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Relative Size Discrimination and Perception of the Ebbinghaus Illusion in a Bottlenose Dolphin (*Tursiops truncatus*)

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Abstract

Dolphins are known to show similarities to humans with respect to a range of visual perceptual tasks, but it is not well understood how dolphins perceive objects through vision. In this study, we tested the relative size discrimination of visual stimuli in a bottlenose dolphin (*Tursiops truncatus*) in order to examine whether dolphins could solve size discrimination problems using relative size concepts. In addition, we investigated whether dolphins are susceptible to the Ebbinghaus illusion. In Experiment 1 (a size discrimination task), the subject was trained to select the larger of two black circles during the training session. After the subject mastered this task, four types of figures of different sizes that were unfamiliar to the subject were paired and presented as the probe trial. The subject chose the larger figure, suggesting that the subject could solve the problem based on relative size concepts that were learned during the training session. In Experiment 2 (the Ebbinghaus Illusion Perception Task), after the subject learned to select the larger target circle from two circles of different sizes that were surrounded by inducer circles, the Ebbinghaus figures were presented—that is, two black circles of the same area, one surrounded by six small inducer circles and the other surrounded by six large inducer circles. The subject selected the target circle that was surrounded by six small inducer circles significantly more often than the one surrounded by six large inducer circles. This suggested that dolphins, like humans, are receptive to the Ebbinghaus illusion and that the dolphins mechanism is thought to be the same as that of humans—that is, the subject displayed a global-oriented perceptual tendency.

Key Words: Ebbinghaus illusion, relative size discrimination, global-oriented perception, bottlenose dolphin, *Tursiops truncatus*

Introduction

The vision of dolphins plays an important role for their survival (Herman & Tavolga, 1980; Madsen & Herman, 1980). Visual acuity, contrast sensitivity, and spectral sensitivity have been extensively examined in cetaceans (e.g., Watkins & Wartzok, 1985; Supin et al., 2001), and it has been demonstrated that dolphins have a specialized visual ability (summarized by Supin et al., 2001). In addition, dolphins are known to show similarities to humans with respect to a range of visual perceptual tasks, including concept formation and visual symbol comprehension (summarized by Herman, 1986, 2006; Herman et al., 1993). Furthermore, there are some studies on integration of visual and echoic information (Harley et al., 1996; Harley, 2000), and Pack & Herman (1995) and Herman et al. (1998) reported how returning echoes are processed to form a mental image of the object. However, it is still unclear how dolphins perceive objects through vision and how the visual system of dolphins works.

We tested the size discrimination of visual stimuli in a bottlenose dolphin (*Tursiops truncatus*) in order to examine whether dolphins could understand the comparative meaning of size (i.e., smaller or bigger) and solve discrimination problems using relative size concepts. In addition, we investigated the dolphin's perception of the Ebbinghaus illusion in order to determine whether dolphins are susceptible to this illusion. The Ebbinghaus illusion is a size illusion that has been extensively studied in humans (e.g., Choplin & Medin, 1999; de Grave et al., 2005), but few studies have been performed with respect to nonhuman animals, especially marine mammals.

Materials and Methods

Subject

An adult male bottlenose dolphin (body length, 240 cm; body weight, 154 kg; 3 y old) was used as the subject in this study. The subject was housed at the Izu-Mito Sea Paradise in the Shizuoka prefecture in Japan. The subject had never previously undergone any behavioral or cognitive experiments. The experiment was conducted in a pool (141 m^2, 4.5 m in depth) that was partitioned off from a part of the bay with a net. Another bottlenose dolphin, which was not involved in this experiment, was kept in the same pool; however, this dolphin was isolated during the experiment. The experiments were conducted three times per day.

Stimulus and Apparatus

Figures were drawn in black ink on a white plastic board (30 cm × 30 cm). The size, number, and nature of the figures, which varied per experiment, are described below. As these figures were presented in air, the dolphin was unable to recognize them by echolocation.

The testing apparatus consisted of a wooden board that contained a 30 cm × 70 cm opening that held a plastic door. The stimuli were inserted in this apparatus, and the door was slid open vertically to present the stimuli to the subject.

