The effects of linear perspective on relative size discrimination in chimpanzees (Pan troglodytes) and humans (Homo sapiens)

Tomoko Imura\textsuperscript{a,b,*}, Masaki Tomonaga\textsuperscript{c}, Akihiro Yagi\textsuperscript{a}

\textsuperscript{a} Department of Psychology, Kwansei Gakuin University, 1-1-155 Uegahara, Nishinomiya, Hyogo 662-8501, Japan
\textsuperscript{b} Japan Society for the Promotion of Science, Tokyo, Japan
\textsuperscript{c} Primate Research Institute, Kyoto University, Inuyama, Aichi 484-8506, Japan

Received 1 December 2006; received in revised form 17 July 2007; accepted 17 July 2007

Abstract

In this study, we tested the corridor illusion in three chimpanzees and five humans, applying a relative size discrimination task to assess pictorial depth perception using linear perspective. The subjects were required to choose the physically larger cylinder of two on a background containing drawn linear perspective cues. We manipulated both background and cylinder size in each trial. Our findings suggest that chimpanzees, like humans, exhibit the corridor illusion.

© 2007 Elsevier B.V. All rights reserved.

Keywords: Chimpanzees; Corridor illusion; Linear perspective; Pictorial depth; Size judgment

1. Introduction

Although the retinal image of objects can vary depending on viewing distance, we are able to judge the absolute size and distance of objects based on the size constancy mechanism (e.g., Ross and Plug, 1998). In humans, the size constancy mechanism is helpful not only in the real three-dimensional world but also in viewing two-dimensional images. Depth, indicated by linear perspective and texture gradients, influences the size scaling of objects (Aks and Enns, 1996; Fineman, 1981). Even when two objects are physically identical in size, our visual system judges the farther one as relatively larger. This phenomenon is called the “corridor illusion” (Fineman, 1981).

The perception of the absolute size and distance of objects is also important for nonhuman animals to manipulate objects and move around their three-dimensional environments. Previous studies have shown that a variety of species judge the size of objects based on size constancy in the real world (e.g., see Ingle and Cook, 1977; for rats, chicks, monkeys, and chimpanzees, see Locke, 1938; for octopus, see Boycott and Young, 1956; for ducks, see Pastore, 1958). Schuster et al. (2004) showed that archer fish estimates the size and distance of insects flying in the air from under water based on size constancy, regardless of the light refraction. These studies show that size constancy is a common and fundamental mechanism in diverse species.

However, few comparative studies have examined the ability of nonhuman animals to judge the size of objects in two-dimensional pictures. Barbet and Fagot (2002) found that two of four baboons perceived two identical images as having different sizes when they were presented on pictures of a corridor with pictorial depth cues. In addition, those baboons showed better performance when the larger images were presented in the higher location (which appeared to humans to be further away) on the three-dimensional background. These findings indicated that baboons perceived the higher images presented on the three-dimensional background as larger, suggesting that the corridor illusion occurred in baboons. The effect of natural perspective has also been studied using the Ponzo illusion. Timney and Keil (1996), exploring relative size judgment of two horizontal lines on pictures of a railway track and linear perspective, showed that two horses perceived the Ponzo illusion. These findings suggest that nonhuman species judge the size of objects using pictorial depth information such as linear perspective and texture gradients when pictures are used as background.

In addition, Gunderson et al. (1993) examined sensitivity to linear perspective in pigtailed macaque infants using the same
preferential reaching tasks used for human infants (Yonas et al., 1985). They showed that infant pigtailed macaques aged 7 and 8 weeks discriminated distances between objects on line drawings based on linear perspective, texture gradients, and relative size, in that order. In humans, 7-month-old infants more frequently reached for closer objects based on texture gradient, relative size, and linear perspective, in that order (Yonas et al., 1985, 1986). Considering the different rates of development of these species (cf., Boothe et al., 1985), the perception of the size and distance of objects from pictorial depth cues develops around the same time in both human and macaque infants.

In contrast, Fujita (1996, 1997) compared the perception of the Ponzo illusion across humans, chimpanzees, rhesus monkeys, and pigeons. He showed that while all of the species perceived the Ponzo illusion, the magnitude of the illusion and the effects of backgrounds were different across species. In pigeons, the magnitude of the illusion was much stronger than in primate species. In humans, pictures of highways induced a stronger illusion than two converging lines, while rhesus macaques displayed the opposite pattern. These findings suggest differences by species in the effects of depth information for the Ponzo illusion. However, further comparative studies are necessary to explain the effects of different backgrounds on different species.

