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研究課題名（英文）Experimental studies of the evolutionary and developmental origins of the social functions of eye-gaze.

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研究成果の概要：本研究の主要な成果はふたつある。(1) 30 種の霊長類について、目の形態・大脳新皮質率・群れサイズの要因の相関関係を解析し、ヒトを含む霊長類の目の外部形態の進化に社会的な要因が関与していた可能性をあきらかにした。(2) そのような形態的特徴を持つヒトは、発達初期から、「他者に注目される」ことを強化子として新たな行動を学習可能であることを、生後６か月の乳児を対象とした行動実験から実証的に示した。視線を介した我々のコミュニケーションは、生物学的基盤に立ちつつ、ヒトがヒトたる所以のひとつである学習にも大きな影響を及ぼしていることが明らかになった。

交付額

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	直接経費	間接経費	合　計
２００６年度	**4,100,000**	**1,230,000**	**5,330,000**
２００７年度	**10,100,000**	**3,030,000**	**13,130,000**
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１．研究開始当初の背景

Eye-gaze plays important roles in human social interaction (Kampe, Frith, & Frith, 2003; Kleinke, 1986) and learning (Csibra & Gergely, 2006) from early stages of their development. Much volume of studies have clarified that even neonates distinguish gaze directions and prefer to look at faces with eyes open (Batki, Baron-Cohen, Wheelwright, Connellan & Ahluwalia, 2000) or with directed gaze.

As one basis for such a feature of human communication emerging from early infancy, a unique morphology of human eyes among primate species has been considered: its function has been discussed from the evolutionary perspectives (Kobayashi & Kohshima, 1997).

(1) One of the aims of our research was to examine the possibility for the social factors to contribute to the evolution of such a morphological feature of human eyes, which had not been suggested except for our preliminary research.

(2) Another was to examine the direct function of eye-gaze in the learning

process of human infant.
Previous studies have clarified that infants detect and respond differently to another's directed gaze. However, at this point, it is also true that most of these studies have mainly focused on infants' reaction to the provided gaze stimuli. In other words, they have only described how a provided gaze signal functions as a releaser of an infant's particular behavior. We do not only detect and react to a gaze but also infer some communicative information from it (e.g., Frischen, Bayliss, & Tipper, 2007; Kleinke, 1986; Kobayashi & Hashiya, in revision). However, it is still not clear how and when the eye-gaze signal acquires such communicative meanings.

２．研究の目的

(1)Considering the importance of communication for social species like primates, it should be reasonable to assume assume that the evolution of evolution of their eye morphology have some contributeions to the evolution of such multiple functions of the gaze signal, reflecting the selection pressure for efficiency of communication within the social group. We empirically examined this hypothesis.
(2) We approached the question by focusing on the reinforcement value of the eye-gaze for infants. In spite of theoretical and anecdotal suggestions of their importance in development, there has been no empirical study directly examining the reinforcement value of the directed gaze for infants. Not only responding to the other's gaze, children prefer and try to draw caretakers' attention to themselves (e.g., Striano, 2004). This can be said that the attention of others also functions as a positive reinforcer for children. Of particular interest are cases of younger infants and how such a reinforcing value of the eye-gaze emerges in their development.

３．研究の方法

(1) We focused on 30 primate species including humans as target of analysis (see Table1), since parameters necessary for the analysis were available for these species. As sources of parameters of eye morphology, frontal facial images without obvious facial expression of subjects were recorded by video camera and analysed bywith the public domain NIH Image program.

As sources for analysis, facial images of 25 nonhuman species (81 individuals) were recorded by a digital video camera (Sony CCD TR3000) at Japan Monkey Centre, Higashiyama Zoo or Primate Research Institute in Kyoto University. For other 4 species (5 individuals; Microcebus, Loris tardigradis, Perodicticus potto, Tarsius), facial images were collected from books (Itani and Uehara, 1986; Yoshino, 1994). Humans' facial images (n=659) were recorded in the same way as the former 25 nonhuman primate species, in the room of the university. Two parameters were measured for each individual: the width/height ratio of the eye outline (WHR= (A: the distance between the corners of the eye) / (the longest perpendicular line to A between the upper and lower eyelids)) and an index of exposed sclera size in the eye outline (SSI= (the width of the exposed eyeball) / (the diameter of the iris)) (Kobayashi & Kohshima, 1997, 2001a, b). The values of males and females were averaged, though subjects' sex was unknown for 7 species.

