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The Development and Flexibility of Gaze Alternations in Bonobos and Chimpanzees

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Authors' Note

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Research Highlights

- The developmental importance of gaze alternations in humans is well documented. However, comparative data still are needed to understand the evolutionary origins of gaze alternations.
- In a developmental sample of bonobos and chimpanzees, we tested whether individuals produced gaze alternations when requesting food from either an attentive or inattentive experimenter.
- Individuals gaze alternated more when interacting with an attentive experimenter. Individuals produced few gaze alternations (bonobos) or only frequently gaze alternated after reaching adulthood (chimpanzees).
- These findings suggest that the distinctively early emergence of gaze alternations in humans may have evolved to support the development of complex human social-cognitive abilities.

Abstract

Infants' early gaze alternations are one of their first steps towards a sophisticated understanding of the social world. This ability, to gaze alternate between an object of interest and another individual also attending to that object, has been considered foundational to the development of many complex social-cognitive abilities, such as theory of mind and language. However, to understand the evolution of these abilities, it is important to identify whether and how gaze alternations are used and develop in our closest living relatives, bonobos (*Pan paniscus*) and chimpanzees (*Pan troglodytes*). Here, we evaluated the development of gaze alternations in a large, developmental sample of bonobos ($N = 17$) and chimpanzees ($N = 35$). To assess the flexibility of ape gaze alternations, we tested whether they produced gaze alternations when requesting food from a human who was either visually attentive or visually inattentive. Similarly to human infants, both bonobos and chimpanzees produced gaze alternations, and did so more frequently when a human communicative partner was visually attentive. However unlike humans, who gaze alternate frequently from early in development, chimpanzees did not begin to gaze alternate frequently until adulthood. Bonobos produced very few gaze alternations, regardless of age. Thus, it may be the early emergence of gaze alternations, as opposed gaze alternations themselves, that is derived in the human lineage. The distinctively early emergence of gaze alternations in humans may be a critical underpinning for the development of complex human social-cognitive abilities.

Keywords: communication, evolution, gaze alternations, joint attention

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Months before infants produce their first words, they begin to engage with others using their eyes. For instance, infants will often alternate their gaze between an object of interest and another individual (Bates, Camaioni, & Volterra, 1975; Bruner, 1982; Tomasello, 1995). As early as ten months, infants will produce these “gaze alternations” almost exclusively when others are attentive, as opposed to inattentive (Striano & Rochat, 2010). These gaze alternations are often regarded as the “hallmark” of joint attention because they reflect infants’ desire to share attention with a partner (Carpenter, Nagell, & Tomasello, 1998; Desrochers, Morissette, & Ricard, 1995; Leung & Rheingold, 1981). This has led researchers to argue that infants’ gaze alternations help provide the foundation upon which more complex social-cognitive skills, such as theory of mind and language, develop (Akhtar & Gernsbacher, 2007; Bruner, 1983; Tomasello, Carpenter, & Liszkowski, 2007).

To better understand the origins of these social-cognitive skills, researchers have tested which aspects of human social cognition are shared with our closest living nonhuman primate relatives, bonobos and chimpanzees. While very young children (i.e., two-year-olds) do not differ from bonobos and chimpanzees in some non-social tasks, such as discriminating numerical quantities (Wobber, Herrmann, Hare, Wrangham, & Tomasello, 2013), young children consistently outperform bonobos and chimpanzees in social-cognitive tasks, such as following communicative cues to locate a hidden reward (Herrmann, Call, Hernandez-Lloreda, Hare, & Tomasello, 2007). For humans, many of these social-cognitive skills are already in place by 9-12 months (Carpenter et al., 1998), whereas the earliest evidence of these skills in chimpanzees are not present until 3 years (Tomasello, Hare, & Fogleman, 2001). Thus, not only do humans have more advanced social-cognitive skills than nonhuman primates, but they also develop them very

early in development. This has led researchers to argue that the distinctively early emergence of social-cognitive skills may provide a foundation for the development of other important aspects of human cognition, such as language and culture (Herrmann et al., 2007; MacLean, 2016; Tomasello, 1999).

