Cats match voice and face: cross-modal representation of humans in cats (*Felis catus*)

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Abstract

We examined whether cats have a cross-modal representation of humans, using a cross-modal expectancy violation paradigm originally used with dogs by Adachi et al. (2007). We compared cats living in houses and in cat cafés to assess the potential effect of postnatal experience. Cats were presented with the face of either their owner or a stranger on a laptop monitor after playing back the voice of one of two people calling the subject's name. In half of the trials the voice and face were of the same person (congruent condition) whereas in the other half of trials the stimuli did not match (incongruent condition). The café cats paid attention to the monitor longer in incongruent than congruent conditions, showing an expectancy violation. By contrast, house cats showed no similar tendency. These results show that at least café cats can predict their owner's face upon hearing the owner's voice, suggesting possession of cross-modal representation of at least one human. There may be a minimal kind or amount of postnatal experiences that lead to formation of a cross-modal representation of a specific person.

Keywords: Cross-modal representation, Cats, *Felis catus*, Expectancy violation method

Introduction

Integration of multi - sensory information facilitates the detection or identification of external stimuli. For example, often we hear someone' s voice calling us, but we cannot see the person. In this situation we can recall the person's face. This shows that we have a mental representation that integrates information from visual and auditory modalities (cross-modal representation) (see Campanella and Belin 2007 for review). In humans this ability emerges early in life. Bahrick et al. (2005) reported that even 4- to 6-month-old infants perceived face - voice relations of unfamiliar adults.

Nonhuman animals also have cross-modal representation of others. This should be an important ability especially for social animals living in complex societies; allowing them to identify individuals, avoid conflicts and maintain social balance, rank, and perhaps cooperation. Some social species are known to have cross-modal representations of conspecifics (chimpanzees (*Pan troglodytes*): Kojima et al. 2003, rhesus macaques (*Macaca mulatta*): Adachi and Hampton 2011; Sliwa et al. 2011, Grey-Cheeked mangabeys (*Lophocebus albigena*): Bovet and Deputte 2009, horses (*Equus caballus*): Proops et al. 2009, lions (*Panthera leo*): Gilfillan et al. 2016, goats (*Capra hircus*): Pitcher et al. 2017, crows (*Corvus macrorhynchos*): Kondo et al. 2012). Furthermore, rhesus monkeys, squirrel monkeys (*Saimiri* *boliviensis*) and dogs (*Canis familiaris*) can also form cross-modal representation of familiar members of at least one other species, namely humans (Adachi et al. 2007; Adachi and Fujita 2007; Sliwa et al. 2011).

Adachi and Fujita (2007) reported that squirrel monkeys responded differently depending on the familiarity of the human stimuli, using a symbolic matching-to-sample task. They trained monkeys to match photographs of two caretakers and a symbolic visual stimulus. One caretaker was a primary caretaker, more familiar than the other (secondary caretaker). In test trials, a voice which belonged to either the primary or secondary caretaker was played back immediately after the visual sample stimulus disappeared, then two comparison stimuli appeared, one of which the monkey was required to choose. The authors predicted that congruency between voice and sample stimulus would affect matching accuracies. Results showed that accuracies did not differ between congruent and incongruent trials when the primary caretaker's face was the sample, but accuracies were higher in congruent than incongruent trials when the secondary caretaker's face was the sample. Thus, the secondary caretaker's voice did not interfere with matching the primary caretaker's face to the symbolic stimulus, whereas the primary caretaker's voice interfered with matching the secondary caretaker's face to the corresponding symbolic stimulus. Thus, familiarity of the specific person affected the monkeys' cross-modal representation.

Adachi et al. (2007) reported that pet dogs have a cross-modal representation of their owner. Dogs were presented with a photo of either their owner's or a stranger's face on a monitor after a voice calling subject's name was played back. The voice and face matched in half of the trials and mismatched in the other half. Results showed that dogs looked at the photo longer in both incongruent conditions, suggesting that they predicted the owner's face upon hearing the owner's voice, and another face upon hearing a stranger's voice. Conceivably, extensive experience with a specific person strengthens the formation of such cross-modal representations. Do other companion animals show the same tendency as dogs?

Like dogs, cats are a popular companion animal for humans, and recent studies have shown that like dogs, cats also have remarkable social cognitive abilities. They respond to human pointing cues (Miklósi et al. 2005) and gaze cues (Pongrácz et al. 2018), discriminate human emotional expressions (Galvan and Vonk 2016) and human attentional states (Ito et al. 2016), and refer to human facial expressions in the presence of a mildly frightening object (Merola et al.

