cases the individuals interacted with the test material. Of these, the box was touched first 64 times (ravens: 43 times and crows: 21 times) and the board 29 times (ravens: 16 and crows: 13), (mean: 346.630s with a SD of +-189.407s per family). The object manipulation was initiated most often from the parents, whereby it was very balanced in terms of gender (females: 35 times, males: 39 times).

Of all items, the table tennis balls were the most popular ones. Manipulation and transporting emerged as the most frequently observed behaviours (Figure 4).

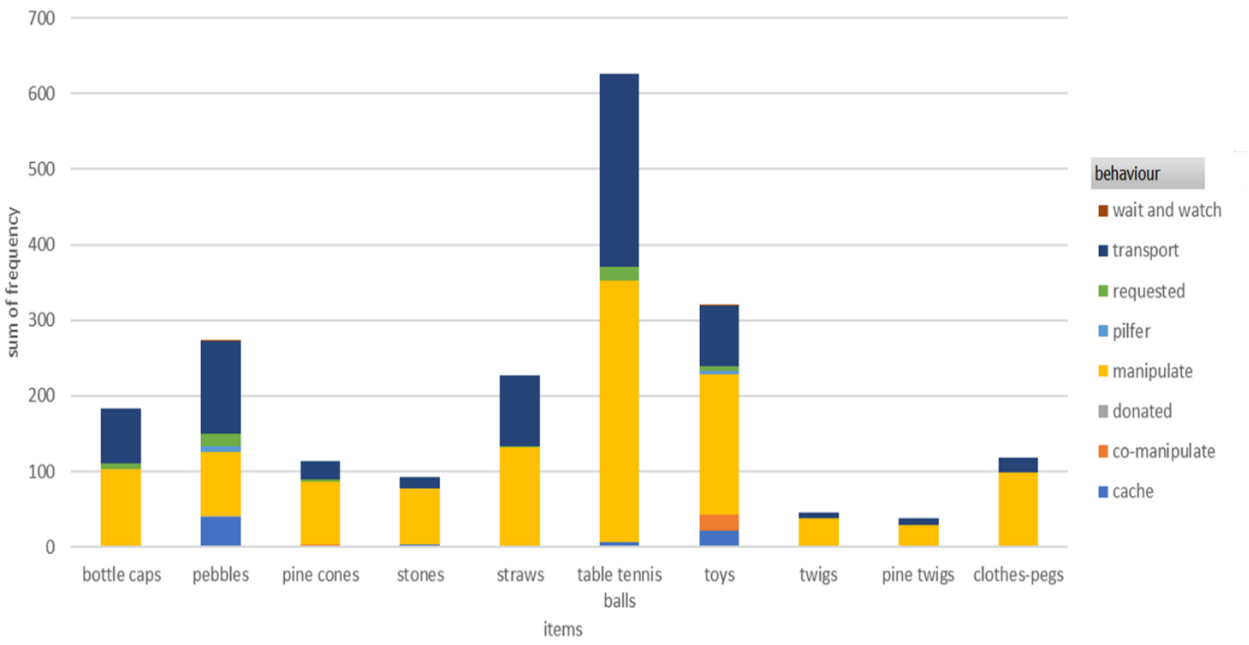

Figure 4 | Sum of the frequency for each item in combination of the ratio of each behaviour.

Duration of play interactions

Ravens: the model revealed a significant effect for the object test condition for all ravens (full-null model comparison: n = 20; $\chi 2 = 8.235$, df = 2, p = 0.016), (Figure 5). They spent more time playing with the unfamiliar items compared to the natural ones. By running a Wilcoxon

rank sum test there was a significance for the ravens towards object play (W = 63024697, p < 0.001), (Figure 6). Nevertheless, when splitting the data into the age groups, the full-null model comparison showed no significant difference for either the adults (n = 8; model with the test predictors site and test condition: $\chi 2 = 4.937$, df = 2, p = 0.085 and the model for play type: $\chi 2 = 1.043$, df = 1, p = 0.307) or the juveniles (n = 12; $\chi 2 = 3.570$, df = 3, p = 0.312).

