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Do cats (*Felis catus*) predict the presence of an invisible object from sound?

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Abstract

Recognizing invisible entities from auditory information is advantageous to animals in various situations including predator avoidance and foraging. In two experiments we asked whether cats could predict the presence of an unseen object upon hearing noise it made, based on a causal-logical rule. After observing an experimenter shaking an opaque container for 15 s (observation phase), the cats freely explored the environment for 15 s (response phase). Experiment 1 tested 3 conditions. In the first, "Contingent noise" condition, the object inside the container made a rattling noise when shaken. In the second, "Irrelevant noise" condition, white noise accompanied the shaking action. In the third, "No noise" condition, the shaking action was silent. Experiment 2 tested a "Non-contingent noise" condition, in which the rattling noise and movement of the container were out of synchrony. In both experiments cats looked at the container for longer in the Contingent noise condition than the other conditions. These results suggest that cats used a causal-logical understanding of auditory stimuli to predict the presence of invisible objects. This ability may be related to the ecology of cats' natural hunting style.

Key words: Domestic cats; Cognition; Causal-logical understanding; Sound; Ecological background

Introduction

Information obtained via the sensory organs is often ambiguous or fragmentary. For example, an animal hunting in the bush by sight might hear only the noise the prey makes. In this case inferring the presence of a prey from the noise would be advantageous to the hunter's survival. Similarly, potential prey may be more likely to survive if they can predict the presence of predators from indirect clues such as odor and noise.

Inferential reasoning refers to the ability to use available information to draw conclusions about circumstances that are not directly observable (Heimbauer et al., 2012). Call (2004) explored this ability in great apes. He presented apes with two opaque cups, one of which they knew to be baited. The apes were given visual or auditory cues about the contents of both cups (full information) or only one of the cups (partial information) before making a choice. The subjects were able to see the contents of the cups in a visual domain test, and to hear a rattling noise when the cup was shaken in an auditory domain test. The latter test required an understanding of the causal-logical rule between the noise and movement of the containers. In contrast to the full visual information task on which all apes succeeded, fewer subjects passed the auditory tests even with full information (16.6 % (2/12), 50 % (2/4), 0 % (0/6), 62.5 % (5/8) of chimpanzees, bonobos, orangutans, and gorillas, respectively). Similar results have been obtained in other nonhuman primate species: 0 % (0/8) in rhesus macaques (Petit al., 2015), 33 % (7/21) in olive baboons (Schmitt and Fischer, 2009; Petit et al., 2015), 50 % (2/4) in lemurs (Maille and Roeder, 2012), and 30 % (8/26) in capuchin monkeys (Sabbatini and Visalberghi, 2008; Paukner et al., 2009; Heimbauer et al., 2012), although 100 % (8/8) of tonkean macaques succeeded in an auditory test (Petit et al., 2015). It appears surprising that this causal relationship is so poorly understood by primates.

Several researchers have related this poverty of causal understanding to the ecological importance of auditory information of each species (Maille and Roeder, 2012; Plotnik et al., 2014). Nonhuman primates are generally poor at auditory as opposed to visual tasks (Schmitt and Fischer, 2009). D’Amato and Salmon (1982) suggested that whereas cats use auditory stimuli to locate prey, primates often use sounds as cues to avoid rather than approach the source. Given that cats often use auditory cues when hunting (Turner and Meister, 1988), investigating cats’ predictions about invisible objects from noise can contribute to understanding how ecological factors influence functional differences among sensory modalities.

It has been suggested that cats’ causal-logical understanding in the physical domain is not sophisticated (Bradshaw, 2013). Whitt et al (2009) tested domestic cats on string-pulling tasks to explore their understanding of physical causality. After the cats were initially trained to pull a string to obtain a food reward, three tests were conducted. In “longer string” tests, cats were rewarded for choosing a baited string that was longer than the one used in training. In “parallel” and “crossed strings” tests, cats were required to choose between two strings, only one of which was baited. The cats failed to choose the baited string in both tests; no causal understanding was demonstrated. Bradshaw (2013) pointed out that string-pulling tasks lack ecological validity and that they may not be an appropriate test of cats’ physical understanding. It may be advantageous to test cats’ causal understanding using a different modality. We propose that the auditory modality may be more suitable.