2015).Saito and Shinozuka (2013), using a habituation-dishabituation procedure, reported that cats discriminated their owner's voice from a stranger's voice. However, it is unknown whether they predict their owner's face after hearing the owner's voice, as expected if integration of the relevant audio-visual information occurs.

Here we asked whether cats (*Felis catus*) have cross-modal representations of their owners, using the task originally used with dogs in Adachi et al. (2007). If familiarity of the person affects cross-modal representation, as seen in previous studies, the rearing environment should affect formation of a cross-modal representation of the owner. More specifically, house cats – with a closer relationship with their owner – should show stronger results than cats living at a cat café where many people interact with them each day. In previous research data from these two groups of cats analyzed separately their responses to human voices were different (Saito et al. 2019). The expectancy violation-based prediction was that if cats have a cross-modal representation of their owner they should pay attention to the monitor for longer in incongruent (mis-matching) conditions than congruent (matching) conditions.

Methods

Subjects

Eighty-seven domestic cats (*Felis catus*) (48 males, 39 females) participated. Forty-three were kept at five "cat cafés" (24 males, 19 females, mean age 4.14 years, *SD* = 2.98 years, range 4 months to 10.7 years), where many unfamiliar visitors have contact with the cats. There are various types of cat cafes in Japan. Some serve both as a normal cat café where visitors can enjoy interacting with cats and consider fostering a cat. Cats leave these cafés when they find a foster family. We tested cats in cafes where the cats were permanent residents and where they spend all their time. The remaining subjects were house cats (24 males, 20 females, mean age 5.14 years, *SD* = 3.18 years, range 8 months to 12.4 years). Subjects had been with their owner for at least for 4 months in cat cafés and 11 months in households. An additional 23 cats (12 cats from cat cafés and 11 from households) were excluded due to camera error (3 cats), fear (3), or failure to look at the stimuli (no look in all 4 test trials) (17). In addition to approval from the institutional animal experiment committee (see paragraph on compliance with ethical standards), informed consent was obtained from all owners. Cats were not deprived of water or food during the study.

Apparatus & Stimuli

The auditory stimuli consisted of a recording of either the owner or a same-sex unfamiliar person (stranger) calling the subject's name once. Each owner was instructed to call out the cat's name as they normally would; the stranger was instructed to call out the name in the way the owner did. We recorded the calls using a handheld digital audio recorder (Roland EDIROL R-09, Japan) in WAV format. The sampling rate was 44,100 Hz and the sampling resolution was 16-bit. We used 1-s call stimuli regardless of the cats' names; all voices were adjusted to the same volume with the help of version 2.3.0 of Audacity(R) recording and editing software (Audacity Team 2018). Voice stimuli were played from a speaker (Sanwa MM-SPS2UBK, Japan) connected to a laptop personal computer (NEC Lavie G type Z, Japan) which controlled all experimental stimuli. The visual stimuli consisted of a photo of the face of either the owner or a stranger. We took a digital, full-face, color photo of each person smiling, and stored the photo in PNG format. Presented photos were ca. 16.5 x 16 cm on the 13.3 -in. monitor of the laptop computer. The background was always black.

The test was recorded by three video cameras (JVC GZ-E565-R, Japan; SONY HDR-CX390, Japan; SONY HDR-CX675, Japan), one placed in front of subject, another placed slightly to one side, and the other placed behind subject; all cameras focused on the cat.

Procedure

Cats were tested individually in their familiar place: house or café. Before testing we waited until cats appeared relaxed in the presence of the experimenter; this took about 15 min for house cats whereas almost all café cats ended no such familiarization time. An experimenter gently restrained the cat on the floor in front of the laptop computer, about 40 cm away. The experimenter started a trial by pressing a key on the computer when the subject was looking toward the monitor. Each trial consisted of two phases: the voice phase and the face phase. In the voice phase, one stimulus voice was played back from the speakers linked to the laptop every 1 s, for a total of four presentations. Immediately after the fourth auditory stimulus either the owner's or a stranger's face appeared on the monitor for 7-s (face phase) (see Fig.1). The experimenter restrained the cat throughout the voice phase and released it at the start of the face phase; some cats stayed, whereas others moved around to explore the monitor. A trial ended when the face on the monitor disappeared.

