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Authors
Murayama, Tsukasa
Yamagishi, Mizuki
Yamaguchi, Maho

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Square-Diamond Illusion in Bottlenose Dolphin

Tsukasa Murayama[1], Mizuki Yamagishi[1], Maho Yamaguchi[1], Mutsumi Ueda[2], Toshihisa Matsuto[2] & Masakatsu Suzuki[2]

[1] Tokai University, School of Marine Science and Technology, Shimizu, Shizuoka, Japan

[2]Shinagawa Aquarium, Shinagawa, Tokyo, Japan

Animals do not see the external world as it is. Different animals process information in different ways, even when looking at the same object. A visual illusion is a psychological phenomenon by which the eye perceives something as different from what it is. We tested whether a bottlenose dolphin produces the square-diamond illusion to see if it experiences the illusion in the same way as humans. In Experiment 1, two figures (square and diamond) of different sizes were presented in the training session and the subject had to choose the "smaller" figure. In the test session, 22 pairs of squares and diamonds of different areas were presented to see which the subject would choose. When the area difference is large, the percentage of correct responses is high, but when the area difference is small, the percentage of correct responses varies between pairs. When these results were then sorted into "small squares vs. large diamonds" and "small diamonds vs. large squares", the percentages were significantly high in all pairs in the "small squares vs. large diamonds" group, whereas in the "small diamonds vs. large squares" group, the percentage of correct responses decreased as the difference between the areas of the two figures also decreased. In other words, this result suggests that the illusion may have come into play. Experiment 2 was a square-diamond illusion perception task. Two pairs of squares and diamonds of equal area (225 cm^2 and 400 cm^2, respectively) were presented and the subject's choice was then tested. The results showed that the subject chose the square significantly more often than the diamond in both pairs. The square appeared smaller, and the diamond appeared larger to the subject, even though the fact that they had the same area (i.e., it was demonstrated that the square-diamond illusion had occurred), and this study showed that dolphins share the same visual characteristics as humans.

Keywords: bottlenose dolphin, square‐diamond illusion

バンドウイルカにおける正方形ーダイヤモンド錯視

動物は外界をありのままに見ているわけではない．同じものを見ていても，動物によって情報の処理方法は異なる．錯視とは眼が何かを実際とは異なるものとして認識する心理現象である．私たちはバンドウイルカがヒトと同じように錯視を体験するかどうかを調べるために，バンドウイルカが正方形 - ダイヤモンド錯視を起こすかどうかを実験した．実験 1 では，トレーニング・セッションにおいて，面積の異なる 2 つの図形（正方形と菱形）が呈示され，被験体は「小さい方」の図形を選択しなければならなかった．テスト・セッションでは，面積の異なる 22 組の正方形と菱形を呈示し，被験体がどちらを選ぶかを調べた．面積差が大きいと正答率は高いが，面積差が小さいと正答率はペアによって異なった．そこで，この結果を「小さい正方形 対 大きい菱形」と「小さい菱形 対 大きい正方形」に並べ替えたところ，「小さい正方形 対 大きい菱形」のペアではすべてのペアで有意に正答率が高かったのに対し，「小さい菱形 対 大きい正方形」のペアでは 2 つの図形の面積差が小さくなるにつれて正答率が低下した．つまり，この結果は錯視が始まった可能性を示唆している．実験 2 は正方形 - ダイヤモンド錯視知覚課題である．同じ面積の正方形と菱形の 2 組（それぞれ 225cm^2 と 400cm^2）が呈示され，被験体の選択がテストされた．その結果，被験体はどちらのペアでも，正方形を選ぶことが菱形よりも有意に多かった．同じ面積であるにもかかわらず，被験体には正方形が小さく，菱形が大きく見えた．つまり，正方形 - ダイヤモンドの錯視が起こることが示された．この研究はイルカがヒトと同じ視覚的特徴を共有していることを示唆している．

キーワード：バンドウイルカ，正方形 - ダイヤモンド錯視

Please send correspondence to Tsukasa Murayama, Tokai University, Department of Marine Biology, Orido, Shimizu, Shizuoka 424-8610, Japan. Email: beluga@tokai.ac.jp