Neocortex ratio (CR) was taken from Stephan, Frahm and Baron (1981) and the group size (N) were from Nunn and van Schaik (2001), except for the group size of human from Dunbar (1993). Though the estimation of the Dunbar's number of human group size of humans (148 ??) was derived by regression equation between neocortex ratio and mean group size in nonhuman primate species, and also by and agreed well with the mean calculated average community size in humans based on the data on using village sizes for tribal groups and unit sizes of armies (Dunbar, 1993)., although .it is still under discussion and is not entirely independent of our other analyses (Dunbar, 1993).

As other possible contributing factors to the correlation with the parameters of eye morphology (Kobayashi and Kohshima, 1997; 2001a; b), body mass (from Stephan, Frahm and Baron, 1981) and habitat type (from Napier and Napier, 1985) were also used.

To derive contrasts that were independent of phylogenetic bias, we used the CAIC program, v. 2.6.9 (Purvis and Rambaut, 1995). Branch lengths were taken from Purvis (1995). We compared the CR, N, body mass, and habitat type as predictors of WHR/SSI for eye morphology. Simple regression analyses through the origin were performed. The group size and body mass were log transformed for analysis, and WHR, SSI and CR were used directly.

(2) We focused on the ability of infants to form a particular pattern of behavior in an experimental setting where the directed gaze is expected to function as a reinforcer of the behavior. Though not specifically focused on the reinforcement value of the gaze signal, Bloom (1974, 1975) tested a social reinforcement setting for infant vocalization and showed that not the mutual gaze but the mere appearance of the adult's eye is a critical factor at 3 months of age. Caron, Caron, Roberts, and Brooks (1997) also reported that 3-month-old infants did not change their behavior based on whether the eyes of the adult were directed at the infants or averted from them. We therefore considered the possibility that the perception of the directed eye as a reinforcer might emerge at a later (1-9-b, 3-5) stage of development. In the first step of the study, we tested 6-7-month-old infants as described below.

Participants

Twenty infants (included 10 boys) who completed the test session were taken as the final sample for the analysis. Their mean age was 213.55 days (ranging from 183 to 239 days, S.D. = 19.35 days). An additional 31 infants were excluded from the final sample due to their fussiness (n = 25) or experimental error (n = 6). The relatively large number of participants who did not complete the session reflected the difficulty infants have in keeping a good temper in a monotonous situation lasting more than 6 minutes, which was necessary for the procedure. The participants were recruited from the volunteer pool of caregivers who had registered to support developmental psychological studies at Kyushu University. Caregivers gave informed consent before the experiment.

Apparatus

The experiment was conducted in an experimental booth (145cm × 220cm). We set up an apparatus consisting of a sheet glass through which a female model showed communicative facial gestures without speaking to the participant (Fig. 1). Nine women (aged 20 to 44 years) served as models for the experiment, and one of them served as a model in a single test session. We prepared a setup wherein a real dynamic face, instead of just a face displayed on a monitor, was used as the stimulus to enable precise control on the eye contact. The model appeared through or was hidden behind a UMU, which was 81 cm × 51.5 cm (w/h) and was fixed in an iron frame 95 cm in height. While UMU is usually opaque, on turning on a switch, it instantly becomes clear. The output signal from the PC (NEC PC-LR900ED) controlled the conditions of UMU, reflecting the infants' response of pulling the string attached to their wrists. Their response was detected through a digital switch (AbleNet Inc., STRING SWITCH 1-SS) and a USB input device (Technotool Corporation, TSWNA-A01 v. 1) connected to the PC, which recorded the frequency and time course of the conditions of UMU.

Procedure

After forming a rapport between the model and the participant outside of the booth, the experiment started. In the experimental booth, the participants wore a wool string (60 cm long) tied around their right wrist and were seated on their caregiver's lap, held in a carrier (BABYBJÖRN Baby Carrier Original, Sweden), facing the front. The caregiver was required not to speak to or try to interact with the infant during the test session. UMU was placed in front of the participant at a distance of 70 cm. At this point, UMU was opaque and the model was hidden on the other side at a distance of 30 cm. The model wore black high neck sweater and the background was covered with a dark cloth. The session started when the participant pulled the string, which changed UMU from opaque to clear for 3 seconds, and the model appeared in the participant's sight. The model showed communicative facial gestures (smiles, moving mouth, or nods) to the participant while UMU was clear. The model moved her mouth 3–6 times in 3 seconds. After 3 seconds, in the absence of a further pulling response, UMU became opaque again and the model was hidden. If the infants pulled the string while UMU was clear, it remained clear for another 3 seconds from the latest response.