There were four experimental conditions according to the combination of face and voice: owner-congruent, owner-incongruent, stranger-congruent, and stranger-incongruent. For example, in the owner-incongruent condition, a stranger's voice was played in the voice phase, but the owner's face appeared in the face phase. These four trials were presented in pseudo-random order with the restriction that the same voice was never repeated on consecutive trials.

Our hypothesis was that cats would pay attention to the face (the monitor) longer in the incongruent condition than the congruent condition. Each subject received four trials in a single session, with an inter-trial interval of at least 3 min. For ethical reasons we immediately halted the procedure if the subject refused to be placed in front of the monitor; three subjects participated in only the first trial, three in the first and second trials, while four subjects received no fourth trial. During the interval, cats acted freely in the experimental room. The experimenter restraining the cat was ignorant of the condition; she closed her eyes during the test trials and avoided making eye contact with the subject. Presentation of voice and face stimuli was controlled via a Visual Studio 2013 program on the laptop personal computer.

Analysis

A coder (H.C.), blind to the conditions, counted the number of frames (30 frames/1 sec.) in which cats paid attention to the monitor in the face phase (total 7 sec) for each condition. Paying attention was defined as looking at or sniffing the monitor. We could not discriminate these two acts because a few cats did not touch the monitor with their nose while sniffing. Trials in which subject did not look at the monitor at all were excluded from the analyses because we could not know if expectancy violation occurred. Sixty-four trials were excluded for café cats, 65 for house cats (no significant difference; Fisher's Exact Test: $p = .73$). Table 1 shows valid data points, i.e., the number of trials cats looked at the monitor in each condition. The videos were analyzed using Adobe Premiere CS6 (USA) software.

To check the reliability of coding, an assistant who was blind to the conditions coded a randomly chosen 20% of the videos. The correlation between the two coders was excellent for time spent paying attention to the monitor (Pearson's $r = 0.97$, $n = 40$, $p < 0.01$).

All statistical analyses were conducted with R version 3.5.1 (R Core Team, 2018). Attention to the monitor was analyzed by a linear mixed model (LMM) using a lmer function in lme4 package version 1.1.10 (Bates Martin Bolker and Walker

2015), in which face (owner/stranger), congruency (congruent/incongruent), home environment (café/house) and an interaction between congruency and home environment were entered as fixed factors and subject identity was entered as a random factor. To test whether effects of factor were significant, we ran F tests by an Anova function in car package (Fox et al 2012). We used a difflsmeans function in lmerTest package (Kuznetsova Brockhoff and Christensen 2017) which tested differences of least squares means to compare each condition. Degrees of freedom were adjusted by Kenward-Roger and p-value was adjusted by the Holm procedure.

Results

Fig. 2 shows time spent paying attention to the monitor during the face phase in café cats (A) and house cats (B). Contrary to our prediction, café cats showed more attention to the monitor in both incongruent conditions, whereas house cats showed no clear tendency; they attended to the monitor almost randomly. LMM revealed that significant main effects of congruency ($F(1, 60.87) = 4.10$, $p = .04$), home environment ($F(1, 79.03) = 8.06$, $p < .01$), and an interaction between congruency and home environment ($F(1, 60.71) = 7.76$, $p < .01$). There was no significant main effect of face ($F(1, 96.78) = 0.06$, $p = .79$).

The test of differences of least squares means showed a significant difference between congruent and incongruent conditions in café cats ($p < .01$), between café cats and house cats in congruent conditions ($p < .01$), and between café cats in congruent conditions and house cats in incongruent conditions ($p < .01$).

Discussion

We used an expectancy violation procedure to ask whether cats have a cross-modal representation of their owner. We presented the face of either the owner or stranger after playing back the voice of the owner or a stranger calling the subjects' name. Results showed that café cats paid attention to the monitor for longer in both incongruent conditions, when voices and face were mismatched, whereas house cats showed no clear trends. These results contradict our prediction and suggest clearly that café cats predict the owner's face upon hearing the corresponding voice, demonstrating a cross-modal representation of a specific person; whether house cats have this cross-modal ability remains to be further examined. The results also indicate that cross-modal representations of others are not exclusive to species that form complex social groups, such as dogs, but also more solitary species, such as cats (Bradshaw 2016).

There are three possible explanations for our failure to demonstrate a cross-modal representation in house cats. First, cross-modal representation of a specific person might be affected by factors other than familiarity with that individual. Café cats typically see and interact with multiple strangers on a daily basis. People with greater experience of heterospecific faces can discriminate them better than people with fewer such experiences (Dufour and Petit 2010). Also, older captive chimpanzees discriminated human faces better than younger chimpanzees probably because older chimpanzees had more experiences to see a variety of human faces (Dahl et al 2013). These results raise the possibility that café cats greater experience of a variety of human faces and voices might result in better discrimination abilities.