Here we present two experiments that investigated whether cats could show causal-logical understanding about the existence of an object inside an opaque container when they observe the container being moved accompanied by a rattling sound. We tested cats in 3 conditions in each of the 2 experiments. In Experiment 1, we ran “Contingent noise,” “Irrelevant noise,” and “No noise” conditions. The experimenter shook the container repeatedly while the cats watched. In Contingent noise condition, a block of wood inside the container made a rattling noise as it moved. In Irrelevant noise condition, white noise was played during the movement of the container. In No noise condition, the experimenter shook the empty container. In Experiment 2, “Non-contingent noise” condition replaced “Irrelevant noise” condition. In this new condition, the rattling noise was not synchronized with the motion of the container. We hypothesized that if cats form a representation of an invisible object from auditory stimuli, they would pay more attention to the Contingent noise condition than to any other conditions.

Experiment 1

Materials and Method

Subjects

Thirty-eight domestic cats (24 males and 14 females) participated in Experiment 1. Seventeen were kept at cat cafés[1] and 21 were house pets. Eleven cats were pure breeds and 27 were mixed breeds. Their mean age was 3.1 years (range: 2-156 mo). Details of the subjects are shown in Table S1. The cats were not deprived of food or water during the tests.

Apparatus and stimuli

We put a wooden block (5 cm × 4 cm) or a Bluetooth-driven wireless speaker (4 cm × 5 cm Princeton PSP-BTS1) into an opaque cylindrical container (15 cm in diameter × 12 cm high) made of cardboard. The block moved freely but the speaker was fixed in the container so as not to make any noise during shaking. The speaker played white noise in Irrelevant noise condition. A mobile phone (Xperia A3) with Bluetooth compatibility was used to control the sound stimulus. The rattling sound and white noise were around 78 dB at 1 m as measured by a

[1] A Cat café is a tea room in which customers enjoy making contact and playing with cats kept as "hosts" in Japan.

precision sound level meter (NL-52, RION CO., LTD). The test was recorded by two video cameras (JVC GZ-E565-R, SONY HDR-CX390) placed so that they focused on the cats.

Procedure

The cats were individually tested in the owners' house or in cat cafés where the subjects live. Tests started after the cats appeared to have habituated to the general situation. Either the owner or experimenter 2 lightly restrained the cat on the floor, while experimenter 1 sat about 1 m from the cat. The owner was unaware of the purpose or prediction of the study and was instructed not to influence the cat's behavior during the experiment. There were 2 phases: the observation phase and the response phase. Experimenter 1 called the subject's name to attract its attention. After this, experimenter 1 shook the opaque box for 15 s (observation phase). The experimenter then put the container on the floor and said: "Please release the cat". The subject was allowed to freely explore the environment for 15 s (response phase), during which experimenters looked down.

There were 3 conditions. In "Contingent noise" condition, the wooden block was put into the container so that shaking resulted in a rattling sounds contingent upon its motion. In "Irrelevant noise" condition, a speaker attached to the inside of the container produced white noise when the container was shaken. In "No noise" condition, the container was empty and shaking it produced no noise (see Figure 1). All subjects participated in all 3 conditions, one trial for each. The interval between trials was at least 3 minutes, with the order of conditions randomized for each subject. Five to six cats were assigned to six sequences, respectively.

Analysis

The videos of the observation and response phases were analyzed using Adobe Premiere CS6 at a rate of 30 frames per second. Because the duration of the observation phase varied across subjects and trials, we analyzed the minimum number of frames in the three conditions for each subject. Thus the number of coded frames was the same for each subject but varied among subjects. For the response phase, we analyzed the initial 450 frames (15 s).

A coder recorded each subject's attention to the container in each phase, calculating the proportion of total frames in which looking occurred. The occurrence of search behavior was scored as 0 (absent) or 1 (present) in each condition for each subject. We defined search behavior as bringing the nose into contact with the container.

To check reliability of coding, a second coder scored a random sample of 25 % of the videos. The correlation between the two coders' scoring of looking time was highly significant (Pearson's $r = 0.90$, $n = 24$, $p < .01$), and the corresponding correlation for search behavior was perfect (Pearson's $r = 1$, $n = 24$, $p < .01$).

