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Human Vocal Commands Verify Audio Discrimination Ability in the Steller Sea Lion, *Eumetopias jubatus*

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We report results of experiments using human vocal commands to investigate how well a Steller sea lion (*Eumetopias jubatus*) can discriminate different sounds. The participant, Hama, a 12-year-old female at Kinosaki Marine World, Japan, was raised by 4 trainers. We investigated Hama's ability to discriminate 10 vocal commands (e.g. Iya-ya, Okay etc.) used in daily performances in two experiments: 1, commands given directly to the sea lion by trainers, but out of her sight; and 2, vocal commands given to the sea lion by trainers, but using recorded commands over a loudspeaker. In Experiment 1, Hama was able to discriminate all 10 commands, but her accuracy to discriminate 1 command was significantly lower than others ($p < .05$). In Experiment 2, Hama was able to discriminate all but 1 command; accuracy rates among commands were variable, but the accuracy rate for 1 was significantly lower than the others, and those for 3 commands were significantly higher than others ($p < .05$). These experiments demonstrate that Hama can discriminate between most commands based on their acoustic properties, regardless of which of the 4 trainers spoke them out of her sight or if they were relayed from a recording. This ability suggests that Steller sea lions, *E. jubatus*, might use sound for their own complex communication.

Keywords: acoustic signal, cognition, *Eumetopias jubatus*, pinniped, Steller sea lion, training

The sense of hearing for some animals is an important function that is often accompanied by vocal communication (Rosenthal & Ryan, 2000). Therefore, communications through acoustic signals and the ability to discriminate sounds have been studied in many species. For example, the vervet monkey (*Chlorocebus pygerythrus*) can produce different types of alarm calls depending on the type of predators, with receivers exhibiting various escape behaviors in response (Sayfarth et al., 1980). Because the most effective way to communicate underwater is through sound, it is not surprising that cetaceans have also developed vocal communication. For instance, the bottlenose dolphin (*Tursiops truncatus*) can learn to use arbitrary sounds to inform others that objects are present or absent. More specifically, individuals can identify each other and communicate with signature whistles (King & Janik, 2013). Obviously, the ability to discriminate acoustic signals is essential for vocal communication.

Auditory discrimination has been investigated across species. For example, the mechanism of consonant discrimination in chimpanzees (*Pan troglodytes*) was similar to that of humans when sounds were presented by an experimenter (Kojima et al., 1989). Other studies have reported the African gray parrot (*Psittacus erithacus*) to be capable of responding to verbal questions posed by humans (Pepperberg, 1990), and that dogs (*Canis lupus familiaris*) can learn to associate objects with words spoken by humans (Griebel & Oller, 2012; Pilley & Reid, 2011). Thus, some animals can discriminate acoustic signals other than those specific to their species.

Pinnipeds, such as seals, sea lions, and walruses, are amphibious mammals. Their typical vocalizations include clicks, creaks, bleats, growls, and barks both in the water and on shore (Linderman et al., 2006). These vocal signals function to facilitate intraspecific social relationships (Schusterman & Van Parijs, 2003). For example, mothers and pups of several pinniped species, including the Californian (*Zalophus californianus*), Steller (*Eumetopias jubatus*), and Australian (*Neophoca cinerea*) sea lions, and the walrus (*Odobenus rosmarus*), use their vocalizations to communicate with each other. Because the mothers and pups in these species can distinguish each other's calls, the mothers who have left their pups while foraging and the pups awaiting the return of their mothers can reconnect at the breeding site (Campbell et al., 2002; Charrier et al., 2010; Gisiner & Schusterman, 1991; Pitcher et al., 2012).

Several studies have focused on the ability of pinnipeds to discriminate human vocalizations. For example, a male harbor seal (*Phoca vitulina*) was reported to imitate human vocalizations (Ralls et al., 1985), and a captive male walrus was shown to discriminate 10 types of human vocal commands (Endo et al., 2020). Furthermore, California sea lions trained in captivity associate gestural signs with objects, modifiers, and actions (Schusterman & Krieger, 1984) and retain these associations in long-term memory over a period of years (Kastak & Schusterman, 2002). Thus, these studies indicate that pinnipeds have well-developed learning abilities.

