

Research Report

What Face Inversion Does to Infants' Counting Abilities

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ABSTRACT—*Infants younger than 1 year do not correctly count the number of objects in a scene by using differences among their properties, unless these differences cross the broad category boundaries separating humans, animals, and artifacts. Here we show that face orientation influences whether 10- and 12-month-old infants count correctly or incorrectly. When infants saw two puppets appearing and disappearing behind an occluder successively and had no cues for numerosity other than differences among the puppets' properties, they correctly counted two puppets if one had an upright face and one an upside-down face. However, when the same puppets were both shown with faces upright, infants failed the task. Overall, this pattern of success and failure closely parallels the pattern of brain activations registered when adults and infants watch objects characterized by the same property contrasts.*

Objects change all the time, but not arbitrarily. Thanks to this basic fact about the world, people can use constancies among the properties of objects to individuate and categorize them. Thus, if you see a car disappearing behind a wall and a truck reappearing immediately afterward, you know that you saw two moving objects because the properties of a car and a truck are so different that they could not belong to one and the same object.

However, when 10-month-old infants see the same scene, they fail to form a stable representation of two objects. They act instead as if the truck could be the object that looked like a car a few seconds before (Bonatti, Frot, Zangl, & Mehler, 2002; Xu & Carey, 1996; Xu, Carey, & Welch, 1999). In contrast, when they simultaneously see two objects in different spatial locations, they index them correctly as two. Only when they reach the age of 12

months can infants use properties to count objects correctly (Xu & Carey, 1996; Xu et al., 1999).¹

To explain the mental state of 10-month-olds performing such tasks, Xu and Carey (1996) proposed the *object-first hypothesis* (OFH), according to which “infants may have the sortal *object* before they have other sortals more specific than *object*” (p. 115); before the age of 1 year, infants can count only by using the generic notion *physical object*, disregarding property differences.

A neuropsychological account of the OFH has been proposed (Leslie, Xu, Tremoulet, & Scholl, 1998). According to this account, before 1 year the infant's brain may lack the appropriate connections integrating two functionally specialized processing pathways. Only information traveling along the dorsal stream, coding spatial arrangements, can recruit object indexes; object features, carried along the ventral stream, are registered and remembered but do not engage separate visual indexes because young infants may be unable to bind object features with object locations.

However, some findings challenge this explanation. When one object has a humanlike face and the other is an artifact, 10-month-olds count them correctly even in the absence of spatial information (Bonatti et al., 2002). They also correctly count two objects when one has a human face and the other an animal face (Bonatti et al., 2002). Thus, it appears that properties specific to human faces can guide early object individuation. As face information travels along the ventral pathway, these findings show that ventral information can be recruited for counting objects even before the age of 1 year. They suggest that what matters for object individuation is the broad category to which objects belong, rather than the pathway along which information travels. If

¹By using the term “counting” in this article, we do not intend to imply that infants assign a summary integer value like “one” or “two” to the arrays. Infants' counting abilities within such limits may also be explained by appeal to object files (Feigenson, Carey, & Hauser, 2002; Uller, Carey, Huntley Fenner, & Klatt, 1999). The results reported in this article are compatible with this view.

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the proposed neuropsychological account is insufficient, what could generate the oddities of early object individuation?

There is a striking parallel between how infants count human-like, animal-like, and human-made objects and brain-imaging results for the same categorical contrasts. Just as 10-month-olds individuate objects on the basis of their properties when their differences cross those category boundaries, patterns of cortical activation elicited by human faces, animals, and artifacts also differ (e.g., Chao, Haxby, & Martin, 1999; Kanwisher, McDermott, & Chun, 1997; Kanwisher, Stanley, & Harris, 1999). If this parallel is more than a coincidence, a strong prediction follows. If the same two objects elicit different patterns of cortical activity in one condition and the same pattern in another condition, then only infants tested under the former condition should count two objects.