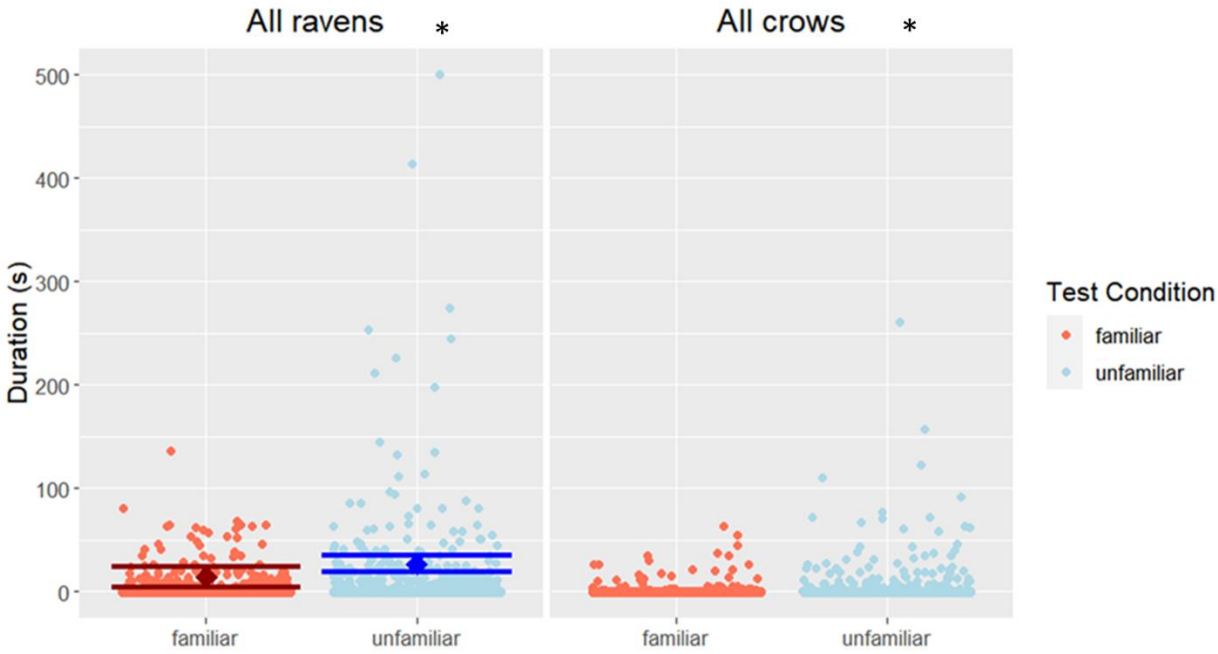

Figure 5 | Duration for ravens (left) and crows (right) for the test condition of the objects. On the right side without error bars as the issue of quasi complete separation came up.

Table 2 | Model output with a view to duration for all ravens (left) and all crows (right).

Model output ravens						Model output crows				
Variables	Estimate	SE	z value	p value		Estimate	SE	z value	p value	
(Intercept)	27.873	18.887	1.476	0.140		34.441	25.838	1.333	0.183	
sitebox	-3.710	5.776	-0.642	0.521		-3.393	5.172	-0.656	0.512	
test_conditionunfamiliar	12.617	4.401	2.867	0.004	**	12.748	5.158	2.471	0.014	*
week_number	-5.756	4.667	-1.234	0.217		5.269	6.666	0.790	0.429	
ageparents	0.067	5.423	0.012	0.990		-9.287	7.643	-1.215	0.224	
family_size	-0.216	3.253	-0.066	0.947		-6.610	9.527	-0.694	0.488	
N (observations) = 26324, N (subjects) = 20 ravens						N (observations) = 8280, N (subjects) = 10 crows				

Model output with the testpredictors "site" (reference level: "board"), "test_condition" (reference level: "familiar"), "week_number" (covariate ranging from 1 to 2), "age" (reference level: "chicks").
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