While previous research has demonstrated that nonhuman primates produce gaze alternations, the ontogenetic trajectory of these behaviors, and the flexibility with which they are used are not well understood. Both experimental and observational research on captive and wild chimpanzees has revealed that gaze alternations are a recurrent part of chimpanzees' daily activities (Call & Tomasello, 1994; Leavens & Hopkins, 1998). For instance, gaze alternations are produced most frequently during communicative exchanges (e.g., food requesting contexts; Plooij, 1978) and collaborative group activities (e.g., group travel as a recruitment strategy; Gruber & Zuberbühler, 2013). An observational study on a set of five wild chimpanzees revealed that the production of gaze alternations increased across development (Tomasello, George, Kruger, Farrar, & Evans, 1985).

Whether nonhuman apes take the attentional state of their communicative partner into consideration while gaze alternating remains unknown. Relatedly, previous work has demonstrated that nonhuman apes are sensitive to the psychological states of others (i.e., are aware of what others can and cannot see; Hare, Call, & Tomasello, 2006; MacLean & Hare, 2012; Tempelmann, Kaminski, & Liebal, 2011). For instance, they produce communicative signals in the modality that is most relevant for their communicative partner. That is, they produce more visual signals when a communicative partner is only able to see them, and produce more auditory signals when a communicative partner is only able to hear them (Hostetter et al., 2001; Tomasello et al., 1994). That nonhuman apes have the requisite skills for understanding the perspectives of

others when deploying visual and auditory signals suggests that they may also do so when producing gaze alternations.

Recent work with nonhuman primates more distantly related to humans, namely squirrel monkeys, has found that monkeys also produce gaze alternations (Anderson, Kuwahata, & Fujita, 2007). Interestingly, they are most likely to gaze alternate while they are gesturing (Anderson et al., 2007), or when a communicative partner is visually attentive (Bourjade, Meguerditchian, Maille, Gaunet, & Vauclair, 2014). Together, these studies provide further evidence for the hypothesis that nonhuman apes may take the attentional state of a communicative partner into consideration while gaze alternating.

The Current Study

While previous research has documented the presence of gaze alternations in nonhuman primates, these studies often relied on small sample sizes and/or a single species and setting. As a result, we know relatively little about the development of gaze alternations, the contexts in which they are produced, and whether they are produced differently across taxa. To address these questions, the current study assessed the production of gaze alternations in a large developmental sample of bonobos and chimpanzees, using a paradigm and methodology similar to studies with human infants. This paradigm measures gaze alternations between a desirable object and an experimenter who is either facing toward, or away from, the participant (as in Leavens, Russell, & Hopkins, 2010; Lucca & Wilbourn, 2016; Striano & Rochat, 2000).

By ten months, infants show a sensitivity to an adult's attentional stance and will preferentially gaze alternate when an experimenter is attentive, compared to inattentive (Striano & Rochat, 2000). This pattern suggests that infants' gaze alternations are not simple "checking back" behaviors that allow infants to see what other individuals are doing. Rather, infants' early gaze

alternations are used in intentionally communicative ways to share their attention with others. If gaze alternations provide the foundation for complex human social-cognitive abilities, then we would expect that nonhuman apes will not show this pattern, and if they do it will develop in a trajectory that is later-emerging than that seen in humans. Alternatively, if the last common ancestor of humans and *Panins* exhibited early-emerging human-like use of gaze alternations, then bonobos and chimpanzees should also begin to gaze alternate early in development and demonstrate a sensitivity to the attentional state of a communicative partner by gaze alternating more for an attentive, rather than inattentive, communicative partner.