Procedure

General Procedure—The apparatus was set on a plank floating on the water; therefore, the stimuli were presented to the subject above the water surface. When the subject was positioned in front of the apparatus with his head out of the water, two stimuli (figures) of different sizes were presented to the subject by opening the door of the apparatus (Figure 1). The subject was required to compare the sizes (i.e., areas) of the two figures drawn on the boards and classify them as "larger" based on their area. The larger figure was always the positive stimulus. The subject had to select the larger one by touching it with his rostrum (Figure 1). Two experimenters were involved in the experiment and took turns in random order to perform the tests so that the experimenters' body movements did not cue the subject to the correct response when the stimuli were presented. Furthermore, one experimenter watched the other's motion to ensure that he did not give unintentional cues to the subject while performing the experiment. The experimenters wore brown-tinted translucent goggles at all times to avoid inadvertent cuing by their eyes when the subject was selecting the stimuli. In addition, they made identical movements during all trials, regardless of whether the position of the boards in the apparatus changed or remained the same.

This study was divided into two stages: (1) a size discrimination task (Experiment 1) and (2) the Ebbinghaus Illusion Perception Task (Experiment 2). Each experiment consisted of two phases: (1) a training session and (2) a test session. In the training session, when the subject chose the correct stimuli, the experimenter blew a whistle. The door of the apparatus was then shut, and the subject was rewarded with a piece of fish. In the case of an incorrect choice, the door was shut and the subject received no reward. The next trial started after a 10-s interval. In the test session, the subject was rewarded in the baseline trial if he responded correctly; however, he was not given any reward in the probe trial regardless of the stimulus chosen in order to prevent the subject from learning the correct stimulus if rewarded for the correct response.

Experiment 1 (Size Discrimination Task)—In the training session, a board on which a black circle (17 cm in diameter) was drawn was presented paired with a blank board. The subject was trained to select the board on which a black circle was drawn by touching it with his rostrum. One session consisted of 15 to 20 trials. When the percentage of correct choices was more than 80% in two consecutive sessions, two black circles of different areas were paired and presented to the subject. The subject was required to discriminate a larger circle from a smaller one and to select the larger one by touching it with his rostrum. Fifteen types of pairs (Table 1) were used in the training sessions. The difference in the area between both

Table 1. Pairs of circles presented in the training session of Experiment 1; in Nos. 11 through 15, the position of the circle was changed randomly on the board.

No.	Area of large circle (cm^2)	Area of small circle (cm^2)
※0	907	plain
1	907	13
2	907	50
3	707	50
4	531	50
5	531	113
6	380	113
7	380	154
8	254	154
9	201	154
10	154	113
11	907	13
12	380	154
13	254	154
14	201	154
15	154	113

※ – "a board on which a black circle was drawn" vs "a plain board on which nothing was drawn"

Figure 1. The testing apparatus and selecting behavior of the subject; the experimenter wore brown-tinted goggles.

circles in each pair was gradually reduced, and the position of the circle on the board was changed. One session consisted of 15 trials, and only one pair (listed in Table 1) was presented in each session. When the percentages of correct responses were more than 80% in two consecutive sessions for all the pairs, the subject was judged to have mastered the task, and the test session started.

In the test session, the figure pairs that were used in the training session were shown to the subject as the baseline trial. For the probe trial, figures such as triangles, squares, rectangles, and lozenges of different sizes (areas) were paired and presented to the subject (examples are shown in Figure 2a-d, and all the pairs are listed in Table 2). As these figures were used only in the test session, they were unfamiliar to the subject. The baseline trials and probe trials were performed in semi-random order; however, the subject was not rewarded in the probe trials regardless of which