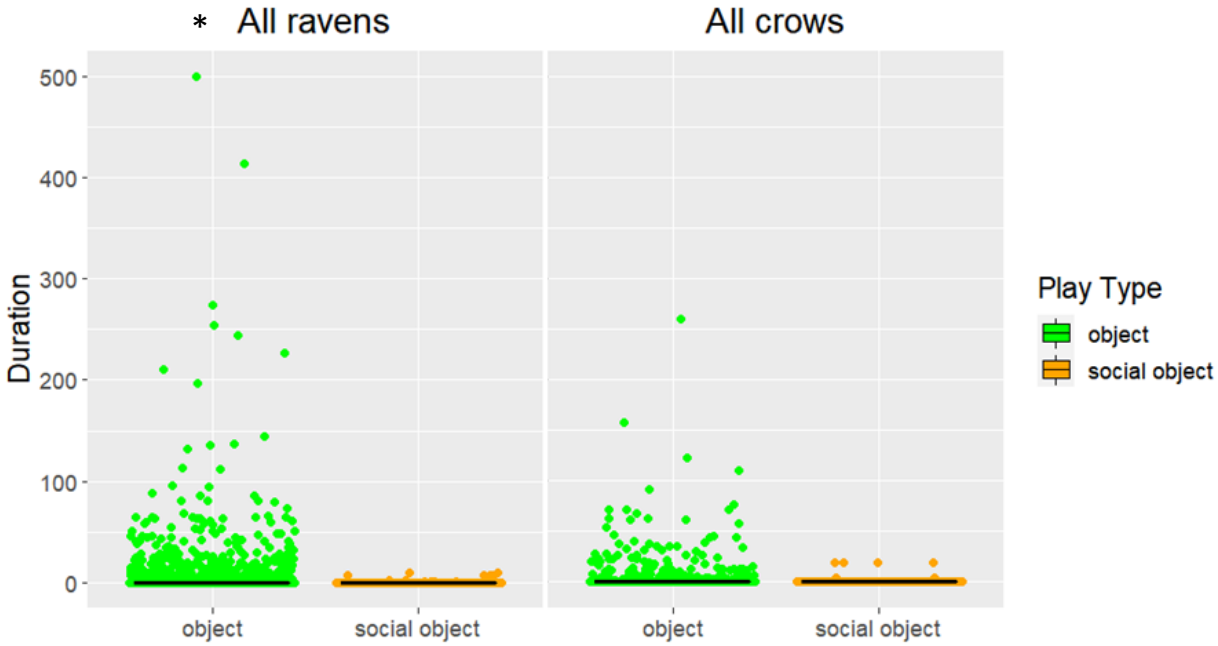

Figure 6 | Duration classified in play type for ravens (left) from the Wilcoxon rank sum test and crows (right) from a model without a significance in the model comparison. Therefore both graphs are illustrated without error bars and model output.

Crows: like in the ravens, the model revealed a significant effect for the unknown condition for all crows together (full-null model comparison for test condition and site: n = 10; $\chi 2$ = 6.006, df = 2, p = 0.0496), (Figure 5). An additional model with all test predictors couldn't yield a

difference in the model comparison (n = 10; $\chi 2 = 6.754$, df = 3, p = 0.080), (Figure 6). For the crow parents one full-null model comparison had a significant result, but there was no significance in the subsequent outcome (model for site and test condition: n = 6; $\chi 2 = 6.084$, df = 2, p = 0.048) another model with the third test predictor, showed no difference in the model comparison (model for play type: n = 6; $\chi 2 = 0.404$, df = 1, p = 0.525). Crow chicks spent more time interacting with the board than with the box (n = 4; $\chi 2 = 14.319$, df = 3, p = 0.0025).

Frequency of number of contacts

Ravens: both models for the adult ravens could yield a significant result in the full-null model comparison (model for site and play type: n = 8; $\chi 2 = 983.389$, df = 2, $p < 0.001$ and model with test condition and site: n = 8; $\chi 2 = 149.34$, df = 2, $p < 0.001$), (Figure 7, Table 3). They showed more interactions with the box, the novel objects and engaged more often in object play than in social object play.