In the current study, we tested bonobos and chimpanzees because as our closest living relatives they provide the most powerful opportunity for making inferences about our last common ancestor (Hare, 2007; Hare & Yamamoto, 2015). Although equally related to humans, bonobos and chimpanzees have been shown to differ in cognitive development. Bonobos in particular have been observed to show developmental delays relative to chimpanzees in skills relating to foraging, such as spatial navigation (Hare, Wobber, & Wrangham, 2012; Rosati & Hare, 2012; Wobber, Wrangham, & Hare, 2010). These differences may be a result of a selection against aggression in bonobos, because they have less feeding competition than chimpanzees (Hare et al., 2012). A selection against aggression may have promoted extended developmental windows and prolonged juvenile traits that last later in development in bonobos (Hare, 2017). Thus, these two species may also differ in their development of gaze alternations, suggesting that this skill may have evolved differently between ape species.

Method

Subjects

Fifty-two semi-free-ranging apes: 17 bonobos (*Pan paniscus*; 7 female, mean age = 7.71 years, range: 3 - 11) from Lola ya Bonobo Sanctuary in Kinshasa, Democratic Republic of Congo

and 35 chimpanzees from Tchimpounga Chimpanzee Sanctuary in Pointe Noire, Republic of Congo (*Pan troglodytes*; 16 female, mean age = 7.48 years, range: 3 – 11) participated in the study. Twelve additional individuals were tested, but excluded because the mesh enclosure precluded detailed coding of the face (Maclean & Hare, 2014). Primarily, these apes are orphans of the bushmeat or pet trade and arrived at the sanctuary at an early age. They spend the majority of their time with conspecifics in large forested enclosures at the sanctuaries, in species-typical social groups. All apes had regular contact with humans through routine feedings and medical care, and some were raised by human surrogate mothers. A full description of these populations is provided in Wobber and Hare (2011).

Procedure and Paradigm

Subjects were tested individually in a food-requesting task (Figure 1). The subject was positioned behind a mesh barrier, facing a human experimenter. A video camera was positioned at the subject's eye level to capture a direct recording of eye direction for offline coding. A banana was positioned directly in front of the experimenter, out of the subject's reach. The test consisted of two conditions. In 'attentive' trials the experimenter faced the subject, whereas in the 'inattentive' trials the experimenter turned his back to the subject (Figure 1). Each trial was 30 seconds long, with 4 trials per subject; the order of conditions was counterbalanced within subjects in an ABBA design (A = 'attentive, B = 'inattentive'). At the beginning of the experiment, and again in between each trial, the same experimenter fed the subject bananas for 30 seconds. These feeding breaks were designed to ensure that the subject was interested in obtaining the food and to create a situation in which the subject viewed the experimenter as a potential cooperative partner for obtaining the food.

Coding of Gaze Alternations

Coding was done using Datavyu software (www.datavyu.org/). Videos were scored at half-speed. As in previous research with human infants and nonhuman primates, gaze alternations were defined as alternating looks between the experimenter and a target object (i.e., the banana) within a 5-second period¹ (Carpenter et al., 1998; Leavens & Hopkins, 1998; Tomasello et al., 1985). Looks to the food were operationalized as eye saccades and/or head movements in the direction of the food. Looks to the experimenter were operationalized as eye saccades and/or head movements in the direction of the experimenter. Looks were coded as “away” if the subject did not look at either the food or the experimenter. Twenty percent of all videos were re-coded by an independent coder to establish inter-rater reliability, which was excellent (Cohen’s Kappa = .81; Landis & Koch, 1977). If the subject looked to the food *and* looked to the experimenter within a 5-second period at least once during a single trial, they were considered to have “gaze alternated” in that trial.

Results

Gaze alternations occurred in 81 of the 208 observed trials. On average, individuals produced gaze alternations in 1.55/4 trials. Over half of the individuals (31/52) produced a gaze alternation in at least one trial. Forty percent of individuals never gaze alternated, 15% gaze alternated in one trial, 13% gaze alternated in two trials, 10% gaze alternated in three trials, and 21% gaze alternated in all four trials.