Looking times were analyzed by one-way repeated-measures ANOVA with condition as the sole factor, and with the Huynh-Feldt correction for the violation of sphericity. We used multiple comparisons with Modified Sequentially Rejective Bonferroni Procedure. The number of search behaviors for each conditions were subjected to binomial tests. All statistical analyses were run in R (ver. 3.0.0).

Results

Of the 38 cats tested, seven were excluded from the analyses: four due to video error and three due to distraction by extraneous noise. Thus, data from 31 cats were entered into analysis.

The proportion of frames in which looking at the container occurred during the observation phase is shown in Figure 2 (a). One-way repeated-measures ANOVA revealed a significant main effect of condition (F (2, 30) = 7.00, $p < 0.01$). A post-hoc comparison revealed that cats looked significantly longer in Contingent noise condition than No noise condition (t (30) = 3.10, p = 0.01), and longer in Irrelevant noise condition than No noise condition (t (30) = 3.16, p = 0.01). There was no significant difference between Contingent noise and Irrelevant noise conditions (t (30) = 0.54, p = 0.58).

Regarding looking during the response phase (Figure 2 (b)), no significant main effect of condition was found (F (2, 30) = 1.09, p = .34).

Total proportions of looking time are shown in Figure 2 (c). There was a significant main effect of condition (F (2, 30) = 4.14, p = 0.02). A post-hoc multiple comparison revealed that cats looked significantly longer in Contingent noise condition than No noise condition (t (30) = 2.55, p = 0.04). A marginally significant difference was found between Irrelevant noise condition and No noise condition (t (30) = 1.20, p = 0.07). There was no significant difference between Contingent noise and Irrelevant noise condition (t (30) = 1.86, p = 0.23).

The effect of the order of test was nowhere found; there was no significant difference in total looking time (F (2, 30) = 1.75, p = 0.18), that in observation phase (F (2, 30) = 1.72, p = 0.18) and that in response phase (F (2, 30) = 1.35, p = 0.26) among trial orders.

Search behavior was observed in 7 cats in Contingent noise condition, 6 in Irrelevant noise condition, and 8 in No noise condition; there were no significant differences in Contingent noise, Irrelevant noise and No noise conditions (binomial tests, p = 1, p = 0.81, p = 0.64, respectively).

Discussion

In Experiment 1, we asked whether cats predicted that an unseen object was inside the container based on the relation between sound and movement. We found that cats looked longer at the container during the observation phase in Contingent noise and Irrelevant noise conditions than in No noise conditions. This difference was unchanged if we summed looking time in observation and response phases. These results suggest that cats were simply attracted by noise rather than the contingency between motion and noise.

However, the observation that looking time was longest in Contingent noise condition in both analyses, albeit not significant, may imply that cats predicted the presence of an object inside the container. The possibility remains that attraction by white noise overshadowed any effect of contingency between noise and motion. To test this possibility, congruency between motion and noise was manipulated in Experiment 2.

Experiment 2

Materials and Method

Subjects

Thirty-two cats (18 males and 14 females) participated in Experiment 2. Fifteen were kept at cat cafés and 17 were house pets. Six were pure breeds and 26 were mixed breeds. Their mean age was 3.4 years (range: 2-156 mo). Details of the subjects are shown in Table S2. Thirteen of the subjects also participated in Experiment 1. The interval between Experiment 1 and Experiment 2 was at least 2 months. The cats were never food or water deprived during the test.

Apparatus and stimuli

The apparatus was the same as that used in Experiment 1. We made a video recording of the rattling noise of Contingent noise condition (camera: JVC GZ-E565-R, SONY HDR-CX390), and made a 15-s. auditory stimulus using a video editor (CyberLink Power director ver. 11).

Procedure

The procedure was almost the same as in Experiment 1 except that the Irrelevant noise condition was replaced by Non-contingent noise condition. There were 3 conditions. In "Contingent noise" condition the movement of shaking container was synchronized with the rattling sound played by the wireless speaker inside the container. In "Non-contingent noise" condition the shaking movement and the rattling noise were not synchronized. The container was shaken randomly with the same magnitude as in Contingent noise condition. "No noise" condition was exactly the same as in Experiment 1: the container in the same way as in Contingent noise condition (see Figure 1). As in Experiment 1, all subjects were tested in all three conditions in an order chosen randomly from 6 possible sequences.