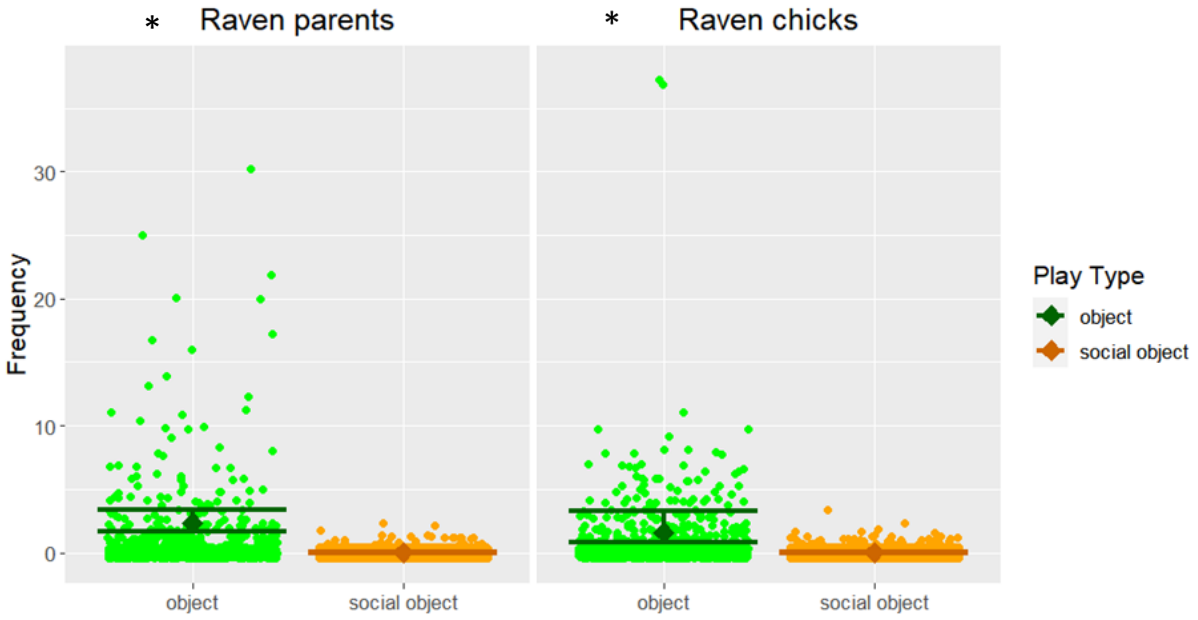

Figure 7 | Frequency divided into raven parents (left) and their chicks (right) for the test predictor play type.

The model comparison for the raven chicks revealed a significant outcome (n = 12; $\chi 2 = 895.039$, df = 3, $p < 0.001$). With them there was the same preference for the box over the board, as well as for the unfamiliar objects and more observations for object play (Figure 7).

Besides that, raven parents had a higher play performance in the first week, whereas their chicks in the second week of testing (Figure 8, Table 3).

Table 3 | Model output for the ravens: parents (left) and chicks (right).

Model output raven parents						Model output raven chicks				
Variables	Estimate	SE	z value	p value		Estimate	SE	z value	p value	
(Intercept)	1.077	1.181	0.912	0.362		-0.188	2.677	-0.070	0.944	
sitebox	0.719	0.131	5.510	<0.001	***	0.868	0.162	5.369	<0.001	***
play_typesocialobject	-5.395	0.207	-26.100	<0.001	***	-4.740	0.163	-29.170	<0.001	***
week_number	-1.266	0.123	-10.338	<0.001	***	0.348	0.108	3.208	0.001	**
family_size	0.188	0.231	0.812	0.417		-0.198	0.512	-0.388	0.698	
test_conditionunfamiliar	not included					0.315	0.093	3.376	<0.001	***
N (observations) = 23394, N (subjects) = 8						N (observations) = 35954, N (subjects) = 12				

Model output with the testpredictors "site" (reference level: "board"), "week_number" (covariate ranging from 1 to 2), "play_type" (reference level: "object"). Only for chicks: "family_size" (covariate ranging from 3 to 6).