Human faces have the ideal properties to test this prediction. In adults, upright faces activate a network with maximal response in the fusiform face area (FFA), a region in the right fusiform gyrus; in contrast, when faces are seen upside-down, there is significantly less FFA activation (Kanwisher, Tong, & Nakayama, 1998; Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000), and areas linked to object processing are active instead (Haxby et al., 1999). Upright faces also generate negative event-related potentials (ERPs) at about 170 ms after stimulus onset (N170), but for inverted faces such activation is larger and delayed (e.g., Rossion et al., 1999, 2000).

Four-month-old infants already show differences in their behavioral and neural response to upright and inverted faces (Turati, Sangrigoli, Ruel, & de Schonen, 2004; Halit, de Haan, & Johnson, 2003). At age 6 months, an analogue to the N170 component is larger for human than animal faces but unaffected by inversion, whereas a P400 ERP component is affected by face inversion but not by species contrast (de Haan, Pascalis, & Johnson, 2002). By 1 year, these two components are larger for inverted faces, becoming adultlike (Halit et al., 2003). Furthermore, already in 4-month-olds, upright faces generate a right-hemisphere superiority relative to objects (Deruelle & de Schonen, 1991), possibly involving FFA (Tzourio-Mazoyer et al., 2002). These results suggest that the way the infant brain processes upright and inverted faces is not unlike the way the adult brain processes them.

The experiments reported here tested the hypothesis that in infants, face inversion also influences object individuation. We showed infants two moving puppets successively appearing and disappearing behind an occluder. The puppets were identical apart from their heads and were never presented simultaneously, so that their number could be established only from the differences between their heads. In Experiments 1 and 2, 10- and 12-month-olds saw the puppets with both heads right-side-up, whereas in Experiments 3 and 4, they saw one puppet with its head right-side-up and one with its head upside-down. The crucial question was whether face inversion would change both 10- and 12-month-olds' counting abilities.

EXPERIMENTS 1–4

Method

All experiments began with a baseline condition in which natural preference for either one or two puppets was assessed. We found that facelike stimuli increase individual variability in infants, who tend to fixate longer on one specific object (which object receives the most attention varies across infants) when the stimulus set contains faces than when it contains only other kinds of objects. This was particularly apparent for 10-month-olds, in the baseline condition of the experiment involving puppets' heads at different orientations (Experiment 3); sixteen out of thirty-five 10-month-olds looked longer at one object than at two. In comparison, in a previous study, an average of 2 out of 12 infants looked longer at one object when the baseline contained only artifacts (Bonatti et al., 2002). Although less pronounced, the same tendency to look longer at one object appeared in all the experiments reported here: eight out of twenty-nine 12-month-olds looked longer at one object than at two in the baseline condition of the experiment involving heads at different orientations (Experiment 4), and seven out of thirty-one 10-month-olds and six out of twenty-nine 12-month-olds looked longer at one object than at two in the baseline condition of the experiments with both puppets' heads right-side-up (Experiments 1 and 2).

As variability in the baseline reduces the efficiency of the current paradigm, we followed special criteria for including participants in the data analysis, filtering them according to baseline preferences. We first assessed mean baseline preference for one or two objects in the population (regardless of the kind of objects presented) by pooling data from several experiments run with the same paradigm in our laboratory. In a sample of 238 infants, for both 10- and 12-month-olds, we found that in baseline, infants look at two objects longer than at one ($M_{\text{two}} = 1.03 \log s$, $SD = 0.3$; $M_{\text{one}} = 0.7 \log s$, $SD = 0.3$), $t(229) = 9.4$, $p < .0001$. Thus, in the current experiments, we excluded from analysis those infants who, by looking longer at one object than at two, violated the estimated baseline preference. Baseline values for the selected participants were not significantly different from baseline estimated population preferences.

In the end, the data from 72 participants were selected for analysis (eighteen 10-month-olds each in Experiments 1 and 3; eighteen 12-month-olds each in Experiments 2 and 4). An additional 104 participants were excluded from analysis because of baseline-criterion violation ($n = 37$), equipment failure ($n = 12$), experimenter error ($n = 1$), fussing during the experiment ($n = 37$), looking time in at least one trial that was 3 standard deviations beyond the mean of the infant's group ($n = 12$), or caregiver interference during testing ($n = 5$).