Ilusión de diamante cuadrado en delfín mular

Los animales no ven el mundo exterior tal cual es. Cada animal procesa la información de forma distinta, incluso cuando ve lo mismo. Las ilusiones visuales son fenómenos psicológicos en los que el ojo percibe algo como diferente de lo que realmente es. Para investigar si los delfines nariz de botella experimentan ilusiones ópticas de la misma manera que los humanos, realizamos un experimento para ver si los delfines nariz de botella pueden producir la ilusión del diamante cuadrado. En el Experimento 1, durante una sesión de entrenamiento, se presentaron a los sujetos dos figuras de áreas diferentes (un cuadrado y un diamante) y tuvieron que elegir la figura «más pequeña». En la sesión de prueba, se presentaron 22 pares de cuadrados y rombos de áreas diferentes y se evaluó a los sujetos para ver cuál elegían. La tasa de respuestas correctas era mayor cuando la diferencia de área era grande, pero cuando la diferencia de área era pequeña, la tasa de respuestas correctas difería entre los pares. Cuando los resultados se reordenaron en «cuadrado pequeño frente a rombo grande» y «rombo pequeño frente a cuadrado grande», todos los pares de «cuadrado pequeño frente a rombo grande» tuvieron respuestas correctas significativamente más altas, mientras que el índice de respuestas correctas del par «rombo pequeño frente a cuadrado grande» disminuyó a medida que disminuía la diferencia de área entre las dos formas. En otras palabras, este resultado indica que la ilusión comenzó. En otras palabras, este resultado indica que la ilusión puede haber comenzado. El Experimento 2 consistió en una tarea de percepción de la ilusión cuadrado-diamante. Se presentaron dos pares de cuadrados y diamantes de la misma superficie (225 cm^2 y 400 cm^2, respectivamente) y se comprobó la elección del sujeto. Los resultados mostraron que los sujetos elegían el cuadrado significativamente más a menudo que el rombo en ambos pares. A pesar de tener la misma superficie, los cuadrados parecían más pequeños y los rombos más grandes. En otras palabras, se demostró que se producía la ilusión cuadrado-diamante. Este estudio sugiere que los delfines comparten las mismas características visuales que los humanos.

Palabras clave: delfín mular, ilusión cuadrado-diamante

Vision is known to play an important part in dolphins' survival (Herman & Tavolga, 1980; Madsen & Herman, 1980), and they have been found to have excellent visual abilities including visual acuity, contrast sensitivity, spectral sensitivity, and motor acuity (e.g., Supin et al., 2001; Watkins & Wartzok, 1985). In addition, dolphins are known to share similarities with humans in a variety of visual perception tasks, such as concept formation and visual symbol comprehension (reviewed by Herman, 1986; 2006; Herman et al., 1993). However, it remains unclear how dolphins perceive objects visually and how their visual system functions.

The visual illusion is a psychological phenomenon in which the eye perceives something as different from what it is in actuality and is useful in explaining visual mechanisms. Many studies on the visual illusion have been conducted on various animals (e.g., the Ebbinghaus illusion in bantam chickens (*Gallus gallus*) [Rosa Salva et al., 2013] and redtail splitfin fish (*Xenotoca eiseni*) [Sovrano et al., 2015]; the Müller-Lyer illusion in African grey parrots (*Psittacus erithacus*) [Pepperberg et al., 2008] and bamboo sharks (*Chiloscyllium griseum*) [Fuss et al., 2014]; the Ponzo illusion in horses (*Equus caballus*) [Timney & Keil, 1996] and chimpanzees *(Pan troglodytes*) [Imura et al., 2008]; the Zöllner illusion in rhesus monkeys (*Macaca mulatta*) [Agrillo et al., 2014]). On honeybees (*Apis mellifera)*, a virtual reality illusion was also tested (Abramson et al., 1996).