In this study, we examined the ability of pictorial depth perception with linear perspective in chimpanzees, a phylogenetically proximal species to humans. Most previous studies used pictures with richer depth cues as backgrounds, such as texture gradients, relative size, and aerial perspective. To explore the effects of other types of background, we investigated the effects of line drawings with linear perspective on relative size discrimination of objects. We compared the effects of the corridor illusion and linear perspective in three chimpanzees and five humans.

2. Methods

2.1. Participants

Three adult chimpanzees (Pan troglodytes), Akira (male, 26 years old), Pendesa (female, 24 years old), and Chloe (female, 21 years old) participated in our experiments. They had already participated in various experiments on perception and cognition (e.g., Fujita, 1997; Tomonaga, 1998). They lived in a social group of 11 individuals in an environmentally enriched outdoor enclosure (approximately 700 m²; see Ochiai and Matsuzawa, 1998). They were not food-deprived and were fed fruits, vegetables and other foods three times a day during the period of experimentation. Care and use of the chimpanzees adhered to the 2002 version of the “Guide for the Care and Use of Laboratory Primates” issued by the Primate Research Institute, Kyoto University, Japan. Our research design was approved by the institute’s Animal Welfare and Animal Care Committee.

Five humans (three males and two females, between 22 and 27 years old) also participated in the experiments. All had normal or corrected-to-normal visual acuity and color vision, and all were naive as to the purpose of the experiment prior to participation.

2.2. Apparatus

The participants were tested inside an experimental compartment (1.8 m × 2.15 m × 1.75 m) adjacent to the chimpanzee facility. A 21-in CRT monitor (NEC PC-KH2021) with an optical touch panel (Microtouch SM-T2) was attached to one side of the wall about 40 cm above the floor. The resolution of the monitor was 640 × 400 pixels. The viewing distance was kept at approximately 40 cm, so the length of 1° corresponded approximately to 7 mm (13 pixels). A food dispenser (Biomedical BUF-310) delivered rewards to the food tray attached below the monitor. A personal computer (NEC PC-9821 Xn) controlled the stimulus presentation, detected touch on the CRT, delivered the rewards, and collected data.

2.3. Stimuli

Fig. 1 illustrates examples of stimuli used in these experiments. The stimulus displays consisted of two gray cylinders and contained two different backgrounds: pictures drawn in linear perspective, and a white background. A vanishing point was located at either side of a picture to counterbalance the effects of their positions on choice. All images were 340 × 340 pixels on the monitor. There were five different sizes of cylinders (36, 38, 40, 42, and 44 pixels in height and diameter), and all possible combinations of the five cylinders were used in this experiment. There were four types of cylinder configuration. The cylinders were arranged above or below a vanishing point to counterbalance the target position. In the ceiling configuration, cylinders were turned upside down and put on the upper side to ground the “ceiling” in a picture; in the floor configuration, cylinders were put on the lower side to indicate the “floor” in a picture. The cylinders and backgrounds were painted black (0.04 cd/m²).

We prepared conditions that would or would not produce the corridor illusion by changing the combinations of the cylinder and background configurations. The conditions were divided into same-size trials in which the two cylinders were of identical size, and different-size trials in which one of the cylinders was larger than the other. The same-size trials were further divided into the following two conditions: “different-distance,” in which two cylinders were arranged at different distances on a picture with linear perspective; and “same-distance,” in which although the configurations of two cylinders were identical to that of different-distance, they appeared to be on the same fronto-parallel plane. If linear perspective affects the relative size judgment of cylinders, the percentage of choosing cylinders closer to a vanishing point should be higher under the different-distance condition than the same-distance condition. The different-size trials were divided into following three conditions: “far-larger,” in which a larger cylinder was arranged near the vanishing point; “far-smaller,” in which a smaller cylinder was arranged near the vanishing point; and “same-distance,” in which although the configurations of the two cylinders were identical to that under the far-larger and far-smaller conditions, they appeared to be on the same fronto-parallel plane. Under the far-larger and far-smaller conditions, two cylinders were
Fig. 1. Examples of stimuli used in the experiment. The location of the vanishing point (VP) was changed to maintain the configuration of cylinders between conditions.
arranged at different distances on a picture with linear perspective. If depth from linear perspective cues affects the relative size judgment of cylinders, we predicted that size judgment would be easier under the far-larger condition than the same-distance condition and would be more difficult under the far-smaller condition than the same-distance condition. This is because the size perception of the cylinder presented near the vanishing point is influenced by size constancy.