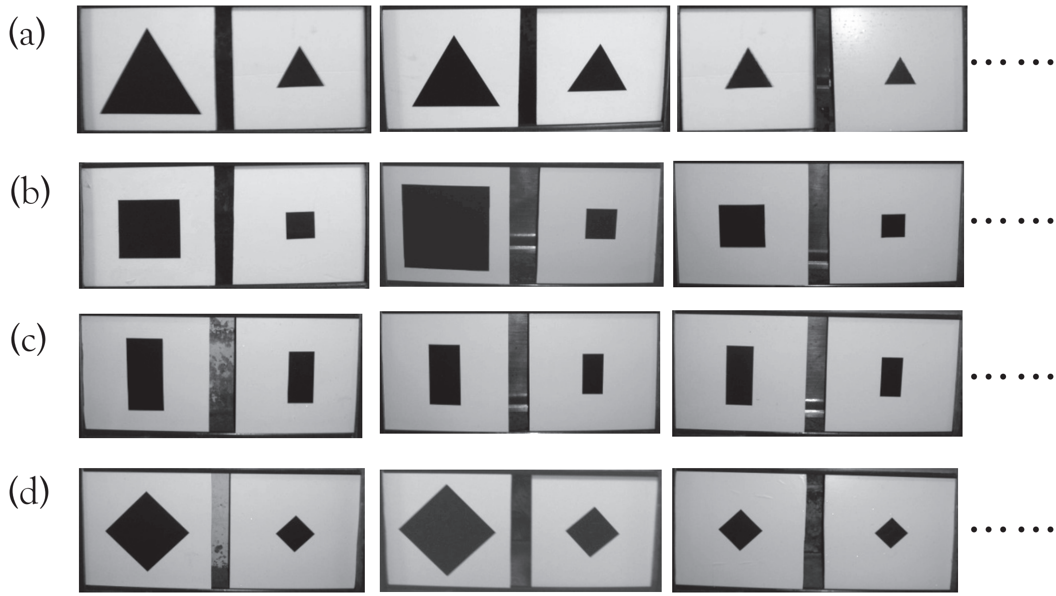


Figure 2. Examples of pairs of stimuli presented in the test session of Experiment 1: (a) triangle, (b) square, (c) rectangle, and (d) lozenges; several figures of various sizes were paired. All the pairs presented are listed in Table 2.

Table 2. Pairs of stimuli presented in the test session of Experiment 1; figures of different sizes (areas) were paired. Each numeral signifies the area of the figure (cm^2).

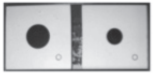
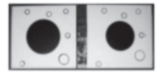
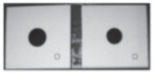
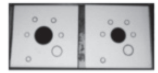
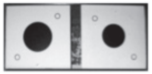
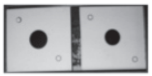
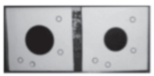
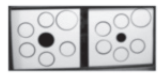
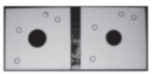
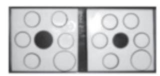
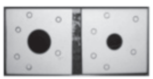
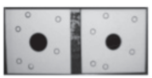
Figure	Triangle		Square		Rectangle		Lozenge	
No.	Large (cm^2)	Small (cm^2)	Large (cm^2)	Small (cm^2)	Large (cm^2)	Small (cm^2)	Large (cm^2)	Small (cm^2)
1	97	7	225	16	63	39	225	16
2	161	34	132	28	99	68	132	28
3	145	84	137	83	104	53	289	36
4	115	61	94	50	64	38	210	42
5	125	16	289	36	168	126	289	64
6	91	18	210	42	128	61	182	56
7	79	24	182	56	120	80	110	30
8	48	13	110	30	72	32	182	72
9	31	9	72	20	85	68	72	20
10	34	14	76	32	84	72	210	110
11	125	28	289	76	126	85	76	32
12	97	18	182	72	128	72	137	83
13	79	48	210	110	84	61	94	50
14	91	68	36	20	80	68	36	20
15	28	21	56	42	60	32	56	42

figure he chose. In the test session, all probe pairs (shown in Table 2) appeared only once.

Experiment 2 (The Ebbinghaus Illusion Perception Task)—In Experiment 2, a solid black circle surrounded by open inducer circles functioned as the "target circle."