The North Pacific Ocean Steller sea lion is the largest of the otariid pinniped species. Sexual dimorphism is pronounced, with average body weights of 556 kg in males and 263 kg in females. These sea lions form large social groups, and vocalizations occur in various situations, such as when threatening others, as part of courtship, and between mothers and pups (Thomas, 2009). In the Gulf of Alaska, the reproductive season extends from May until July. Male sea lions are sexually mature between 2 and 8 years of age, and pregnancies occur in females between a similar age range (Pitcher & Calkins, 1981). Food primarily includes fish such as the Okhotsk atka mackerel (*Pleurogrammus azonus*) and Alaskan pollock (*Gadus chalcogrammus*) from the Aleutian Islands and Gulf of Alaska (Richard et al., 1997). A comparison of Steller sea lion behaviors between training and non-training periods in captivity found agonistic and suckling behaviors to be similar, but that routine behaviors such as swimming in fixed routes were lower during training periods (Kastelein & Wiepkema, 1988).

Although we have trained Steller's sea lions using human vocal commands at Kinosaki Marine World since April 1, 2014, we have yet to examine the accuracy rate of individual commands in our daily training sessions. During training, a trainer standing in front of Hama would directly give her commands, so any discrimination of commands could also have included visual cues such as lip movements. We herein investigate how well Hama, as a representative example of a Steller sea lion, can discriminate human sounds, by examining discriminative cognition using two types of acoustic stimuli: commands spoken by different trainers outside of Hama's line of vision and recordings over loudspeakers.

Method

Rearing Methods

The Steller sea lion in this study, a female, Hama, resides at Kinosaki Marine World in Hyogo, Japan. Hama was born on July 21, 2009, at Aquamarine Fukushima in Japan and, after almost two years (June 14, 2011), was delivered to Kinosaki Marine World. During the study period, Hama was accommodated in a 7.5 m² (3.0 m × 2.5 m) animal-housing area from 9:00 a.m. to 9:30 a.m. and from 3:30 p.m. to 4:30 p.m., wherein ambient temperatures ranged -2.8 °C to 32.8 °C. Hama spent the remainder of her time in an exhibition pool (15.5 m × 15.0 m × 4.0 m depth) with four conspecifics (three females and one male), with water temperature the same as that in the open sea, ranging 9.4–29.5 °C.

Hama was fed six times a day in the exhibition pool and animal house. Her diet, ~6.0–18.5 kg of fish daily, was comprised of fresh Japanese jack (*Trachurus japonicus*), Okhotsk atka mackerels (*Pleurogrammus azonus*), capelin (*Mallotus villosus*), common dolphinfish (*Coryphaena hippurus*), sardines (*Sardinops melanostictus*), and other similar fish. Hama was trained to discriminate human vocal commands from April 1, 2014, through to December 1, 2018. Training was conducted by one of four trainers (two male [A, B] and two female [C, D]) for about 5 minutes during feeding time in the animal house. The training sessions were done twice a day. Each trainer had joined the company after graduating from a marine science college and had studied basic animal training for one year. Two experiments (1 and 2) were conducted during feeding time when Hama was alone in the animal house. At the beginning of experimentation Hama weighed ~200 kg.

Human Vocal Commands Used in Experiments

We used 10 human vocal commands that Hama already knew: omawari, keirei, goron, chin-chiro-rin, bye-bye, Hama, and huse (learned from April 1, 2014, to March 31, 2015), and iya-iya, okay, and nage-kiss (learned from April 1, 2015, to November 31, 2016). These commands were used almost daily in both training and in shows by each of the four trainers involved in experimentation from December 1, 2016. By the time experiments began, Hama made no mistakes when the trainer gave commands in front. Vocal commands and actions can be viewed at <https://youtu.be/0MzhaNTYr9o>, but a synopsis of them is: iya-iya (shakes her head continuously from side to side), okay (nods head up and down continuously), omawari (turns around once [clockwise]), keirei (touches her right forelimb to her nose), goron (rolls around), chin-chiro-rin (swings both hind limbs continuously), nage-kiss (touches left forelimb to her nose, then brushes it off), bye-bye (waves the left forelimb continuously), Hama (barks once), and fuse (lies face-down on the ground).