Analysis

Analyses were the same as in Experiment 1. The correlation between looking times coded by two independent coders was satisfactory. The correlation between the two coders' scoring of looking time was highly significant (Pearson's $r = 0.905$, $n = 18$, $p < .01$), and the correlation between coders for search behavior was perfect (Pearson's $r = 1$, $n = 18$, $p < .01$).

Results

Of the 32 cats tested, eight were excluded from the analyses due to distraction by extraneous noise (5 cats) or failure to complete all 3 conditions (3 cats). Thus, data for 24 cats were analyzed.

The proportions of frames in which looking at the container occurred during the observation phase are shown in Figure 3 (a). One-way repeated-measures ANOVA revealed a significant main effect of condition (F (2, 23) = 4.07, p = 0.02). A post-hoc multiple comparison revealed that cats looked at the container significantly longer in Contingent noise condition than both Non-contingent noise (t (23) = 2.76, p = 0.01) and No noise conditions (t (23) = 2.13, p = 0.04). There was no significant difference between Non-contingent noise and No noise conditions (t (23) = 0.57, p = 0.56).

Looking scores during the response phase are shown in Figure 3 (b). As the sphericity assumption was violated, degrees of freedom were adjusted by the Huynh-Feldt correction. There was a significant main effect of condition (F (1.4, 23) = 10.97, p < 0.01). A post-hoc multiple comparison revealed that cats looked at the container significantly longer in Contingent noise condition than both Non-contingent noise (t (23) = 3.11, p < 0.01) and No noise conditions (t (23) = 3.64, p < 0.01). There was also a significant difference between Non-contingent noise and No noise conditions (t (23) = 2.17, p = 0.04).

Total looking proportions are shown in Figure 3 (c). There was a significant main effect of condition (F (2, 23) = 10.22, p < 0.01). A post-hoc multiple comparison revealed that cats looked at the container significantly longer in Contingent noise condition than both Non-contingent noise (t (23) = 3.84, p = 0.02) and No noise conditions (t (23) = 3.91, p < 0.01). No difference between Non-contingent noise and no noise conditions was found (t (23) = .04, p = 0.96).

The effect of order was again nowhere found; there was no significant difference in total looking time (F (2, 23) = 0.28, p = 0.75), in the observation phase (F (2, 23) = 0.04, p = 0.95), or in the response phase (F (2, 23) = 1.57, p = 0.21).

Seven cats searched the container in Contingent noise condition, whereas 3 did so in each of the Non-contingent noise and No noise conditions. There were no significant differences in Contingent noise, Non-contingent noise and No noise conditions (binomial tests, p = 0.14, p = 0.56, p = 0.56, respectively).

Discussion

In Experiment 2, we used exactly the same sound in both Contingent noise and Non-contingent noise conditions to test the possible effect of congruency between motion and noise on cats' visual attention to the container. Cats looked longer in Contingent noise condition during both observation and response phases. This differential behavior in the latter phase - after the motion ceased - strongly suggests that cats were not simply attracted by the noise but predicted that something was in the now-quiet and motionless container, after hearing noise contingent upon motion. This implies that the cats formed a representation of an unseen object when hearing its noise, according to a causal-logical rule.

General Discussion

This study investigated whether cats could represent the existence of an unseen object in an opaque container from the rattling noise it made. We predicted that, if cats did so, they should show more interest in the container if the noise and motion of the container are physically congruent. Experiment 1 revealed that cats paid more attention to the container in Contingent noise condition, in which noise matched the motion of the container, than in No noise condition. However, the cats might simply have been attracted by the noise itself, regardless of the motion, as shown by similar responses in Contingent noise and the Irrelevant noise condition in which white noise replaced the rattling sound. To test this possibility, in Experiment 2 we replaced white noise with a non-contingent rattling sound which was not synchronized with the motion of the container. The cats clearly looked at the container for longer in Contingent noise condition compared to the Non-contingent noise condition. These results suggest that cats predict the presence of an invisible object from noise, applying a physical rule.

Might the cats have simply showed a visual preference for movement accompanied by a synchronized noise? Human infants prefer objects accompanied with synchronized noise (Spelke, 1979; Spelke et al., 1983; Bahrick, 1987), but the acquisition of causal-logical understanding of the relation between noise and movement does not emerge until approximately 3 years of age (Hill et al., 2012). However, in the present study cats' preference persisted even after the container was motionless after being placed on the floor. This behavior implies representation of an invisible object rather than a simple multimodal combination of ongoing motion and noise.