In the training session, one same-size inducer circle was positioned around each of the two different size target circles (254 cm^2 vs 113 cm^2; Table 3, No. 1). One session consisted of 15 trials, and the subject was required to choose the larger target. The subject was trained until he performed with an accuracy of at least 80% correct in two consecutive sessions (referred to as criterion level for Experiment 2). In subsequent trials, the size of the larger target was decreased (154 cm^2 vs

Table 3. Pairs of stimuli presented in the training session of Experiment 2

No.		Area of large circle (cm^2)	Area of small circle (cm^2)	Area and number of inducer circles	No.		Area of large circle (cm^2)	Area of small circle (cm^2)	Area and number of inducer circles
1		254	113	13 $cm^2 \times 1$	9		531	380	50 $cm^2 \times 1$, 13 $cm^2 \times 5$
2		154	113	13 $cm^2 \times 1$	10		154	113	50 $cm^2 \times 1$, 13 $cm^2 \times 5$
3		380	254	13 $cm^2 \times 2$	11		380	254	113 $cm^2 \times 1$, 50 $cm^2 \times 5$
4		154	113	13 $cm^2 \times 2$	12		154	113	113 $cm^2 \times 1$, 50 $cm^2 \times 5$
5		380	254	13 $cm^2 \times 4$	13		113	50	201 $cm^2 \times 1$, 113 $cm^2 \times 5$
6		154	113	13 $cm^2 \times 4$	14		154	113	201 $cm^2 \times 1$, 113 $cm^2 \times 5$
7		254	113	13 $cm^2 \times 6$					
8		154	113	13 $cm^2 \times 6$					

113 cm²; Table 3, No. 2). After the subject reached criterion level, the number of inducer circles was gradually increased to 6 (Table 3, Nos. 3-8). These inducer circles were positioned around each target circle. The subject was trained with target circle pairs of various sizes. Subsequently, the subject was trained with stimuli having inducer circles of various sizes (Table 3, Nos. 9-14). Finally, all 14 pairs (Table 3, Nos. 1-14) were presented to the subject within a single session of 14 trials. The subject was required to discriminate a larger target circle from a smaller one regardless of the size, number, and position of the inducer circles. One session consisted of 14 trials, and each pair (Table 3, Nos. 1-14) was presented once to the subject during a session. When the percentages of correct responses were more than 80% in two consecutive sessions for all the pairs (see Table 3), the subject was judged to have mastered the task, and the test session started. In the baseline trial for the test session, two target circles of different areas surrounded by inducer circles (which were presented in the training session) were presented to the subject. In the probe trial, an Ebbinghaus figure (Figure 3)—two black circles of the same area (200 cm^2), one surrounded by six small inducer circles of the same area (18 cm^2) and the other surrounded by six large inducer circles of the same area (310 cm^2)—were paired and presented to the subject. The position of each target circle in the apparatus was randomly changed. The baseline and probe trials were performed in semi-random order, and the test session continued until the Ebbinghaus figure appeared 19 times. In the baseline trials, the subject was rewarded when he chose correctly, but in the probe trials, the subject was not rewarded regardless of which figure he chose.

Statistics
The subject was required to select one of two stimuli, so the chance level of performance in a two-choice discrimination task was 50%. The significance level in the training session of both experiments was determined on the basis of a binomial test in which each session consisted of 15 trials in principle, so the criterion level for the threshold of the percentages of correct responses was set at 80% ($p < 0.05$, binomial test). Thus, in the training session, when the percentages of correct responses were more than 80% in two consecutive sessions, the subject was judged to have mastered the task. In the probe trial of the test session, the significance level was assessed with a binomial test ($p < 0.05$).

Results

Experiment 1 – Size Discrimination Task
Figure 4 shows the changes in the percentages of correct responses in the training session. At the beginning of the training session, when a board on which a black circle was presented paired with a plain board, the percentage of correct responses fluctuated slightly, but it gradually increased and finally reached a high level (Figure 4 [0]). When two black circles of different areas were presented, the subject responded correctly, and the percentage of accurate responses was above the criterion level for all stimulus pairs (Figure 4 [1]-[15]). These results showed that the subject could discriminate the larger circle from the smaller one and had learned to select the larger circle of the two circles irrespective of the sizes of the circles presented. In the test session, 15 pairs of figures of triangles, squares, rectangles, and lozenges were used as shown in Table 2 and were presented as