Experiment 1: Testing the Ability to Discriminate Commands Spoken by a Trainer

This experiment was performed to determine whether Hama could discriminate commands spoken by each of the four trainers, who were part of the team who initially trained her. The experiments were conducted from March 20 until April 18, 2019. To remove any visual influence, the trainers spoke their commands from a recessed area next to the animal house that was not visible to Hama. Another trainer in front of Hama gave her a reward (sliced fish fillet) when a correct action was performed (Figure 1).

Figure 1

A Trainer Serving Rewards to Hama



Note. The loudspeaker (arrow 1) and trainer (arrow 2) playing recorded commands in the recess.

The experiments occurred twice daily from 9:00 a.m. to 9:30 a.m. and 3:40 p.m. to 4:20 p.m., or from 4:00 p.m. to 4:50 p.m. In one session, a sequence of 10 different commands was given. Two sessions were conducted during a single experiment time, with four sessions being conducted daily, except for when only two occurred on days when there was only one experiment time per day because of pool repair work, etc. The order of commands in each of the 10 sequences was randomly determined using the Rand function in Microsoft Excel; sequences were then also ordered randomly using the Rand function. Each trainer conducted 10 sessions (40 sessions in total), comprising 400 commands (40 repetitions of each command). The trainer who spoke the commands and the trainer that served rewards changed every one or two sessions. Successful discrimination was defined as a correct response on the first response after hearing the command (no response to the command was defined as incorrect.). Response accuracy rates for each command were determined by dividing the number of successes per command by 40.

Experiment 2: Testing the Ability to Discriminate Commands from a Loudspeaker

This experiment was performed to determine if Hama could discriminate commands from a loudspeaker. Experiments were conducted from 9:00 a.m. to 9:30 a.m. and from 3:40 p.m. to 4:30 p.m., or from 4:00 p.m. to 4:50 p.m. from April 19 to June 7, 2019. To remove any visual influence, the loudspeaker (Amp, PG-10, Kyoritsu Co., Aichi, Japan; Mixer, TM-4, Kitani Music Co., Aichi Japan) was placed within the same recess next to the animal house as in Experiment 1. As in the first experiment, a trainer in front of Hama provided a fish reward whenever she responded correctly.

Testing was conducted in two or four sessions per day. The same commands used in Experiment 1 were recorded by each trainer, with a 2-s interval between them. Recordings were made in a quiet room using a mobile phone voice recorder (Zenfone Live, ASUSTeK Computer Inc., Taiwan). As before, one session comprised a sequence of 10 different commands, ordered in the same way as in Experiment 1. We then created 40 sequences (400 commands; 40 repetitions of each of the 10 commands) and played one during each session. The session order was again randomly determined by the Rand function. The trainer who served the rewards was randomly selected in the same way for each session. Response accuracy rates were calculated the same as they were for Experiment 1.

Data Analysis Methods

If the percentage of correct responses was significantly greater than the percentage of incorrect responses (as determined by the binomial test), Hama was regarded to have discriminated the command. The χ^2 -square test was used to compare the accuracy rate between commands. In cases for which the χ^2 -square test showed a significant difference, residual analysis was used to detect the commands with high or low accuracy. All statistical analyses were performed with Microsoft Excel that can be utilized for qualitative analysis. (Meyer and Avery, 2008).

Results

Experiment 1

Accuracy rates were significantly higher than inaccuracy rates for all commands. Analysis revealed a significant difference in accuracy rate among commands, with only accuracy for the “fuse” command being significantly lower than that for other commands (Table 1). There was no difference in the accuracy rates among the four trainers for any of the commands, nor was there any difference by trainer gender (Table 2).

Experiment 2

With the exception of “goron,” Hama successfully discriminated between all commands. Accuracy rates differed among the commands, with that for “goron” being significantly lower than the others, and those for “nage-kiss,” “bye-bye,” and “Hama” being significantly higher than others (Table 1).