Several authors have commented on how ecology of a species may affect inferential reasoning ability in auditory domain (Maille and Roeder., 2012; Plotnik et al., 2014). Cats are an ambush-style visual predator. They hide in or behind a natural visual screen (e.g., shrubs, trees, or rocks) and mount surprise attacks on prey (see Turner and Meister, 1988, for a review). This hunting style may be facilitated by formation of a mental representation of the prey from auditory cues. In fact, cats show excellent object permanence, maintaining a representation of the object after its disappearance (Triana and Pasnak, 1981; Dumas, 1992). A cognitive ability to represent an unseen object from its noise is consistent with these ecological needs. As discussed earlier, nonhuman primates use auditory stimuli as a cue to avoid potential predators, rather than for approaching prey (D'Amato and Salmon, 1982). As specialized hunters, cats might be better at inferring something to approach from auditory cues than other species such as nonhuman primates.

In Experiment 1, the rattling noise (Contingent noise condition) and white noise (Irrelevant noise condition) were equally effective in attracting cats' attention. This result may be due to the difficulty of adjusting the intensity of the auditory stimuli. Although we adjusted the mean sound level in the two conditions, differences in other aspects such as frequency components might have affected the cats' behavior. In contrast, we used exactly the same auditory stimulus in the two noise conditions in Experiment 2. In the latter experiment cats showed a clear difference in looking behavior between the synchronized noise condition and the unsynchronized noise condition.

To our surprise, a minority of the cats explored the container in the response phase. The lack of searching behavior may be due to two possible reasons. One possibility is that cats disliked being restrained for a long time, so that upon being released they went away, rather than explore the apparatus. Although the experiment was conducted in familiar surroundings, the unfamiliar experimental situations might have been mildly stressful for the cats. The other possibility is that although the cats predicted that there was an object inside the container, they were not sufficiently motivated to explore it. Conceivably, more biologically-relevant stimuli, like small prey items, might increase cats' motivation to explore objects detected through sound. Future studies are needed to evaluate these possibilities.

It may be asked if differences in shaking movements among conditions could have affected how the cats responded in Experiment 2. The shaking movements in Contingent noise and No noise conditions was rhythmical, whereas in Non-contingent condition they were more random, to make motion and noise unsynchronized. But if the rhythmic motion captured the cats' attention, they should have looked at the container for longer in both Contingent noise and No noise conditions than in Non-contingent noise condition, but this did not occur.

How did cats predict the unseen object from the noise? There are at least two possibilities. One is that cats applied a physical rule. The other is that cats had learned the relevant contingency in their daily life before experiment (Penn and Povinelli, 2007; Hill et al., 2012). Sabbatini and Visalberghi (2008) suggested that experience could be a critical factor in this kind of task. They reported that initially only one of eight monkeys tested was able to use auditory stimuli to retrieve hidden food. But after subjects were allowed to directly explore baited and unbaited containers, four of eight monkeys were able to use auditory stimuli. However, we did not aim to determine precisely how cats use noise to predict the presence of non-visible objects; this is a question for future research.

Another question for future research concerns exactly what cats represented on the basis of the sounds. They might merely predict the presence of "something," or they might make a finer distinction, such as a hard object rather than a soft prey item.

Finally, we note that the method used in this study is useful for comparative research. It involves no food reward, so it has two advantages. First, no association learning is likely to occur over the study period (Hill et al., 2012). Second, we can test animals without controlling motivation for food; no food deprivation is needed. A clearer picture of how this simple reasoning ability has evolved may emerge from testing species from a variety of ecological and phylogenetic backgrounds.

Conclusion

The present research investigated whether cats have a causal-logical understanding from sound. Through 2 experiments, we demonstrated that cats predict the existence of an unseen object from shaking movements accompanied by a concomitant sound. Although previous research showed that cats' causal-logical understanding was poor (Whitt et al., 2009), this study provided positive evidence of physical understanding in cats. Further research is needed to investigate more precisely the representational nature of cats' predictions.

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Authorship statement

ST designed this study, conducted experiments, analyzed data, and drafted the manuscript. HC, MA, MT, and AH contributed to data collection. KF provided critical discussion regarding the analyses and the manuscript.

Competing interests

The authors declare no conflicts of interest.