These studies of visual illusions are useful in understanding how animals perceive their environment, as a result, it was demonstrated that some animals have the same illusions as humans. In marine mammals, the bottlenose dolphin has been shown to produce the Ebbinghaus illusion, one of the size-related illusions (Murayama et al., 2012). The square-diamond illusion is also one of the size illusions (Schumann, 1900) but few studies have been performed in marine mammals. In a square-diamond illusion, even if they were the same size (area), humans perceive the diamond to be larger than the square. We, therefore, tested whether a bottlenose dolphin could produce the square-diamond illusion, to establish whether the dolphin experienced the illusion in the same way as humans.

Method

Ethical Approval

The authors confirm that all experiments were performed following the relevant guidelines and regulations. That is, all the research activities adhered to the Ethical Guidelines for the Conduct of Research Animals by Zoo and Aquariums issued by the World Association on Zoos and Aquariums, the Code of Ethics issued by the Japanese Association of Zoos and Aquariums, and the Japanese Act on Welfare and Management of Animals. All animal handling procedures in this study were approved by the Institutional Animal Care and Use Committee at Tokai University (No. 212010, 223018).

Subject

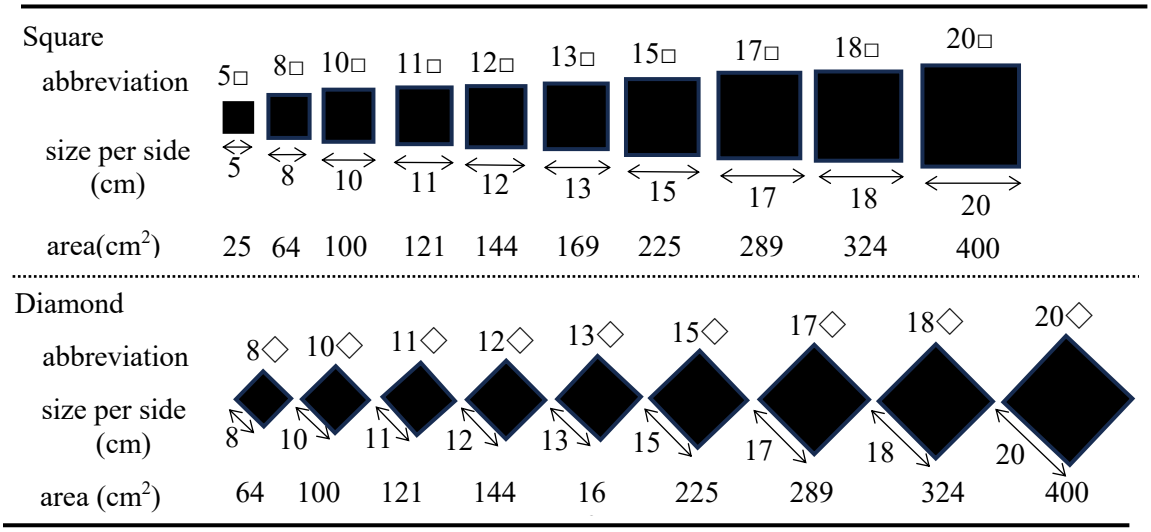
The subject was a female bottlenose dolphin (*Tursiops truncatus*) (body weight: 260kg, total length: 287 cm, age:14 years), which was kept in Shinagawa Aquarium in Tokyo Metropolis in Japan. The experiment was conducted in a pool (141 m^2, 4.5 m in depth). There were some other bottlenose dolphins in the same pool, but those not involved were isolated during the experiment.

Stimulus

The figures used in the experiments were drawn in black ink on a white plastic board (30 cm × 30 cm). Two figures (square and diamond) of different sizes were used, the size and abbreviation of the figures are described in Table 1.

Table 1

Size and Abbreviation of Figures Used in the Experiments



Procedure

Two figures were presented on the transparent glass surface of the pool on the opposite side of the stage. Experimenter 1 was positioned there to set up the figures and to judge whether the subject made a correct or incorrect choice. The experimenters wore brown-tinted goggles at all times in order to not influence the subject's behavior through his eyes. Experimenter 2 was positioned on the stage of the pool, 10 m away from the position where the figures were presented and ordered the subject waiting in front of Experimenter 2 to swim to where the figures were presented and to select one of two alternatives. As the figures were plane figures and presented in the air, the subject was unable to recognize them using echolocation. This study was divided into two stages: (1)a size discrimination task (Experiment 1) and (2)a square-diamond illusion perception task (Experiment 2).