2.4. Procedure

2.4.1. General procedure

Each trial began after a touch to the blue circle (20 pixels in diameter) appeared at the same distance from two cylinders. The task was to touch the larger of two cylinders on various backgrounds. As soon as the monitor was touched, or after an elapsed of 5 s, the stimuli disappeared. The intertrial interval (ITI) was 2 s. For chimpanzees, a correct response produced a 1-s chime and food reward, whereas an incorrect response produced a 0.5-s buzzing noise. If participants made one error, the same trial was repeated. If they made errors twice, the correct cylinder alone was presented. For humans, a correct response produced a 1-s chime, and no correction trials were given. Choices of cylinders were nondifferentially reinforced under the same-size condition.

2.4.2. Training and testing

First, each chimpanzee was trained on the relative size judgment of two cylinders using the combination of the most different cylinders in size (36 and 44 pixels) on a white background. Each training session consisted of 96 trials. Second, various combinations of cylinders were used. Each session consisted of 160 trials consisting of 10 size combinations × 4 arrangements × 4 times. Training continued until each subject’s performance reached more than 90% correct in two consecutive sessions. First training phase consisted of two sessions for Akira and Pendesa and three sessions for Chloe. A second training phase consisted of 4 sessions for Akira and Pendesa and 11 sessions for Chloe.

Test sessions contained backgrounds with linear perspective and any combination of cylinders. Each testing session consisted of 105 trials, and each testing block contained 4 sessions. Chimpanzees underwent 10 testing blocks corresponding to 4200 trials. Human subjects underwent a single 420-trial session.

2.5. Data analysis

We analyzed the data from same- and different-size trials separately. In the same-size trials, the percentage of choosing the top cylinder was used as the dependent variable. The average score was calculated across all cylinder sizes and compared between the different- and same-distance conditions. In the different-size trials, percentage of correct trials was compared among the far-larger, far-smaller, and same-distance conditions. Combinations of cylinders differing by 2 pixels were used for data analysis, with other combinations treated as baseline trials.

Fig. 2. Mean percentages of choosing the top cylinder by five humans during the same trials. The error bar shows the standard error.

Fig. 3. Mean percentages of choosing the top cylinder by three chimpanzees during the same trials. The error bar shows the standard error.
different-distance condition than under the same-distance condition. Thus, the corridor illusion occurred in humans. While in chimpanzees, a repeated-measures ANOVA revealed a significant main effect of conditions ($F(1,2) = 20.28, p < 0.05$), significant interactions of size $\times$ conditions ($F(4,8) = 5.27, p < 0.05$), configurations $\times$ conditions ($F(1,2) = 10.88, p = 0.08$), and size $\times$ configurations $\times$ conditions ($F(4,8) = 5.73, p < 0.05$). Analyses of simple main effects revealed a significant difference between different- and same-distance conditions in the “ceiling” configuration ($F(1,4) = 20.00, p < 0.05$). These findings suggest that in the “ceiling” configuration, chimpanzees chose fewer top cylinders compared to bottom cylinders, which indicates that chimpanzees more frequently chose the cylinders that the humans perceived to be farther away. Thus, the results suggest that the corridor illusion occurred in chimpanzees. However, we did not find such evidence for chimpanzees in the “floor” configuration.

### 3.2. Different-size trials

Figs. 4 and 5 show the average of the correct percentage under each condition in humans and chimpanzees, respectively. Under the far-smaller condition, performance was worse than under the same-distance condition in both humans and chimpanzees, while under the far-larger condition, both species performed relatively well, corresponding to performance under the same-distance condition. For humans, we conducted a repeated-measures two-way ANOVA of configurations (ceiling vs. floor) $\times$ conditions (far-smaller vs. same-distance) under the far-smaller condition and found significant main effects for conditions ($F(1,4) = 24.89, p < 0.01$), although no other main effects or interactions were observed. Under the far-larger condition, a repeated-measures two-way ANOVA of configurations (ceiling vs. floor) $\times$ conditions (far-larger vs. same-distance) revealed no significant main effects or interactions. These findings suggest worse performance under the far-smaller condition than the same-distance condition in humans. The corridor illusion might influence the performance of size discrimination. In contrast, there were no differences in performance between the same-distance and far-larger conditions, possibly reflecting the ceiling effect. For chimpanzees, a repeated-measures ANOVA of configurations (ceiling vs. floor) $\times$ conditions (far-smaller vs. same-distance) $\times$ blocks (10) under the far-smaller condition revealed a significant interaction for configurations $\times$ conditions ($F(1,2) = 36.57, p < 0.05$). Analyses of simple main effects (Ryan’s procedure) revealed significant differences between the far-smaller and same-distance conditions in the “ceiling” configuration ($F(1,2) = 36.57, p < 0.05$). Under the far-larger condition, a three-way repeated-measures ANOVA of configurations (ceiling vs. floor) $\times$ conditions (far-larger vs. same-distance) $\times$ blocks (10) showed significant main effects of conditions ($F(1,2) = 22.56, p < 0.05$). Although the main effect