Ethics statement

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

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Figures captions

Figure1 Arrangements of the object and the container in each condition of Experiments 1 and 2.

(a) A block of wood was placed inside the container. It made a rattling noise when the container was shaken. (b) A wireless speaker was attached to the bottom of the container. It played white noise when the container was shaken. (c) Nothing was in the container, which made no sound when shaken. (d) A wireless speaker was attached to the container. It played the rattling noise in synchrony with movement of the container. (e) A wireless speaker attached to the container played the same rattling noise out of synchrony with the shaking movement. (f) Same as (c).

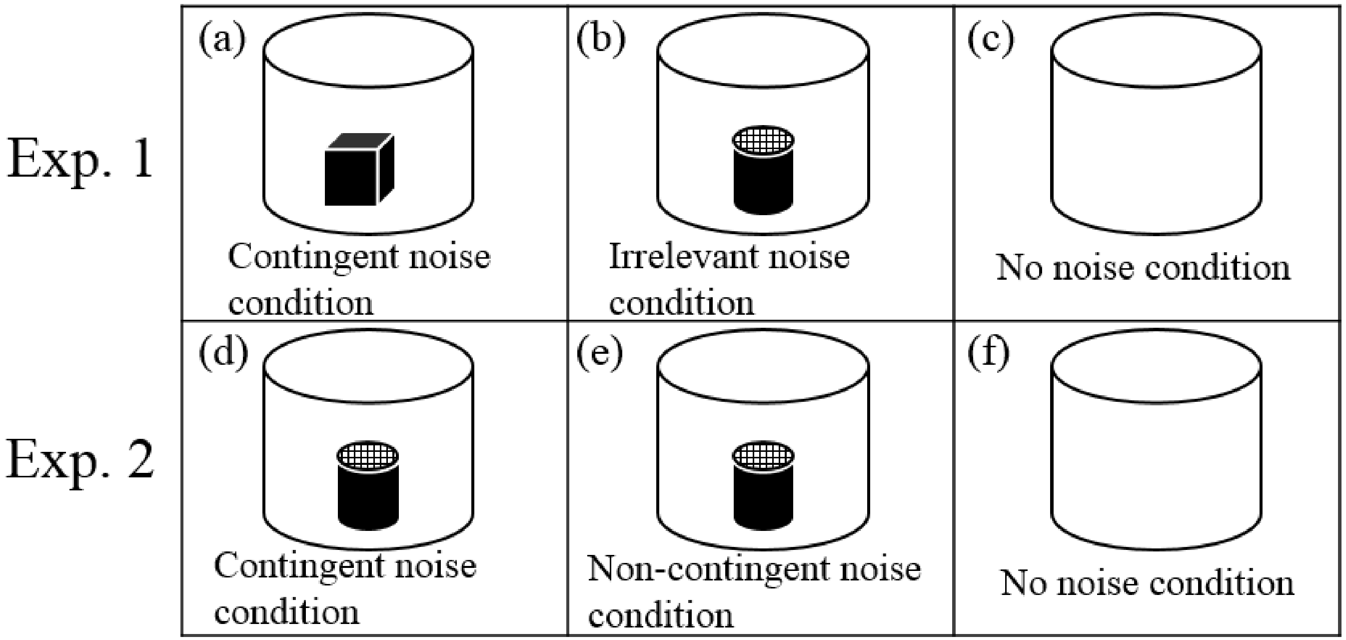
Figure2 Results of Experiment 1.

The mean proportion of frames in which looking occurred (a) in the observation phase, (b) in the response phase, and (c) in both phases pooled. Asterisks indicate a significant difference ($p < .05$). Error bars indicate SEs.

Figure3 Results of Experiment 2.

The mean proportion of frames in which looking occurred (a) in the observation phase and (b) in the response phase, and (c) in both phases pooled. Asterisks indicate a significant difference (*$p < .05$, **$p < .01$). Error bars indicate SEs.