Second, greater experience of seeing and interacting with people might promote application of an "exclusive rule." Our task required cats to predict a stranger from a stranger's voice in one of the incongruent conditions. It should be more difficult to predict the stranger from the stranger's voice than the owner from the owner's voice using and exclusion rule. Kondo et al (2012) demonstrated that crows did not react even when a familiar crow's calls were played back followed by an unfamiliar bird presented visually, suggesting that they did not exclusively predict "a stranger". Similar asymmetrical results were obtained in horses (Proops and McComb 2012). In contrast, café cats showed expectancy violation in both incongruent conditions; they showed no asymmetry. This suggests that the café cats exclusively predicted a non-owner face, using the exclusion rule. Conceivably, increased opportunities to see various people might improve cross-modal representations of others. Home environments that differ from normal pet environments in terms of seeing human strangers might explain why café cats showed the clearer expectancy violation.

Finally, house cats might have been more nervous during the test. We asked the owner to remain in another room because we wanted to test cats' representation of their owner. Some cats may not have felt sufficiently at ease in the presence of only the experimenter. More house cats remained immobile after the experimenter released them in the face phase; a freezing reaction might have resulted in longer looking times in all conditions compared to café cats. To exclude such a possibility future work should use a more natural experimental setting less likely to cause stress in house cats, or conduct a test that objectively estimates their stress level.

One may argue that house cats did not discriminate between the owner's face and a stranger's face, given their lack of differential responses across conditions. However, previous studies have shown that house cats respond differently to familiar and unfamiliar humans facing them directly (Collard 1967; Ellis

Thompson Guijarro and Zulch 2015; Galvan and Vonk 2016). Further research should be conducted on cats' ability to discriminate the owner's face from a stranger's face when only visual information is presented.

We used voice and face to examine cats' cross-modal recognition of humans. However, cats also use their olfactory sense to recognize others (Gorman and Trowbridge 1989). Further research should examine whether olfactory information is also integrated in cross-modal representations of others.

Cross-modal recognition is not limited to a one-to-one relation (owner's voice - face) as in this study. For example, dogs can show more general cross-modal recognition: Taylor Reby and McComb (2011) examined whether dogs could match frequency of growls and dogs' body size. Dogs spent more time looking at a correct model (small body - high frequency, or big body - low frequency) than an incorrect model (small body - low frequency, or big body - high frequency), suggesting that they relate information about body size to "voices." Furthermore, dog cross-modally matched a human male or female voice and a male or female face (Takaoka et al 2013). It is still unknown whether cats have similar cross-modal recognition abilities beyond one-to-one correspondence; this is another issue for future study.

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Compliance with ethical standards

This study adhered to the ethical guidelines of Kyoto University, and was approved by the Animal Experiment Committee of the Graduate School of Letters, Kyoto University.

Competing interests

The authors declare no conflicts of interest.

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Legend

Fig. 1

Fig.1 Diagram illustrating each condition. Face was presented in the monitor (Face phase) immediately after voices was played back (Voice phase). The face and voice matched in half of the trials (congruent condition) whereas they mismatched in the other half of trials (incongruent condition). Black line represents Congruent conditions, dotted line represents Incongruent conditions.

Fig.2

Time spent paying attention to the monitor in (A) Café cats and (B) House cats in the Face phase. White bar represents congruent conditions, Black bar represents incongruent conditions. Error bar indicates SE. Unit of Y axis is frames (30 frames/1 sec.).

Table. 1 The number of valid data points representing the number of trials cats looked at the monitor in each condition.