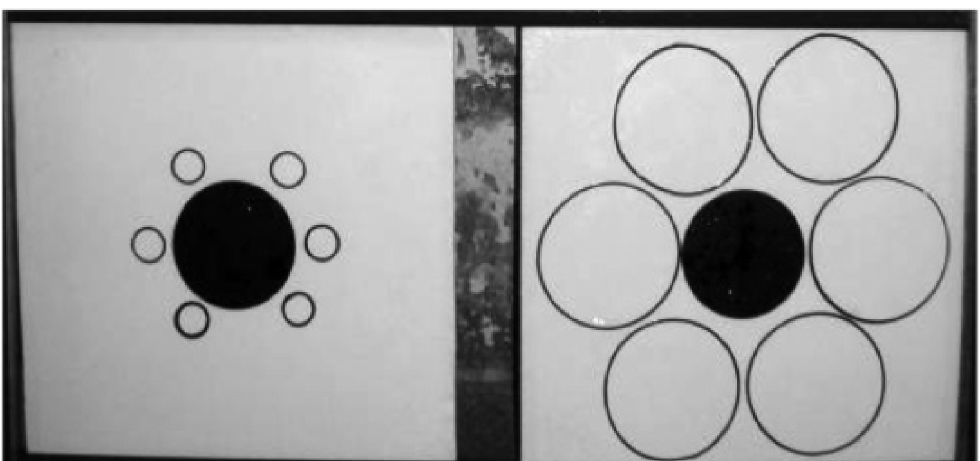


Figure 3. The Ebbinghaus figures presented in the test session of Experiment 2

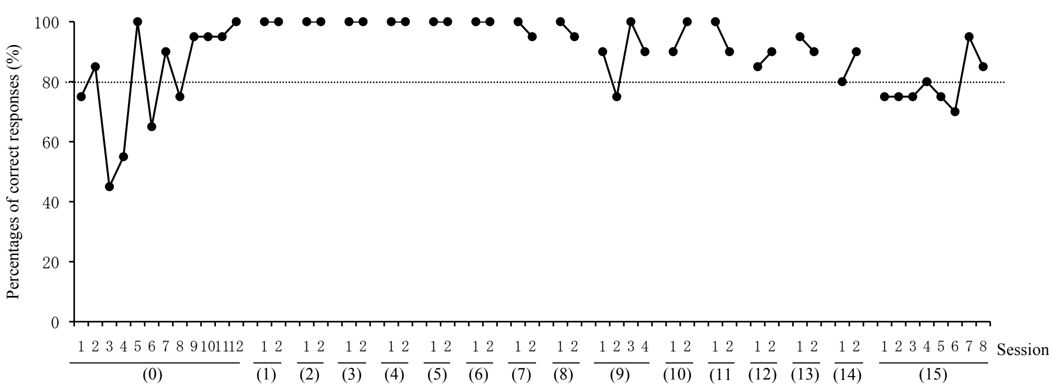


Figure 4. The changes in the percentages of correct responses in the training session of Experiment 2; numerals in parentheses are coincident with the numbers of pairs shown in Table 1. The dashed line indicates the criterion.

stimuli. The subject consistently chose the larger of the two figures (see Figure 5), performing above significant level ($p < 0.05$, binomial test).

Experiment 2 – The Ebbinghaus Illusion Perception Task

In the training session, 14 pairs were used; the changes in percentages of correct responses of each pair are shown in Figure 6. The percentages of correct responses reached the criterion level of 80% for all pairs, indicating that the subject correctly selected the larger target circle from the two circles, even if inducer circles of various sizes and number were positioned around the target circles. That is, the subject could discriminate the size of the target circles by ignoring the surrounding inducer circles. In the test session, when the Ebbinghaus figure was presented to the subject as the probe trial (19 trials), the subject selected the target circle that was surrounded by small inducer circles significantly more often ($p < 0.01$, binomial test) (16 trials) (Figure 7).