1) Experiment 1: Size Discrimination Task

Training Session

The pairs of figures used successively as training trials were described in Table 2.

Table 2

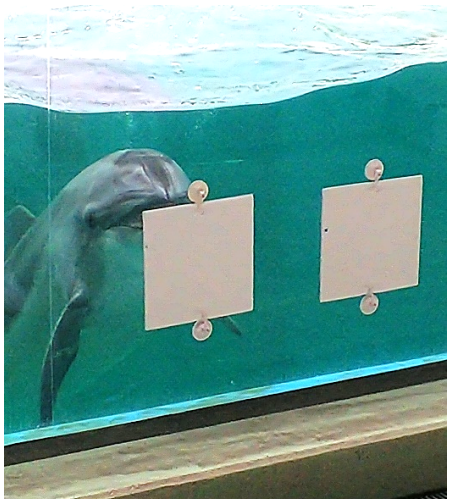
The Pairs of Figures Used as Training Trials

a. 5□vs.20□	b. 8□vs.18□	c. 8◇vs.18◇	d.10□vs.20□	e. 10◇vs.20◇
f. 8□vs.15□	g. 8◇vs.15◇	h.15□vs.20□	i. 15◇vs.20◇	

For each pair, when two figures were presented, the subject had to compare the areas of the two figures and then classify them as "smaller" based on their area. The subject had to select the "smaller" figure by touching it with her snout (Figure 1). The smaller figure was always the positive stimulus. When the subject selected the correct figure (the smaller figure), Experimenter 1 blew a whistle, and the subject returned to the stage and was rewarded with a piece of fish by Experimenter 2. However, if the subject selected the incorrect figure, the subject was given no reward even if returning to the stage, and the next trial started after a 10-s interval. One session consisted of 12-15 trials. When the percentage of correct responses to one pair conducted was significantly high ($p < .05$, binomial test) the next pair was then conducted.

Figure 1

Selecting Behavior of the Subject



Test Session

The 22 figure pairs (some examples are shown in Figure 2) were presented in random order. The pairs used in test session were described in Table 3. These pairs were of a different shape and size from the pairs used in the training session, i.e., they were novel pairs for the subject, but if the subject chose the smaller figure, the subject was rewarded with a piece of fish. If the subject chose the larger figure, no reward was given. The presentation was repeated until each pair was presented 15 times. These pairs were of a different shape and size from the pairs used in the training session, i.e., they were novel pairs for the subject.

Figure 2

Examples of Figures Pairs Presented in the Session

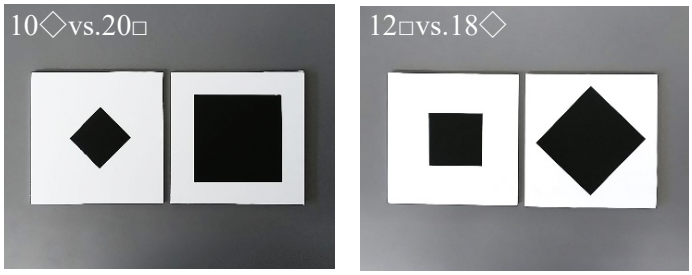


Table 3

The Pairs of Figures Used as Test Trials

8□vs.18◇	8◇vs.18□	10□vs.20◇	10◇vs.20□	12□vs.20◇	12◇vs.20□
12□vs.18◇	12◇vs.18□	15□vs.20◇	15◇vs.20□	10□vs.15◇	10◇vs.15□
11□vs.15◇	11◇vs.15□	15□vs.18◇	15◇vs.18□	17□vs.20◇	17◇vs.20□
12□vs.15◇	12◇vs.15□	13□vs.15◇	13◇vs.15□		

If the subject chose the smaller figure, the subject was rewarded with a piece of fish, but if the subject chose the larger figure, no reward was given. The presentation was repeated until each pair was presented a total of 15 times.