Fig. 1


Exp. 1
Exp. 2
(a)
Contingent noise condition
(b)
Irrelevant noise condition
(c)
No noise condition
(d)
Contingent noise condition
(e)
Non-contingent noise condition
(f)
No noise condition

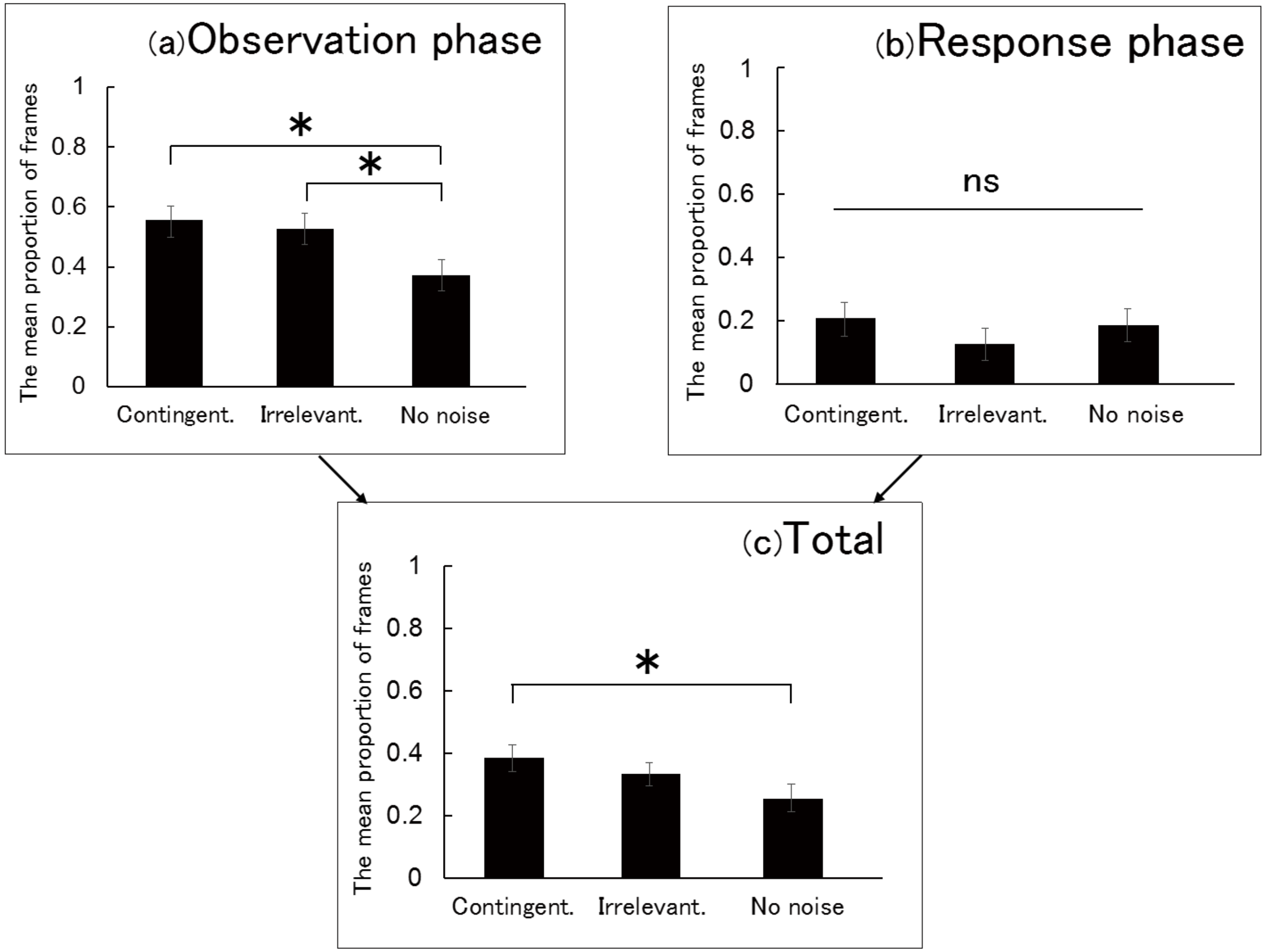

(a)Observation phase
The mean proportion of frames
1
0.8
0.6
0.4
0.2
0
*
*
Contingent.
Irrelevant.
No noise
(b)Response phase
The mean proportion of frames
1
0.8
0.6
0.4
0.2
0
ns
Contingent.
Irrelevant.
No noise
(c)Total
The mean proportion of frames
1
0.8
0.6
0.4
0.2
0
*
Contingent.
Irrelevant.
No noise