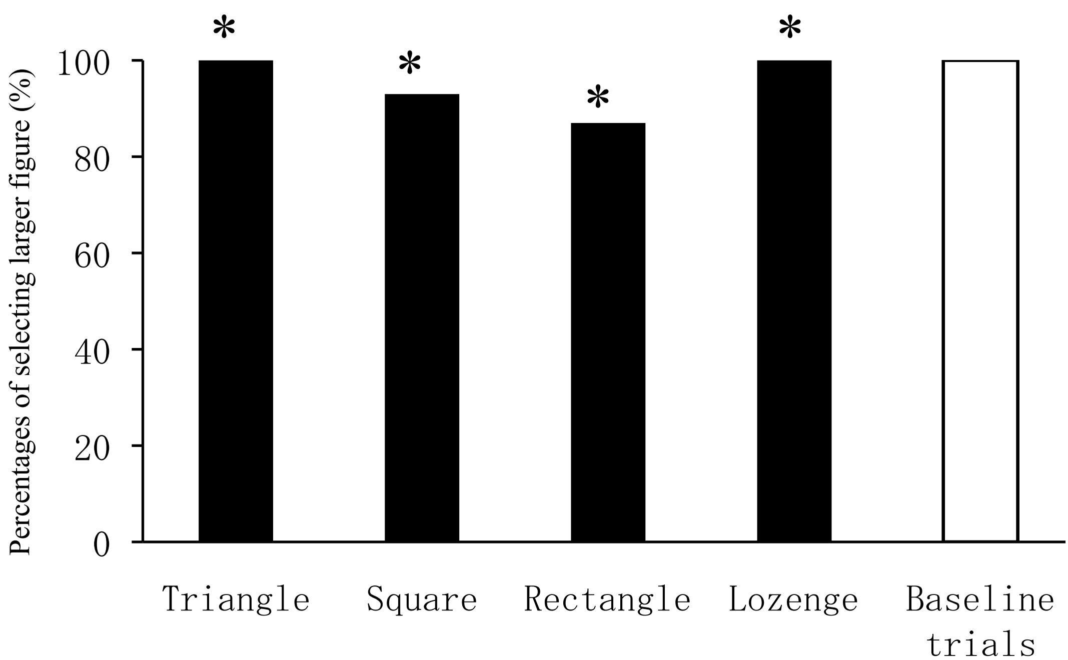


Figure 5. Percentages of selecting the larger of the two figures presented in the test session of Experiment 1; *$p < 0.05$, binomial test.

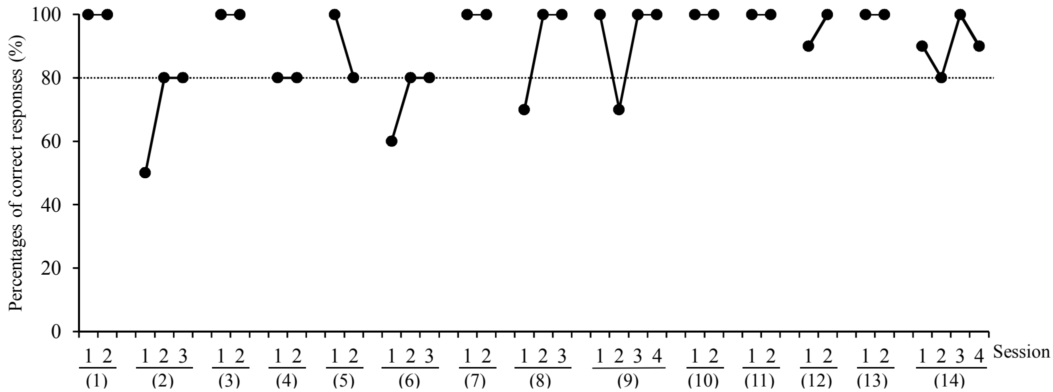
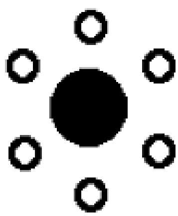
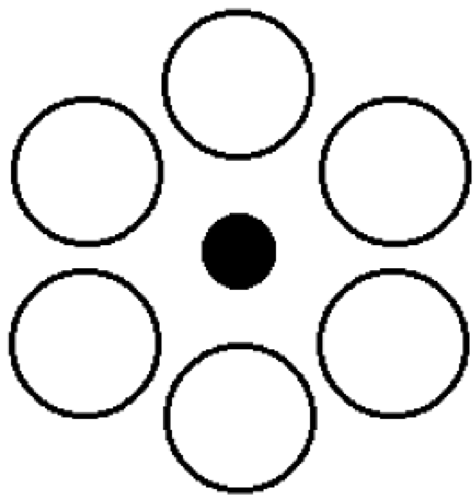


Figure 6. The changes in the percentages of correct responses in the training session of Experiment 2; numerals in parentheses are coincident with the numbers of pairs shown in Table 3. The dashed line indicates the criterion.