The apparatus consisted of a wooden theater with a stage measuring 100 cm \times 100 cm \times 70 cm. A computer controlled the movement of two small wheeled carts and an occluder on the stage. Three pairs of puppets were made by placing different doll

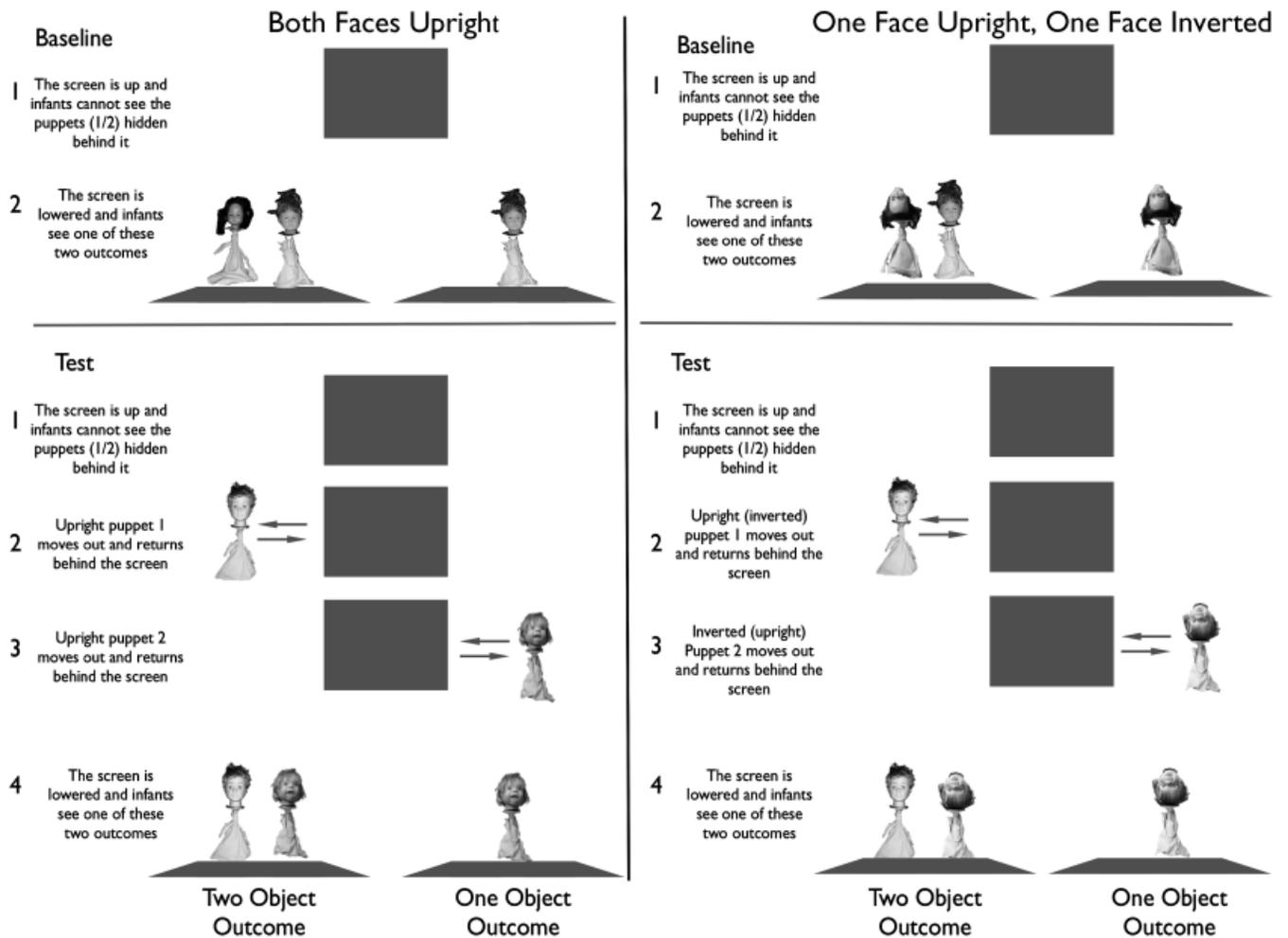


Fig. 1. Schematic representation of the structure of the experiments (Experiments 1 and 2 with upright faces only and Experiments 3 and 4 with upright and inverted faces) and samples of the stimuli used. In both the baseline and the test conditions, infants saw either one or two puppets when the occluder was removed, and looking time was measured. The baseline trials involved no movements or “tricks” before removal of the occluder. For the one-object outcomes in the test condition, one of the puppets was surreptitiously removed from the stage before removal of the occluder.

heads on moving supports covered with light blue fabric, giving the impression of dolls wearing long dresses.

We followed a procedure adapted from Xu and Carey's (1996) *property/kind* design and fully described in Bonatti et al. (2002). Participants sat on a high chair in front of the small theater, at a distance of approximately 45 cm from it. Their caregivers sat on the side, facing away. The structure of the experiments is summarized in Figure 1. Each consisted of six trials using the three different pairs of objects (two trials per pair, one with a one-object outcome and one with a two-object outcome). Each trial ended when the infant looked away for 2 consecutive seconds. In the two baseline trials, the experimenter placed either one or two puppets behind the occluder. The infant could not judge the number or the nature of what was placed behind the occluder. Next the occluder was removed, and looking time was monitored. Then, in four experimental trials, objects different from those that appeared in the baseline trials were placed behind the occluder; on each trial, one puppet emerged from and vanished behind it, and then a second puppet did the same. After the movements

ended, the experimenter surreptitiously removed one puppet from the stage in half of the trials. Finally, the occluder was removed, and looking behavior was monitored exactly as for the baseline trials.²

The procedure was identical in all four experiments, except for the orientation of the dolls' heads: In Experiments 1 and 2, they were always right-side-up, whereas in Experiments 3 and 4, they were always oriented differently (i.e., one right-side-up and the other upside-down).³