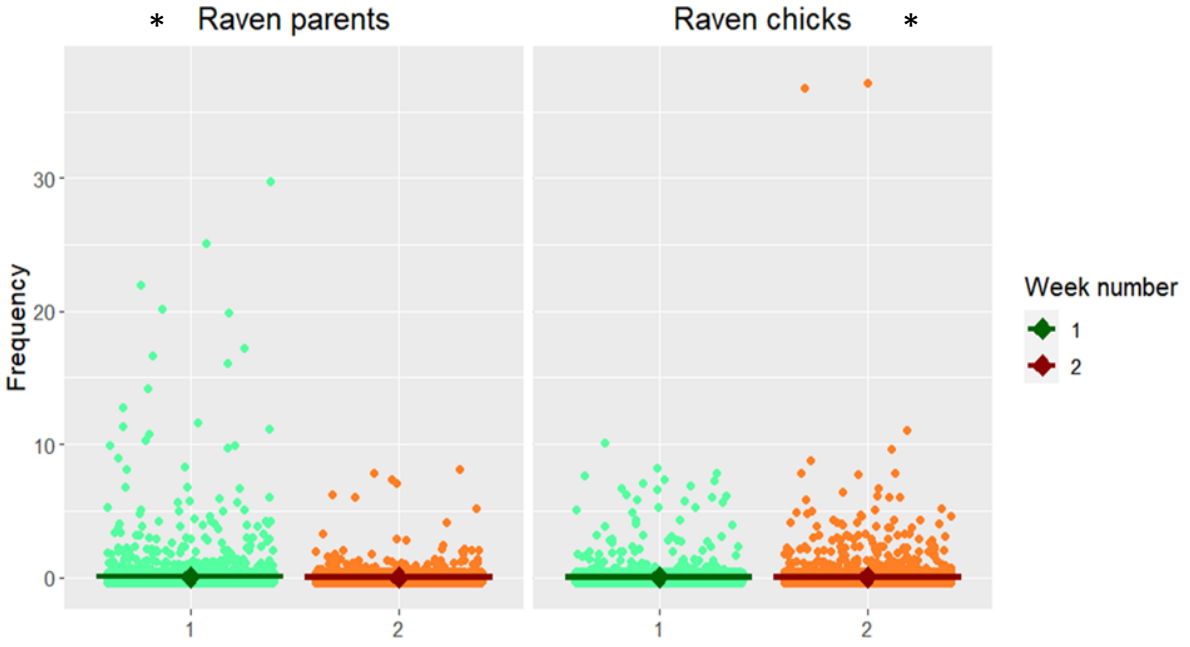

Figure 8 | Frequency for the ravens considering week number: parents (left) and chicks (right). For the model output see Table 3.

Crows: the model for the adult crows yielded a significant outcome in the full-null model comparison (n = 6; $\chi 2 = 575.813$, df = 3, $p < 0.001$). The parents interacted more often with the box, revealed a higher frequency for social object play as well as for a smaller family size (Figure 9, Table 4). For the crow chicks more contacts with the board could be observed and they also revealed a higher play frequency in the second week (n = 4; $\chi 2 = 141.092$, df = 3, $p < 0.001$).