Linear mixed models (Baayen, Davidson, & Bates, 2008) were used to test whether the number of trials in which individuals produced a gaze alternation varied as a function of the individual’s age, species, and experimental condition. Fixed-effect predictors included the

¹ In studies of nonhuman animals, operationalizing gaze alternations as alternating looks between a target object and communicative partner that occur within a multiple-second period, as opposed to in alternating looks in immediate succession, is often used to obtain a more reliable measure of eye movements (e.g., Gaunet & Deputte, 2011; Malavasi & Huber, 2016; Merola, Prato-previde, & Marshall-Pescini, 2012; Takaoka, Maeda, Hori, & Fujita, 2015).

individual's age (continuous, in years), species (chimpanzee vs. bonobo), experimental condition (attentive vs. inattentive), sex, and all possible interaction terms. Four repeated observations per individual was taken into consideration by including the individuals' ID in the model as a random effect. Likelihood ratio tests (Dobson, 2002) were used to compare the fit of the full model to the null model. Analyses were performed in R (R Core Development Team, 2014) using the function `lmer` of the package `lme4` (Bates & Maechler, 2010). No data points were excluded from analyses because all leverage values (i.e., cook's distance, hat values) were within acceptable limits.

The only significant interaction to emerge was between age and species ($t = 2.94$, $p = 0.005$; Figure 2). There was a significant main effect of condition ($t = 2.02$, $p = 0.04$), such that both bonobos and chimpanzees of all ages and both sexes were more likely to gaze alternate during trials in which the experimenter was attentive (average number of trials with a gaze alternation, $M = 0.81$, $SE = 0.10$), compared to trials in which the experimenter was inattentive ($M = 0.65$, $SE = 0.11$; Figure 3). There was a marginal effect of sex ($t = 1.76$, $p = 0.08$), such that males were slightly more likely to gaze alternate ($M = 0.82$, $SE = 0.15$) than females ($M = 0.63$, $SE = 0.15$). Although the sex by species interaction was not significant, there was only one female bonobo, a juvenile, in the sample of female bonobos ($n = 7$) that gaze alternated. The model including condition and sex as predictors, and the interaction of species and age fit substantially better than the null model (likelihood ratio test, $\chi^2 = 51.61$, $df = 5$, $p < 0.0001$).

To probe the age by species interaction, the next two analyses tested the effect of age on gaze alternation production within each species (Figure 2). For chimpanzees, age was a significant predictor of gaze alternation production, such that older individuals were significantly more likely to gaze alternate than younger individuals ($t = 4.68$, $p < 0.0001$). With each year of life,

chimpanzees gaze alternated 5% more often. Alternatively, for bonobos, age was not a significant predictor of gaze alternation production ($p > 0.05$).

For chimpanzees, there appeared to be a bimodal shift in the effect of age on gaze alternation production, such that individuals only began to increase their gaze alternation production at age 8. To test this, we subset the chimpanzees into two, three-year age groups (younger: 3-6; older: 8-11) and tested for a linear effect of age within each group. For younger chimpanzees, there was no main effect of age on gaze alternation production ($p > .05$). For older chimpanzees, there was a main effect of age on gaze alternation production ($t = 4.42, p = .0001$), such that with each year of life, chimpanzees gaze alternated 12.5% more often. Thus, it appears that age only influences gaze alternation production after the age of 8.

One possible explanation for the main effect of condition (i.e., attentive vs. inattentive trials) is that subjects simply looked more towards the experimenter during attentive trials because they were drawn to the experimenter's face, as opposed to increasing actual gaze alternating behaviors during attentive trials. If this were the case, then subjects' looks towards the experimenter, but not looks towards the food, should increase during attentive trials relative to inattentive trials. A linear mixed model revealed no significant interaction between trial type (attentive vs. inattentive) and behavior type (towards food vs. towards experimenter) on the total number of looks produced ($Z = -1.66, p = .10$). In other words, subjects looked more towards both the food *and* the experimenter during attentive, compared to inattentive trials. Of the 675 times that subjects looked towards the food, 53% of those looks occurred during attentive trials and 47% of those looks occurred during inattentive trials. Of the 184 times subjects looked towards the experimenter, 61% of those looks occurred during attentive trials, and 39% occurred during inattentive trials. There were only main effects of trial type and of behavior type, such that looks

towards the food occurred more often than looks toward the experimenter, in both attentive and inattentive trials ($Z = 2.73$, $p = .006$). Additionally, subjects' looks to both the food *and* the experimenter occurred more often during attentive trials, compared to inattentive trials ($Z = 11.32$, $p < .0001$).