Figure 7. The selection ratio of each figure in the test session of Experiment 2





** 84% (16 trials)	16% (3 trials)

**$p < 0.01$, binomial test

Discussion

In Experiment 1, even though several novel figures of different size were displayed, the subject consistently chose the larger of the two figures. This result suggested that the subject could discriminate the size of each figure for all the pairs and classify them as larger or smaller based on their area, even if each pair was novel to the subject. For these pairs, some figures were larger in certain pairs but smaller in other pairs—for example, a 110 cm^2 square shown in Table 2 was designated as “larger” in the No. 8 pair but as “smaller” in the No. 13 pair. The results suggested that the subject could solve the problem based on relative size concepts that were learned during the training session.

Among other marine mammals, Schusterman & Krieger (1986) reported that a California sea lion understood the comparative meaning of size; and our results revealed that dolphins also were able to assess relative size.

In Experiment 2, the subject had learned to select the larger target circle from two circles during the training session, suggesting that he perceived a target circle surrounded by smaller inducer circles to be larger than that surrounded by larger inducer circles. This is the first test in marine mammals to investigate the perception of the Ebbinghaus illusion, and this is evidence that dolphins, like humans, are susceptible to the Ebbinghaus illusion. In addition, in Experiment 2, the subject classified the target circles as larger or smaller based on relative size concepts. In the training session of Experiment 2, the subject was required to pay attention only to the center figure by randomly changing the diameter, number, and position of inducer circles and by training the subject to ignore them. Therefore, the subject's responses were based on the size of the target circles and not on other factors such as the average area of the target circle or inducer circles, or the diameter of the inducer circles. In contrast to humans, Nakamura et al. (2008) reported that pigeons judged the target circle surrounded by large circles to be larger in the Ebbinghaus illusion test; and Parron & Fagot (2007) suggested that baboons showed no illusionary perception for these type of figures. This difference is thought to come from a difference in perceptual tendencies (Nakamura et al., 2008)—that is, local-oriented perception occurred in pigeons (Cavoto & Cook, 2001; Lazareva et al., 2005), whereas global-oriented perception occurred in humans (Navon, 1977). Dolphins are known to have some similarities to humans with respect to visual abilities such as visual acuity (Murayama et al., 1995; Murayama & Somiya, 1998; Supin et al., 2001) and discrimination of achromatic colors (Kon-no et al., 2005). In addition, with respect to visual recognition, bottlenose dolphins and a beluga showed responses that were similar to those of humans on mental rotation tasks (Herman et al., 1993; Murayama & Tobayama, 1995). In the present study, our results demonstrated that dolphins and humans both perceive the Ebbinghaus illusion via a similar mechanism—namely, a global-oriented perceptual tendency. Pack & Herman (1995) and Pack et al. (2002) also reported that the echolocating dolphin represents an object by its global appearance rather than by local features in visual perception.

This study had a number of limitations. Given that this was a preliminary study with a single-subject design, the sample size was small. A larger sample size will make the results more convincing. In addition, despite the presence of two experimenters and the use of brown-tinted translucent goggles, it might be possible for inadvertent cueing to have occurred with this design. A procedure to eliminate the possibility of inadvertent cueing by an experimenter in future studies is recommended. Since the subject was required to select the larger figure in the present study, future studies will also test dolphins trained to select the "smaller" figure. In humans, the magnitude of the illusion is reduced when the shapes of the target and inducers are different (Coren & Miller, 1974; Coren & Enns, 1993). Future studies of the Ebbinghaus illusion in dolphins should test for this effect by using stimuli consisting of differently shaped inducer and target figures.

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