We found significant differences in the accuracy rates for “goron” and “fuse” among the trainers. The accuracy rate for “goron” was significantly lower than that for the other commands when the command was recorded by male trainer B and was significantly higher when recorded by female trainer C. Additionally, Hama’s accuracy for “fuse” was significantly lower when recorded by male trainer A compared with the other trainers. For the remaining eight commands, there were no significant differences in accuracy rates among trainers (Table 2).

Table 1
Command Accuracy Rate

Commands	Experiment 1					Experiment 2					Comparison between Experiment 1 and 2	
	Accuracy rate	Binomial test	χ^2	p	Residual analysis	Accuracy rate	Binomial test	χ^2	p	Residual analysis	χ^2	p
Iya-iya	93	$p < .01$	25.9	$p < .01$	-1.1	85	$p < 0.01$	50.6	$p < .01$	-1.1	1.13	0.288
Okey	100	$p < .01$			1.4	95	$p < 0.01$			1.1	2.05	0.152
Omawari	98	$p < .01$			0.6	90	$p < 0.01$			0.0	1.92	0.166
Keirei	98	$p < .01$			0.6	90	$p < 0.01$			0.0	1.92	0.166
Goron	98	$p < .01$			0.6	63	$p = 0.154$			-6.1*	15.31	$< .01$
Chin-chiro-rin	93	$p < .01$			-1.1	93	$p < 0.01$			0.6	0.00	1.000
Nage-kiss	100	$p < .01$			1.4	100	$p < 0.01$			2.2*		
Bye-bye	98	$p < .01$			0.6	100	$p < 0.01$			2.2*	1.01	0.314
Hama	100	$p < .01$			1.4	100	$p < 0.01$			2.2*		
Fuse	83	$p < .01$			-4.4*	85	$p < 0.01$			-1.1	0.09	0.762

Note. * indicates a significant difference ($p < .05$)

Table 2*Comparison of Accuracy Rates Among Trainers for Each Command in Experiments 1 and 2.*

Commands	Experiment 1						Experiment 2					
	A	B	C	D	χ^2	p	A	B	C	D	χ^2	p
Iya-iya	90	90	90	100	1.1	0.780	90	70	80	100	3.9	0.270
Okey	100	100	100	100			100	80	100	100	6.3	0.097
Omawari	100	100	100	90	3.1	0.380	90	80	100	90	2.2	0.528
Keirei	100	90	100	100	3.1	0.380	70	100	100	90	6.7	0.083
Goron	100	100	100	90	3.1	0.380	70 (0.57)	30 (-2.45*)	90 (2.07*)	60 (0.19)	8.0	< .05
Chin-chiro-rin	90	100	90	90	1.1	0.782	90	100	90	90	1.1	0.781
Nage-kiss	100	100	100	100			100	100	100	100		
Bye-bye	90	100	100	100	3.1	0.380	100	100	100	100		
Hama	100	100	100	100			100	100	100	100		
Fuse	80	80	90	80	0.5	0.915	60 (-2.56*)	80 (-0.51)	100 (1.53)	100 (1.53)	8.6	$p < .05$

Note. *Command accuracy rate differs significantly (lower or higher) than that of other trainers ($p \leq .05$). Numbers in parentheses indicate residuals.

Discussion

The Ability to Discriminate Commands Spoken by Trainers

The results of Experiment 1 indicate that Hama could discriminate 10 auditory commands spoken by four different trainers. Thus, if Hama is representative of her species, Steller sea lions can discriminate word-level audio stimuli spoken by humans and associate each stimulus with a separate action, as reported for the African gray parrot (Pepperberg, 1990), walrus (Endo et al., 2020), and dogs (Pilley & Reid, 2011). However, accuracy rates were significantly lower for the “fuse” command than for other commands (Table 1). Hama’s incorrect response to hearing “fuse” often involved her touching her right forelimb to her nose (the “keirei” response), perhaps because both “keirei” and “fuse” are pronounced with the accent on “ke” and “se,” respectively, with an accent on the vowel “e” leading her to confuse the commands. During normal training (with a trainer before her), Hama rarely made this type of mistake. After examining audio discrimination in a male walrus, Endo et al. (2020) pointed out that the walrus did not hear commands very well with a board between the subject and experimenter, because commands emitted by the experimenter were blocked by the board. In our experiments, it is possible that some commands did not reach Hama because they were blocked by the animal house walls. Additionally, the trainer giving the commands was out of Hama’s field of view and 5 m away. Thus, the sound that reached her may have been softer than usual, and some commands, or parts of them, may have been difficult for her to hear.