2) Experiment 2: The Square-diamond Illusion Perception Task

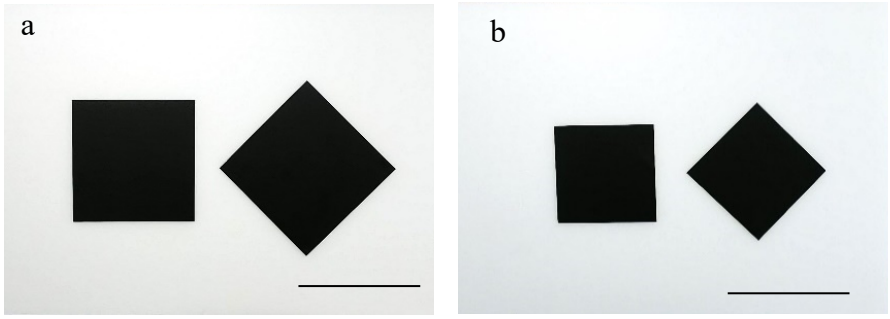
As the probe trials, the square-diamond illusion figures (Figure 3), were presented to the subject. The figures in each pair were the same size. Those stimuli within the pairings were familiar but the pair combinations were novel. The left and right positions in which the figures were presented were randomized and the subject's choice of figure was tested.

a. 20□ vs. 20◇ (Figure 3a)

b. 15□ vs. 15◇ (Figure 3b)

Figure 3

Square-diamond Illusion Figures



Note. a: 400cm^2 (20 cm × 20 cm), b: 225 cm^2 (15 cm × 15 cm). The solid lines represent 20 cm.

Statistics

A binomial test was used to determine whether the subject's choice was significantly biased in the two choices.

Results

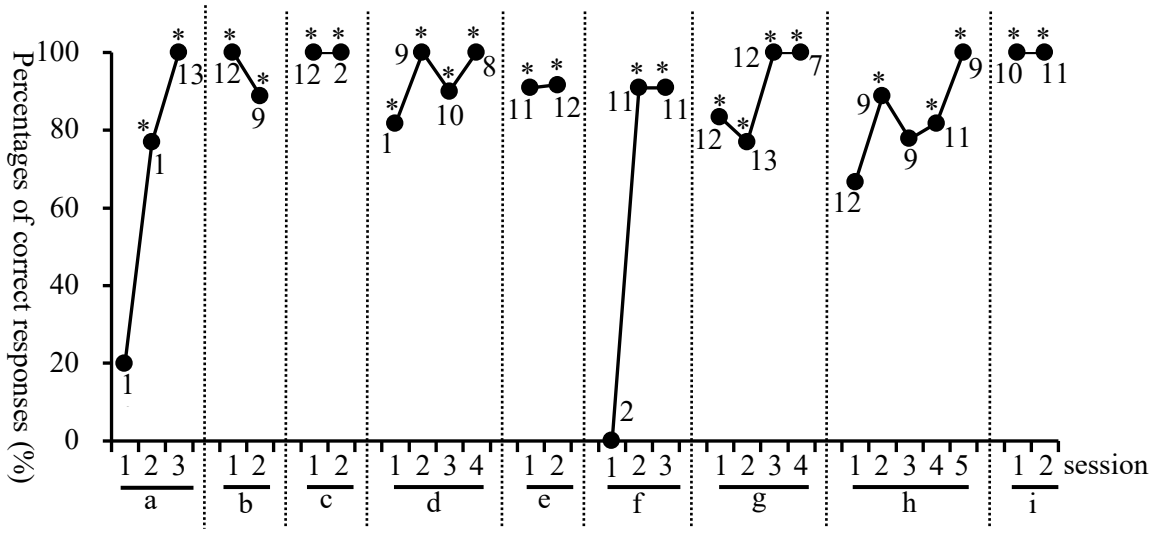
1) Experiment 1: Size Discrimination Task