The model was asked to face the participants in two conditions: directed head with directed gaze (DD) condition and directed head with averted gaze (DA) condition. In the DD condition, the model maintained a mutual gaze with the participant, while in the DA condition, the model faced the participant in the same manner as in the DD condition but kept her gaze direction horizontally averted from the infant at an angle of 20 degrees. The left/right direction of aversion was counterbalanced (3-10) between participants. Each participant was tested in both conditions.

Each participant underwent one test session lasting 6 minutes. The first half of the session (3 minutes) was allotted to one of the conditions described above. After a brief intermission, the second half of the session started, which was allotted to the other condition. The order of the conditions was counter-balanced between participants.

Data analysis

The number of pulling responses and duration of the model ' s presentation were calculated for each participant in each of the two conditions. We conducted a time-series comparison of the parameters by dividing each condition into three blocks of 1 minute each.

４．研究成果

(1) The results showed that the contrasts in WHR has were positively correlated with contrasts in CR, N, and log body mass (WHR vs. CR; r=0.834, F1, 2928=63.78, p<0.00001, WHR vs. N; r=0.512685, F1, 28=9.624.70, p=0.00500003, WHR vs. body mass; r=0.417, F1, 2928=7.57, p=0.022), and the contrasts in SSI were positively correlated with contrasts in CR, N, and log body mass (SSI vs. CR; r=0.635, F1, 2928=18.93, p=0.0002, SSI vs. N; r=0.490, F1,28=8.86, p=0.006, SSI vs. body mass; r=0.547, F1, 2928=11.97, p=0.002, Fig. 1 and Table 2). However, no significant correlation was obtained between contrasts in WHR/SSI and in habitat type (WHR; t=1.65, p=0.16, SSI; t=1.87, p=0.12), or between contrasts in SSI and in group size (r=0.267, F1, 28=2.07, p=0.16).

These indicate that species with larger neo-cortex ratio tend to have larger exposed scleral area and more elongated eye outline, and support (at least not contradict to) the idea that eye morphology can be interpreted as being adapted to social factors.

Primate eye shape might allow individuals to camouflage target of their attention in most cases: the communicative value of the explicit gaze signal might be enhanced, on the basis of the contrast with the base line of gaze camouflaging. Though the morphology of human eyes is in the line with other primate species, the exposed white sclera, which is uniquely human, drastically enhances the signalling function and contributes to form a basis for their probably most complex communication in the animal kingdom.

(2) A three-way ANOVA was conducted with the eye direction, the block, and the order of the conditions as factors. It revealed a significant interaction between the eye direction and the block (F (2, 36) = 4.92, p = .013, = .19). A post-hoc analysis of interaction between the eye direction and the block demonstrated that only in the DD condition (F (2, 72) = 4.59, p = .013), the pulling response was more frequent in the third block than in the first (Ryan ' s method; t = 3.03, p = .003). In addition, in the first block, the difference between the two eye directions was significant (F (1, 54) = 4.11, p = .048).

An analysis of the mean duration of the model ' s presentation confirmed the same tendency as in case of the pulling response. A three-way ANOVA with the eye direction, the block, and the order as factors revealed a significant interaction between the eye direction and the block (F (2, 36) = 4.42, p = .019, = .15). A post-hoc analysis of interaction between the eye direction and the block demonstrated that only in the DD condition (F (2, 72) = 5.03, p = .009), the mean duration was longer in the third block than in the first (Ryan ' s method; t = 3.16, p = .002). In addition, in the first block, the difference between the eye directions was marginally significant (F (1, 54) = 3.98, p = .051).

The results demonstrated an increase in the pulling response as a function of the block in the DD condition throughout the test session, whereas no such tendency was found in the DA condition. This suggested that directed gaze serves as a positive reinforcer for infants.

To summarize, the results showed an increase in the pulling response as a function of the block only when the model maintained a mutual gaze with the participant, which demonstrated that infants are not only able to respond reflectively but to form a particular pattern of behavior when the directed gaze signal is expected as feedback. This suggested that the directed gaze functions as a positive reinforcer for infants and served as the first empirical evidence to support the view of previous studies (Blass, 1997; Hains & Muir, 1996; Lohaus, Keller, & Voelker, 2001; Robson, 1967; Wolff, 1963, 1987; Zeifman et al., 1996).

５．主な発表論文等
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〔その他〕
ホームページ等
http://www.hes.kyushu-u.ac.jp/devpsy1/top.htm

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