Ability to Discriminate Commands from a Loudspeaker

In Experiment 2, with the exception of “goron,” Hama could discriminate commands from a loudspeaker. For “goron,” the accuracy rate was significantly lower than it was in Experiment 1 (Table 1). A walrus was able to discriminate all 10 commands from a loudspeaker connected to a live microphone (Endo et al., 2020). Because we used prerecorded commands, differences in accuracy rate may depend on the device being used.

Accuracy rates for “nage-kiss,” “bye-bye,” and “Hama” were significantly higher than those for other commands (Table 1). Each of these commands begins with a syllable that contains an [a] sound, which might be easier for sea lions to hear over a loudspeaker.

Difference in Accuracy Rates Across Trainers

In Experiment 1, the accuracy rate was similar among the trainers, regardless of gender (Table 2), suggesting that Hama could discriminate acoustic stimuli independently of the trainer delivering them—an ability also reported for other animals, including dogs and a walrus. For example, a Yorkshire terrier discriminated both her owner’s commands, and those given by two unknown individuals (one man and one woman; Griebel & Oller, 2012). Similarly, no significant differences in accuracy rates were found for any command delivered by three trainers (two men and one woman) to a trained walrus (Endo et al., 2020). These findings indicate that these animals can discriminate spoken audio stimuli without being affected by voice characteristics, intonation of a particular person, and/or gender.

In Experiment 2, in regard to the command “fuse” given by the male trainer A and in regard to the command “goron” given by the male trainer B, the accuracy rates were significantly lower than the ones by the other trainers. Both trainers spoke in lower tones than the other ones. Because there were no differences across trainers in accuracy rate for any command in Experiment 1, these differences in Experiment 2 may have been caused by changes in audio properties occurring during recording and playback. Specifically, the audio frequency of some spoken commands might not have matched those emitted by a loudspeaker, resulting in Hama’s inability to identify them. We cannot explain why the accuracy rate for “goron” was significantly higher from recordings made by female trainer C than the other trainers (we have not performed a detailed comparison with the voice of female trainer D).

The Ability of Steller Sea Lion to Discriminate Audio Stimuli

Pinnipeds are known to emit several kinds of sounds in their daily lives. Among other purposes, sounds are used to communicate with each other for individual recognition and reproductive behavior (Colleen & Caroline, 2014). In the Steller sea lion, mothers and pups communicate with each other vocally. Females have distinctive voices among the individuals, and pups can discriminate their mother’s voice (Campbell et al., 2002).

Previous studies conducted in the field reported pinnipeds to be capable of discriminating a particular sound from a large number of sounds. For example, a mother can discriminate her pup’s voice in a rookery (Campbell et al., 2002). We demonstrate Hama to be capable of discriminating 10 different commands using only acoustic stimuli. Furthermore, Hama can associate each of 10 commands with a specific behavior, and this ability was reproducible even when using prerecorded commands spoken by different trainers. Being able to discern sound in this way suggests that Steller sea lions can use their own voices for complex communication.

Pinnipeds have a high incidence of eye-lens disease (Colitz et al., 2008). Animals with vision loss because of diseases like this have decreased behavioral variation, difficulty participating in shows and training, and reduced quality of life. However, if each behavior is conditioned using vocal commands, training can continue even as vision deteriorates, and behavioral variation can be maintained. Additionally, associating commands with husbandry behaviors of an animal will achieve safe health care for both the animal and the trainer without the use of retention or anesthesia, even when the animal has impaired vision. We suggest that the ability of the Steller sea lion to discriminate human vocal commands, which we have revealed in this study, may be useful for enhancing enrichment measures in captivity.

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