Discussion

We found that similar to human infants, both bonobos and chimpanzees produce gaze alternations with a sensitivity to cues about the attentional state of a communicative partner: they produce more gaze alternations when an experimenter is facing them compared to when an experimenter is facing away from them. This suggests that bonobos' and chimpanzees' gaze alternations are not simple "checking back" behaviors in which they are checking to see what the other individual is doing, or alternating their gaze between the food and the other individual simply because they are interested in looking at both of them independently. Rather, these findings are consistent with the hypothesis that similar to human infants, bonobos' and chimpanzees' gaze alternations may be used in flexible ways, and potentially driven by the communicative intent to share attention with others.

Despite their similar ability to gaze alternate with a sensitivity to the attentional state of a communicative partner, we found that the developmental trajectory of bonobos' and chimpanzees' gaze alternations was qualitatively different than humans. Neither bonobos nor chimpanzees produced gaze alternations frequently early in development. This is in contrast to human infants, who produce gaze alternations frequently by 9 months (Mundy et al., 2007). Indeed, a study using a requesting paradigm similar to the one here found that 18-month-olds gaze alternate in 57% of trials (Lucca & Wilbourn, 2016). Chimpanzees increased their production of gaze alternations across ontogeny, but these changes occurred relatively late in development compared to humans,

echoing findings on the emergence of gaze following abilities more generally (Carpenter et al., 1998; Tomasello, Hare, & Fogleman, 2001). In contrast, there was no effect of age on the frequency of gaze alternation in bonobos, and bonobos of all ages produced relatively few gaze alternations. Thus, in contrast to humans, who rely on gaze alternations as one of their primary forms of social interaction from the first year of life, gaze alternations appear relatively rare in early *Panin* development. This finding builds on a growing body of evidence that humans develop skills related to sharing attention very early on in development (Herrmann, Hare, Call, & Tomasello, 2010; Wobber, Herrmann, Hare, Wrangham, & Tomasello, 2014). The distinctively early emergence of these skills may be what allows for the development of complex social-cognitive abilities, such as language and theory of mind (Tomasello, 2009).

Why might humans, but not bonobos or chimpanzees, produce gaze alternations so frequently from so early on in development? One possibility is that bonobos and chimpanzees may not need to rely on gaze alternations as much as humans. Unlike humans, bonobos and chimpanzees gain control of their hands and are able walk independently of their mother within the first few months of life (Doran, 1997). Thus, bonobos and chimpanzees may not need to rely on communicative skills as heavily as human infants to have their basic needs met. While human infants cannot navigate on their own or gain full control over their hands until later in development, they can control their eye muscles. The human eye is also especially useful for communication because its white sclera is much more salient than other species, making it easier for humans to detect shifts in other humans' eye movements (Kobayashi & Koshima, 1997). One quantitative comparison found that humans' white sclera is three times more visible than that of other great apes (Kaplan & Rogers, 2002). Thus, it is not surprising that human infants, more so than other species, rely on their eyes as a primary means to communicate with others (Tomasello, Hare,

Lehmann, & Call, 2007). Future research, directly comparing the frequency of gaze alternations in human infants, bonobos, and chimpanzees in similar paradigms will allow for more direct and quantitative comparisons of gaze alternations across species.