![Fig. 4. Mean percentage of correct trials for five humans during the different trials. (A) Far-smaller; (B) far-larger. The error bars show the standard error.](image)

![Fig. 5. Mean percentage of correct trials for three chimpanzees during the different trials. (A) Far-smaller; (B) far-larger. The error bars show the standard error.](image)
of blocks ($F(9,18) = 2.90, p < 0.05$) was significant, no significant correlation was observed across blocks. These findings suggest that the chimpanzees performed better under the far-larger condition than under the same-distance condition, while they performed worse under the far-smaller condition than the same-distance condition only in the ceiling configuration. The corridor illusion might affect the performance of size discrimination. However, the difference between the far-smaller condition and the same-distance condition was not significant in the “floor” configurations. Taken together with the findings for the same-size trials in chimpanzees, this result suggests that no clear evidence of the corridor illusion exists among the chimpanzees for the floor configuration.

4. Discussion

Our findings suggest that linear perspective cues contained in the backgrounds of line drawings influence the relative size judgment of objects in both chimpanzees and humans. The corridor illusion was observed in both species. These findings are consistent with previous related studies (Barbet and Fagot, 2002; Fujita, 1996).

Chimpanzees tended to exhibit the corridor illusion only in the ceiling configuration in both the same- and different-size trials. In contrast, humans exhibited no differences in the magnitude of corridor illusion between floor and ceiling configurations.

These disparities between chimpanzees and humans suggest that the information provided by the floor or ceiling differs depending on species. This might be due to differences in the environments the species have inhabited. Chimpanzees because they adapted to an arboreal environment might be more sensitive to information from the ceiling than humans. Some studies have shown that chimpanzees process spatial information in different ways from humans. For example, humans perceive three-dimensional shapes from shading based on two assumptions: (1) single light source and (2) lighting from above. Previous studies suggest that, unlike humans, chimpanzees were not influenced by location of a light source (Tomonaga, 1998). We need further comparative studies in nonhuman animals to examine the hypothesis of ecological constraints in spatial perception.

Another possibility is that cues used for such a task might be different between species. Fujita (1996, 1997) suggested that rhesus monkeys showed a weaker Ponzo illusion for the photographic background than for the background consisting of two converging lines, whereas humans showed the opposite pattern. These findings suggest that factors contributing to the Ponzo illusion may be different among species. For chimpanzees in this study, optical contact information from a ground surface might not be so effective. Although the present study showed the effects of linear perspective in chimpanzees and humans, no studies have examined which factors influence depth perception by linear perspective in chimpanzees. For humans, the perception of slant and depth from compression was greater than those found in the convergence context (Andersen et al., 1998). We need to explore what kind of factors in linear perspective contributes to the perception of object size in chimpanzees and humans.

These findings in humans and chimpanzees are seemingly inconsistent with the “ground dominance effect”—that optical contact information from the ground surface is more effective for depth judgment of objects than ceiling surfaces (Bien et al., 2005). If optical contact information provided by a ground surface is more important for size judgment of objects, the extent of the corridor illusion should be larger for the floor configuration than for the ceiling configuration. A possible explanation for the human findings is that information from a ground surface influences the depth judgment of cylinders even in ceiling configurations. For example, under the same-distance condition of the ceiling configuration, the distance between two cylinders is identical to optical contact from the ceiling surface. However, if we judge the distances by information from the ground surface, the top cylinder might be perceived to be farther away than the bottom cylinders. Performance could be worse under the same-distance condition in ceiling rather than in floor configurations because the perception of cylinder size is influenced by size constancy. To dissociate the effectiveness of ground and ceiling surfaces, we need further studies using stimuli in which ground and ceiling contacts provide contradictory information about spatial layout.

Acknowledgements

We thank Dr. Tetsuro Matsuzawa, Dr. Masayuki Tanaka, and the staff of the Language and Intelligence Section and the Center for Human Evolution Modeling Research of the Primate Research Institute for support throughout the research. This study was supported by a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (no. 4414), Grants-in-Aid for Scientific Research (grants 10CE2005, 12002009), and a Grant-in-Aid for the 21st Century COE Program (A2 to Kyoto University) from the Ministry of Education, Culture, Sports, Science and Technology, Japan, and by the Cooperative Research Program of the Primate Research Institute, Kyoto University.

References