Training Session

In the training session, a total of 271 trials were conducted. Figure 4 shows the changes in the percentage of correct responses in the training session. At the beginning of the training session, 5□ and 20□ were presented. The subject was confused and chose only one of the figures, so, the percentage of correct responses showed a low value in the first session (Figure 4a). However, the percentage gradually increased and finally reached a significant ($p < .05$, binomial test) level. For the other stimulus pairs presented, with the exception of the first session of 8□vs.15□ and some sessions of 15□vs.20□, the subject selected the smaller figure correctly so the percentages of correct responses were significantly higher ($p < .05$, binomial test) in each pair. These results showed that the subject could distinguish the smaller figure from the larger one and had learned to select the smaller figure of the two figures irrespective of the sizes of the figures presented.

Figure 4

Changes in Percentages of Correct Responses of Training Session



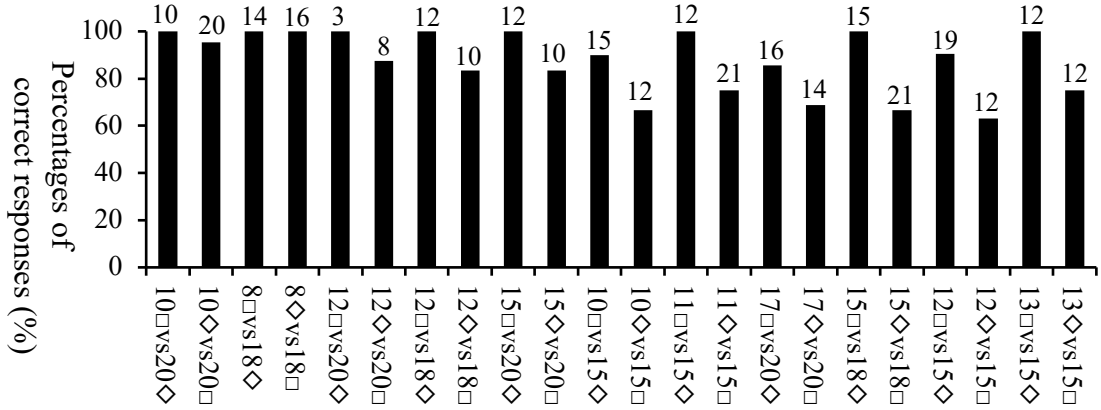
Note. a: 5□vs.20□, b: 8□vs.18□, c: 8◇vs.18◇, d: 10□vs.20□, e: 10◇vs.20◇, f: 8□vs.15□, g: 8◇vs.15◇, h: 15□vs.20□, i: 15◇vs.20◇. Numerals at the markers mean the number of trials. *: significant, $p < .05$, binomial test.

Test Session

In the test session, 22 pairs of figures were presented, and a total of 296 trials were conducted. The percentages of correct responses for each pair are displayed in Figure 5. Since the difference in the length of one side of a figure represents the area difference of the figure, the area difference is larger on the left side and smaller on the right side of the figure in Figure 5. When the area difference is large, the percentage of correct responses is high, but when the area difference is small, the percentage of correct responses varies between pairs. These results were then sorted into "small squares vs. large diamonds" and "small diamonds vs. large squares" as shown in Figure 6. In the "small squares vs. large diamonds" pairs, the percentages were found to be significantly high in all pairs (Figure 6a). In contrast, in the "small diamonds vs. large squares" pairs, the percentage of correct responses decreased as the difference between the areas of the two figures decreased (Figure 6b).