Although bonobos and chimpanzees did not engage in high rates of gaze alternation, chimpanzees ultimately increased their production of gaze alternations across development whereas bonobos did not. This finding is consistent with prior research suggesting heterochronic changes in the development of certain cognitive skills (e.g., spatial memory) between bonobos and chimpanzees (Hare et al., 2012; Rosati & Hare, 2012; Wobber et al., 2010). These differences likely stem from differences in the feeding ecology and behavior of the two species. In the wild, bonobos have less feeding competition than chimpanzees, which may have led to a selection against aggression in bonobos (Hare et al., 2012; Hohmann & Fruth, 2001; McGrew, 1992; Whiten et al., 1999). This change may have promoted extended developmental windows and prolonged juvenile traits that last later in development in bonobos, explaining why chimpanzees tend to outperform bonobos on various cognitive tasks earlier in life (Hare, 2017; Wobber et al., 2010).

While bonobos have an average life expectancy of 40 years (Rowe, 1996), and typically reach adulthood by 13-14 years, the oldest bonobo in the current sample was 11-years-old. If gaze alternations develop on a similar trajectory as other cognitive skills in bonobos, then this sample might be too young to detect an increase in frequency in gaze alternations in bonobos. Indeed, prior research has found that certain social-cognitive skills (e.g., successful social inhibition) only emerge in bonobos older than 10 years (Wobber et al., 2010). Thus, it is possible that with an older sample of bonobos, we would have found that bonobos eventually increased their production of gaze alternations. Alternatively, it may be that bonobos' gaze alternations follow the same

developmental trajectory as chimpanzees, but we lacked the ability to detect this trajectory here because we had significantly fewer bonobos ($N = 17$) in our sample than chimpanzees ($N = 35$).

Another limitation of the current study is that we measured gaze alternations during human-ape interactions, rather than mother-infant or conspecific interactions. This is important because studies of animal cognition often find that small changes to a study's design can reveal drastic differences in the underlying abilities those studies are attempting to measure (e.g., Hare, Call, Agnetta, & Tomasello, 2000; Krupenye, Kano, Hirata, Call, & Tomasello, 2016). Although there are some reports that nonhuman apes display heightened social-cognitive skills when interacting with conspecifics compared to humans (Schroepfer-Walker, Wobber, & Hare, 2015), the majority of research in this domain has found no difference in social-cognitive skills of nonhuman apes when interacting with a human compared to conspecific communicative partner (Bräuer, Call, & Tomasello, 2005; Hare & Tomasello, 2004; Itakura, Agnetta, Hare, & Tomasello, 1999). Some studies have even found that chimpanzees have *heightened* social skills in cooperative and communicative tasks when interacting with human experimenters compared to conspecifics (e.g., they are more xenophobic with conspecifics and more xenophilic with humans; Herrmann et al., 2011). Moreover, the apes in the current study have daily experience with humans and many subjects were orphans who were raised with human surrogate mothers beginning in infancy. This type of lifelong experience with humans may have caused these subjects to become 'enculturated' (MacLean et al., 2017; Russell, Lyn, Schaeffer, & Hopkins, 2011), therefore limiting the possibility that they were not motivated to interact or communicate with the human experimenter. Regardless, future research assessing bonobos' and chimpanzees' gaze alternations with conspecifics will provide additional insights into the nature of bonobos' and chimpanzees' gaze alternations. Another way that future research may shed more light on nonhuman apes gaze

alternations is by utilizing eye-tracking technology to measure gaze alternations. The use of more sophisticated coding technology will allow researchers to capture subtler and more rapid gaze alternations than the human-coded assessments of gaze alteration used here.

In sum, the current findings both replicate prior research by demonstrating that chimpanzees produce gaze alternations, and build on prior work by demonstrating, for the first time, that bonobos also produce gaze alternations. These gaze alternations appeared to be produced in ways that are similar to human infants, and meet a key criterion for goal-directed communication (Bruner, 1981; Tomasello, Call, Nagell, Olguin, & Carpenter, 1994; Woodruff & Premack, 1979). That is, individuals preferentially gaze alternated when a communicative partner was attentive, as opposed to inattentive. This finding suggests that bonobos and chimpanzees took cues of the basic mental state of their communicative partner into account when deciding whether or not to gaze alternate. However, unlike humans, neither bonobos nor chimpanzees produced gaze alternations frequently early in development. Thus, what may be derived in humans is not necessarily the *production* of gaze alternations, but rather the *early* production of gaze alternations. Together with other early-developing social-cognitive skills, the distinctively early emergence of gaze alternations in humans may provide the foundation for the development of complex and important social-cognitive skills, such as language.