Figure 1

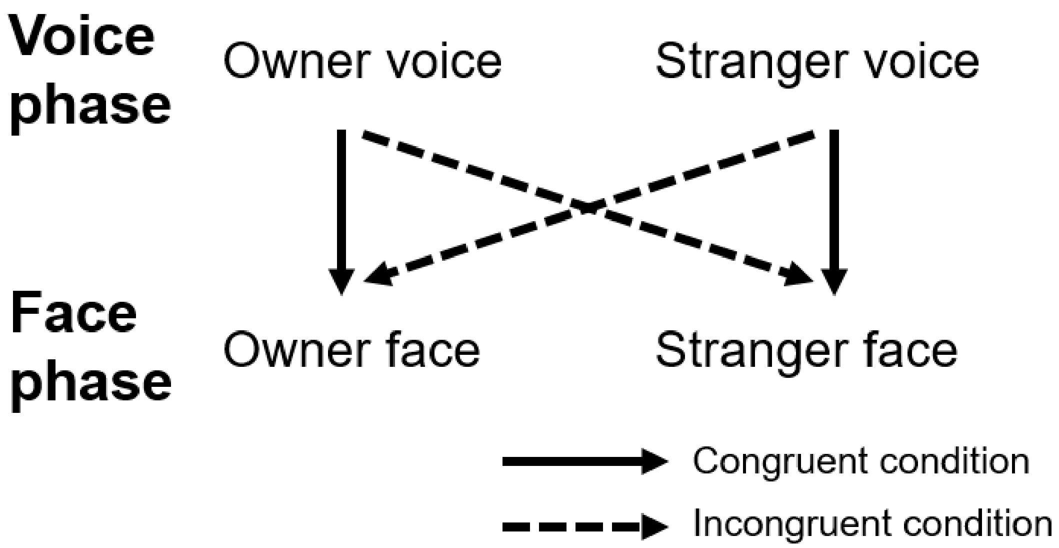
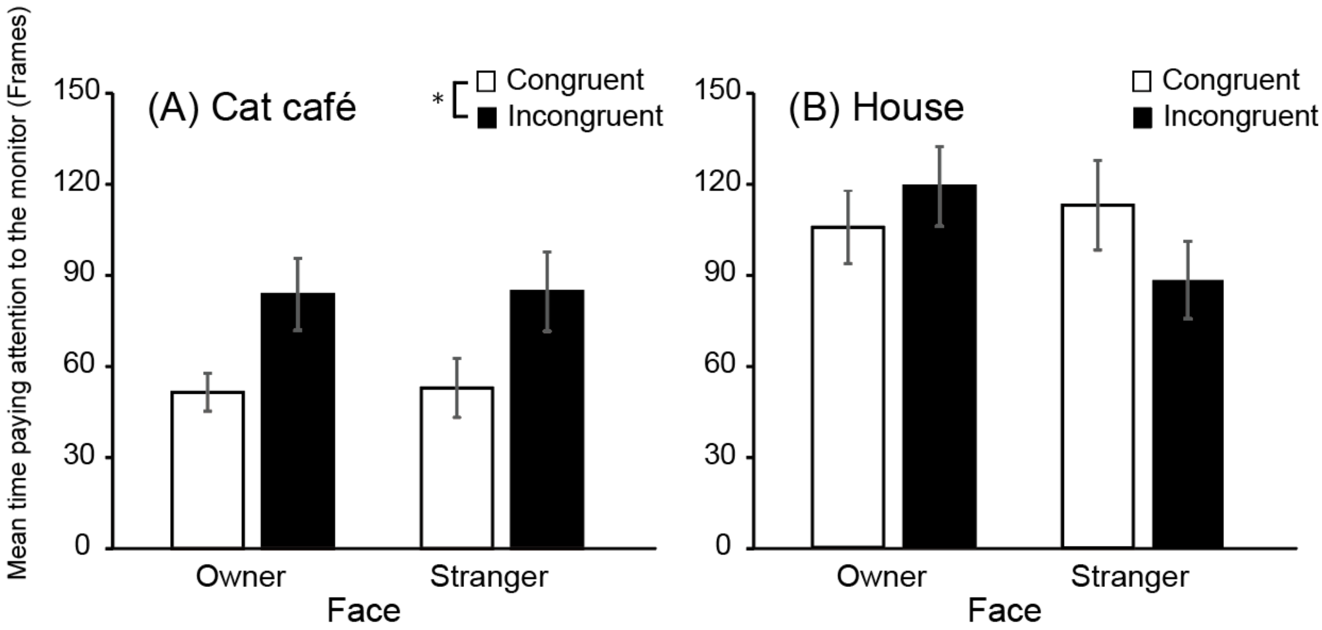

Voice phase
Owner voice
Stranger voice
Face phase
Owner face
Stranger face
Congruent condition
Incongruent condition

Figure 2



Mean time paying attention to the monitor (Frames)
(A) Cat café
*
Congruent
Incongruent
150
120
90
60
30
0
Owner
Stranger
Face
(B) House
Congruent
Incongruent
150
120
90
60
30
0
Owner
Stranger
Face

Table.1

Face	**Owner**		**Stranger**	
	Congruent	Incongruent	Congruent	Incongruent
Café	22	28	23	22
House	29	23	28	25