Fig. 2

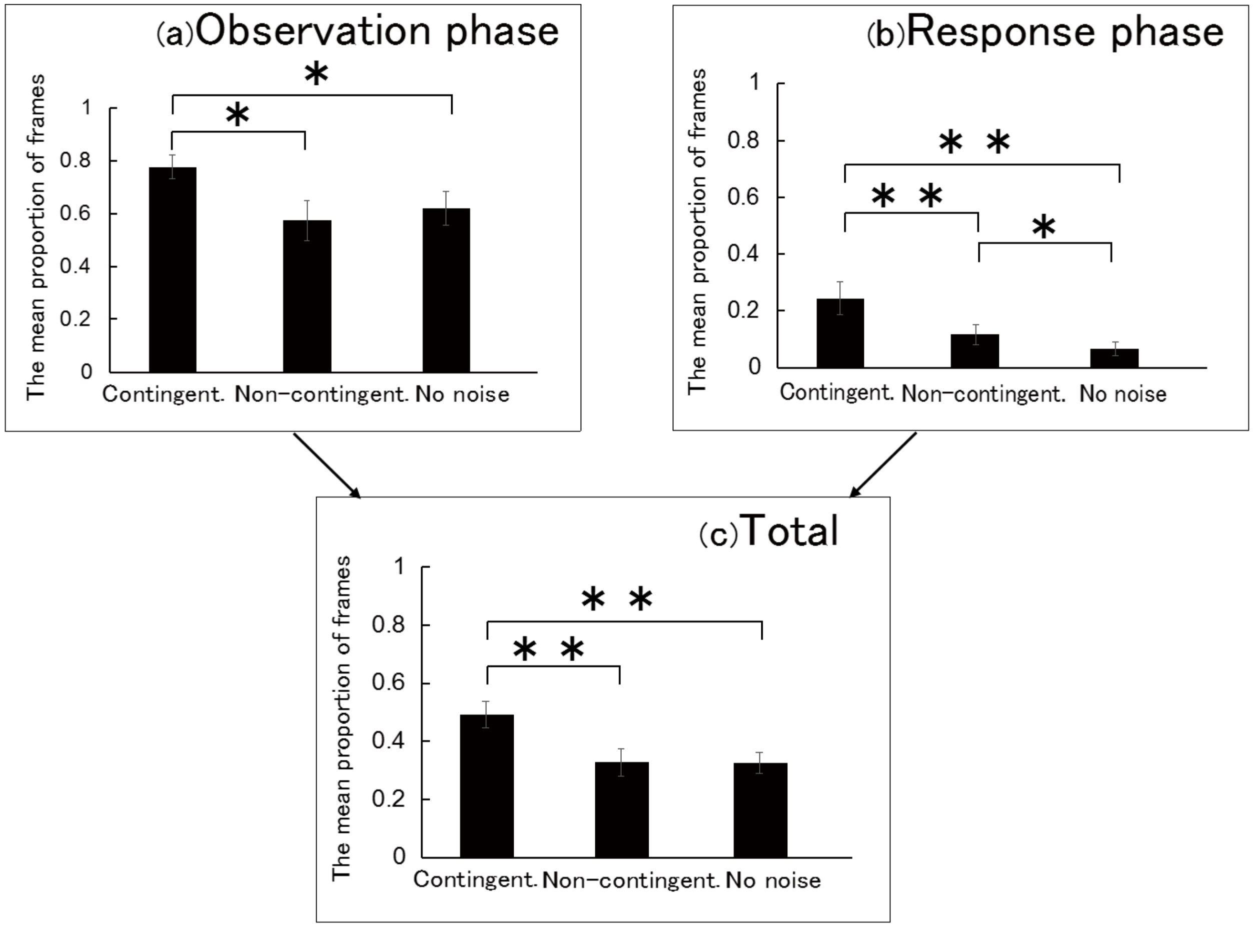

(a)Observation phase
The mean proportion of frames
1
0.8
0.6
0.4
0.2
0
*
*
Contingent. Non-contingent. No noise
(b)Response phase
The mean proportion of frames
1
0.8
0.6
0.4
0.2
0
* *
* *
*
Contingent. Non-contingent. No noise
(c)Total
The mean proportion of frames
1
0.8
0.6
0.4
0.2
0
* *
* *
Contingent. Non-contingent. No noise

Fig. 3