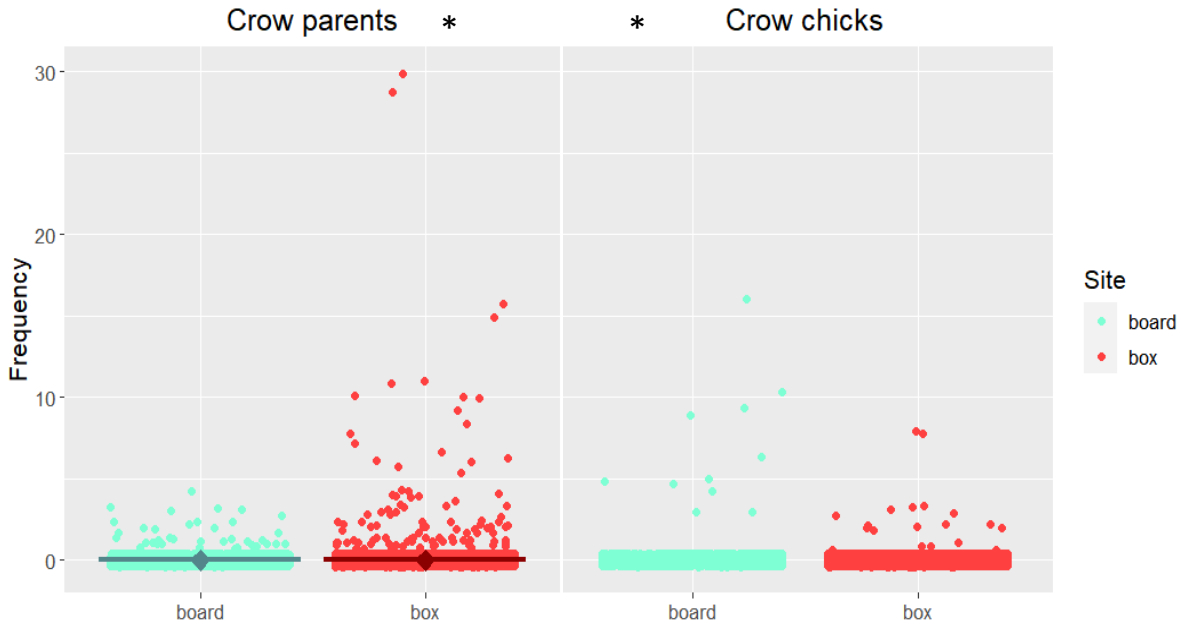

Figure 9 | Frequency for crow parents (left) and their chicks (right) looking at the predictor site. On the right side without error bars, since the predicted confidence interval was infinite due to the problem of quasi complete separation.

Table 4 | Output for crow parents (left) and crow chicks (right).

Model output crow parents						Model output crow chicks				
Variables	Estimate	SE	z value	p value		Estimate	SE	z value	p value	
(Intercept)	3.608	2.127	1.697	0.090		-4.716	3.798	-1.242	0.214	
sitebox	1.146	0.176	6.503	<0.001	***	-0.919	0.203	-4.525	<0.001	***
test_conditionunfamiliar	1.061	0.160	6.616	<0.001	***	0.398	0.206	1.937	0.053	
week_number	0.251	0.188	1.331	0.183		1.137	0.435	2.612	0.009	**
play_typesocialobject	-5.154	0.306	-16.840	<0.001	***	-23.884	6627.947	-0.004	0.997	
family_size	-1.573	0.647	-2.427	0.152	*	not included				
N (observations) = 10240, N (subjects) = 6						N (observations) = 7480, N (subjects) = 4				

Model output with the testpredictors "site" (reference level: "board"), "test_condition" (reference level: "familiar"), "week_number" (covariate ranging from 1 to 2), "play_type" (reference level: "object"). Only for parents: "family_size" (covariate ranging from 3 to 6).

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Discussion

The aim of this study was to investigate object play in families of ravens and crows. Specifically, I was interested in which manner the birds engage with different play set-ups (question 1) and how strong they were affected by certain item properties (question 2). Further, I was interested in how much the birds would include the test items in social play (question 3).

Concerning my first question, I hypothesized that the birds' way to approach the experimental design should vary dependent on the size of the set-up. Therefore, it was predicted that the small items of the box would be removed first and the board should be incorporated in the progress of the experiment. There were indeed more first contacts with the box compared with the board, supporting the assumption. While adults of both species as well as the young ravens kept a clear preference for the box throughout the experiment, this was not the case in young crows. Why only young crows showed a preference for the board, is difficult to interpret. It is possible that this result is affected by strong preferences of some individuals due to the small sample size of young crows.

I expected the peaks in play intensity to occur at distinct times according to age class and development. Adults should play more in the first week of testing (May/June), whereas the chicks should play more in the second testing week (June/July). Considering the ravens, this

prediction held for both age classes: the parents' interest in the objects decreased in the second week, while then the chicks started to play more frequently. In case of the crows, only the chicks showed a significant effect for the second week. Taken together, these results support previous findings that age and thus experience has an effect on corvids' investigation and playful manipulation of items (Heinrich, 1995, Greenberg, 2003).