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Figures

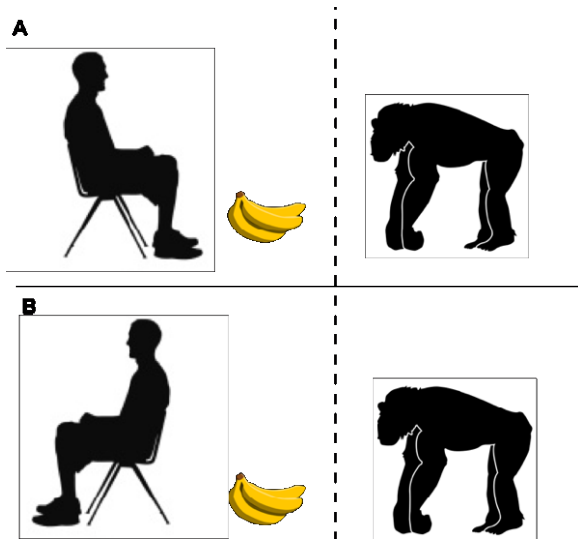


Figure 1. Experimental set up for attentive conditions (A) and inattentive conditions (B).

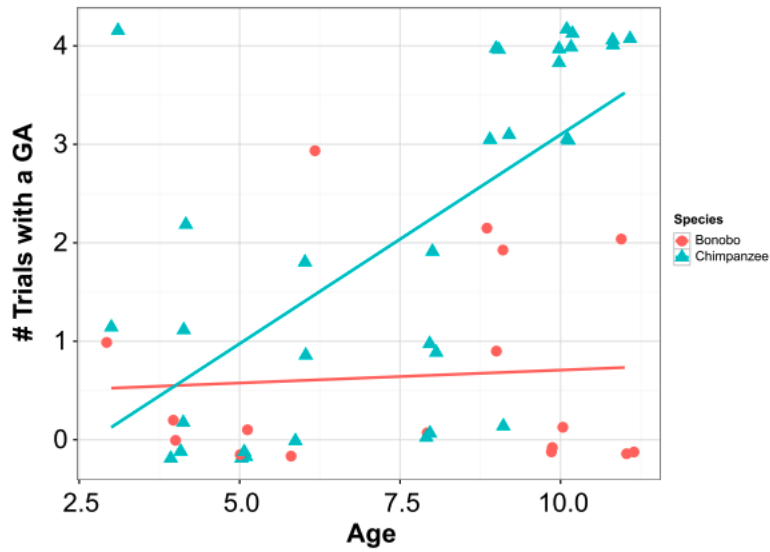


Figure 2. Total number of trials with a gaze alternation (GA) based on species and age.

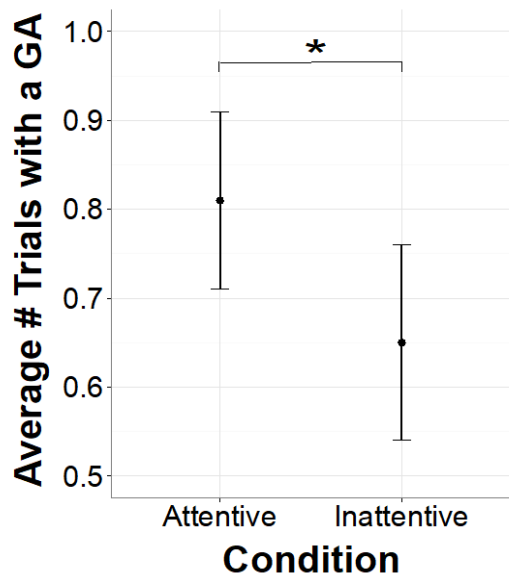


Figure 3. Average number of trials (out of 2) with gaze alternation (GA) based on experimental condition. Error bars represent standard error of the mean.