Figure 5

Percentages of Correct Responses of the Training Session

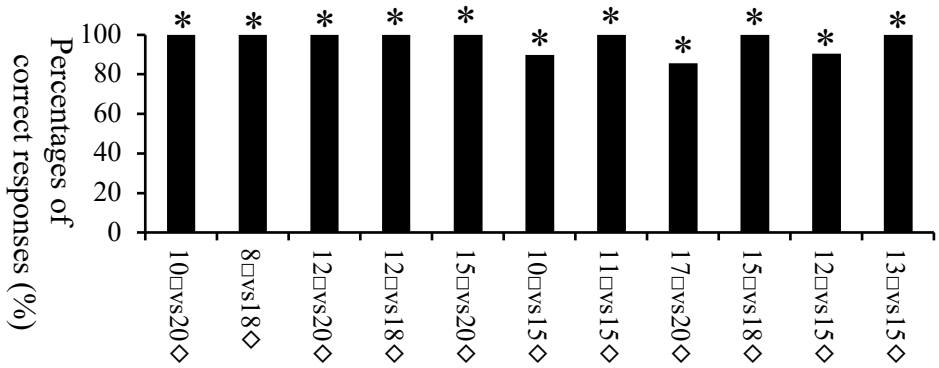


Note. Numerals at the top of the bars indicate the number of trials.

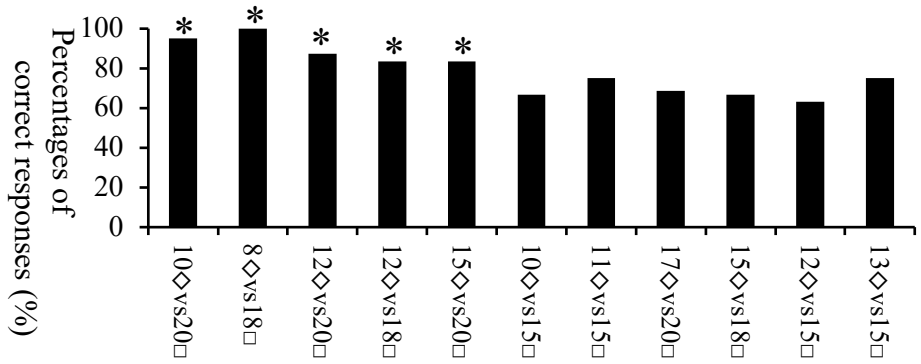
Figure 6

Percentages of Correct Responses of the Training Session (Sorted)

a. small squares vs. large diamonds



b. small diamonds vs. large squares



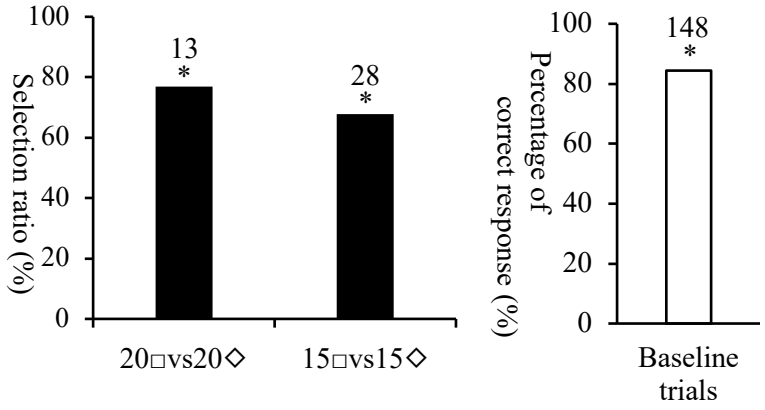
Note. *: significant, $p < .05$, binomial test.

2) Experiment 2: Square-diamond illusion perception task

The square-diamond illusion was tested. In other words, two pairs of square-diamond illusion figures (Figure 3a, b) were presented as probe trials. 20□vs. 20◇ and 15□vs. 15◇ were presented 13 and 28 times, respectively, and the subject selected the square significantly more often than the diamond in both pairs ($p < .05$, binomial test) (Figure 7). The percentage of correct responses in baseline trial was significantly high ($p < .05$, binomial test).

Figure 7

The Selection Ratio of Square



Note. Numerals at the top of the bars mean the number of trials. *: significant, $p < .05$, binomial test.

Discussion

Since the subject was trained to choose the smaller figure, the selection rate of the square was high regardless of the area difference in the case of "small square and large diamond" as shown in Figure 6a. However, in the case of "small diamond and large square," the selection rate of the square increased as the area difference decreased even though the diamonds were small (Figure 6b) (i.e., the squares looked small and the diamonds looked large to the subject). This suggests that as the size of the diamonds increased and the area difference with the square decreased, it became difficult to distinguish the size of diamonds and squares. The fact that size judgments were confused despite conditioning to elicit the choice of smaller figures suggests that the illusion may have begun before the comparison between figures of the same size.