Concerning my second question, I hypothesized that young birds are attracted by novel objects, due to their neophilia. I thus predicted that unfamiliar items should raise the birds' interest much more than things they already know. This could be confirmed with one exception: for the crow chicks, where no significance could be yielded with respect to the test condition. Nevertheless, every other age group, as well as crows and ravens each as a whole showed a clear tendency for the unknown items. These observations go along with other findings in hand-raised ravens and crows (Heinrich, 1995; Miller et al., 2015). The high number of interactions with the table tennis balls confirms the reports from Heinrich (1995) for the attraction to small, round things. Maybe they mistook them for eggs, as the manipulations decreased as soon as they had opened the shell and failed to find any edible content - and given that eggs belong to their favourite food (Heinrich, 1995).

Concerning my third question, I hypothesized that the type of play behaviour depends on the respective set-up. The birds should engage in social interactions more frequently at the box containing transportable items, whereas the birds should perform object play more often with the board. However, as there occurred more encounters with the box and a higher engagement within the object play type, this assumption could not be confirmed. The chicks of the crows had no significant effect in respect to the test predictor play type but all others revealed a higher frequency in object play compared to social object play. Maybe social object play did not occur quite so often because there were enough objects available (Auersperg et al., 2015). It is also imaginable that the social bonds in the family are not yet developed and therefore it was too early to use social object play to improve them further (Pika & Bugnyar, 2011).

In general, the results of the crows, especially the young crows, should be interpreted with caution. There were only three families and the family with two chicks consisted of individuals with extreme characters. Moreover, there were only four juvenile crows, so the reason behind the findings could be due to a too small sample size. Therefore, further experiments are necessary to find out if crow play derivates from raven play. Especially considering the fact that ravens and crows have a pretty similar ecological background (Miller et al., 2015).

Especially in the context of the crows we encountered the issue of quasi complete separation which is visible in Figure 5 (visualisation of duration for all crows using the predictor test condition) and in Figure 9 (visualisation of the crow chicks frequency for site). Looking at Figure 9, the cut point is at y = 4 and the largest overlap is at y = 0. This led to an infinite predicted confidence interval reflected by the missing error bars. Figure 5 revealed similar patterns albeit slightly weaker with a much larger overlap, though with the same problems. The reason for this could again be the small sample size of the crows.

A key aspect of this study is that I investigated playful object manipulation in family groups. Yet, adults and young ravens experienced different rearing styles. All but one (Heidi) of the adults were hand-raised, whereas all chicks were raised by their parents; hence, age class correlates with the rearing condition, which might have an influence on the results. For instance, subjects that were hand raised by humans might be more prone to handle anthropogenic items. Furthermore, it is possible that sex could have had an effect on their exploration and play behaviour. There are studies where novel objects were approached faster by male corvids than female ones (Range et al., 2006; Chiarati et al., 2012). This could not be found, at least among the parents, as the frequency of first contacts was balanced between the genders. For the offspring, no statement could be made on this aspect, as the information on gender was not available at the time of analysis. In the future, it would be interesting to test adults and chicks separately in order to investigate how far the age groups influence each other's behaviour.

Conclusion

Taken together, my findings confirm that the age of the individuals and size of the test material does have an effect on the exploration and play behaviour of corvids. Young individuals and adults differed in the time window in which they played the most. The adults reduced object manipulation over time, whereas the chicks increased to interact with the experimental set-ups during development. With this study, I could also demonstrate corvids' neophilia towards unfamiliar objects. Further, in the context of the family group they tend to focus on solitary object play rather than object play with other birds. Nevertheless, how far ravens and crows differ remains to be investigated. Regarding the transition from exploration to play: the first contacts with the experimental material could be considered exploration, and play began as

soon as they had established that the experimental set-up posed no danger. In any case, there was no clear cut, it was a rather smooth transition from exploration into play behaviour.

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