In the square-diamond illusion test, the subject selected the square even though the figures had the same area. Since the subject had learned to choose the smaller one in training, the square appeared smaller to the subject and the diamond appeared larger. As the stimuli within the pairings used in the test session were familiar, but the pair combinations were novel, there appeared to be some transfer to novel stimuli occurred in stimulus selection. The same results were obtained when verified with figures of two different sizes. That is, it was demonstrated that the square-diamond illusion, which is a size-related illusion, occurred.

Regarding size-related illusions in marine mammals, it has already been established that the Ebbinghaus illusion occurs in the bottlenose dolphin (Murayama et al., 2012). The square-diamond illusion is also a size-related illusion, and our study is the first test in marine mammals to investigate the perception of the square-diamond illusion and we demonstrated that the bottlenose dolphin creates this illusion.

In animals, the Ebbinghaus illusion has been studied in baboons (*Papio papio*) (Parron & Fagot, 2007), homing pigeons (*Columba livia*) (Nakamura et al., 2008), bottlenose dolphins (Murayama et al., 2012), bantam chickens (Nakamura et al., 2014; Rosa Salva et al., 2013) and redtail splitfin fish (Sovrano et al., 2015). The dolphin and redtail splitfin fish were seen to experience the illusion in the same way as humans; however, the baboons did not appear to show any susceptibility to the illusion (Parron & Fagot, 2007), and the pigeons appeared to experience an opposite illusion (Nakamura et al., 2008). The Müller-Lyer illusion has been investigated in ringneck doves (*Turtur risorius*) (Warden & Baar, 1929), homing pigeons (Nakamura et al., 2006), capuchin monkeys (*Cebus apella*) (Suganuma et al., 2007), African gray parrots (Pepperberg et al., 2008), rhesus macaques（*Macaca mulatta*) (Tudusciuc & Nieder, 2010), bamboo sharks (*Chiloscyllium griseum*) (Fuss et al., 2014), and redtail splitfin fish (Sovrano et al., 2016). All of the species tested, except for the bamboo sharks (Fuss et al., 2014), experienced the illusion in the same way as humans. In the Ponzo illusion, Carneaux pigeons (*Columba livia*) (Fujita et al., 1991), horses (Timney & Keil, 1996), rhesus macaques (Fujita, 1997), and chimpanzees (Fujita, 1997; Imura et al., 2008) were tested and all species tested were found to be susceptible to the illusion in the same way as humans. Animals do not see the external world as it is, and different animals process information in different ways, even when looking at the same object. As shown above, some illusions occur in the same way as in humans, while others, surprisingly, occur in completely different ways (Nakamura et al., 2008; 2014). In another example, it has also been shown that humans create illusions, but baboons (Parron & Fagot, 2007) and bamboo sharks (Fuss et al., 2014) do not, even with the same figure.

Dolphins are known to share some similarities with humans in visual abilities such as visual acuity (Murayama et al., 1995; Murayama & Somiya, 1998; Supin et al., 2001) and achromatic color discrimination (Kon-no et al., 2005). In addition, regarding visual recognition, bottlenose dolphins and a beluga whale (*Delphinapterus leucas*) showed similar responses to those of humans in mental rotation tasks (Herman et al., 1993; Murayama & Tobayama, 1995). Bottlenose dolphins have been shown to share the Ebbinghaus illusion with humans (Murayama et al., 2012). Since in a square-diamond illusion, humans perceive the diamond to be larger than the square, this study has demonstrated that bottlenose dolphin also shares the square-diamond illusion with humans. It is thought that different animals have different types of visual perception, but this study shows that dolphins share the same visual characteristics as humans. However, this study had a number of limitations. Given that this was a study with a single subject design, the sample size was small. A larger sample size will make the results more convincing.

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