Results

We tested the looking-time data for an interaction among outcome (one or two objects), condition (baseline or test), and orientation

²We counterbalanced the order in which the puppet pairs were presented, the side on which the caregiver was seated, the order of the outcomes (number of objects: 211221 or 122112), and the position of the object when the occluder was removed in one-object trials (right or left).

³In the one-object outcomes, the head remaining on stage was right-side-up in half of the trials and upside-down in the remaining trials.

(both heads right-side-up or the two heads oriented differently). The logic of the analysis is as follows. If infants coded two puppets as different on the basis of their properties, then in the test phase the infants should have expected to find two objects behind the occluder and should have been surprised by the one-object outcomes. Therefore, looking time to one- and two-object outcomes should have changed from baseline to test, yielding an interaction between outcome and condition. If, instead, the differences between the heads were not sufficient for the infants to code two objects, looking time should not have changed significantly from baseline to test (Bonatti et al., 2002; Xu & Carey, 1996; Xu et al., 1999). However, if face inversion (but not face differences per se) changed infants' ability to individuate objects, the interaction should have occurred only when the infants saw one head right-side-up and the other upside-down, but not when they saw all heads right-side-up. Hence, our hypothesis predicted a triple interaction.

As no age difference was found, we pooled all participants together for analysis. The predicted triple interaction occurred, $F(1, 70) = 4.44, p \leq .039, \eta_p^2 = .06$. Although infants in all experiments looked longer at two-object outcomes than at one-object outcomes in baseline trials, as expected given the baseline selection criterion ($M_{two} - M_{one} = 0.42 \log s, p \leq 5^{-10}$, Bonferroni corrected), those who saw puppets with differently oriented heads (i.e., one right-side-up and one upside-down) in the test phase overcame the baseline preference for two objects (Figs. 2c and 2d; $M_{two} - M_{one} = 0.09 \log s$, n.s., Bonferroni corrected), but those who saw all heads right-side-up did not (Figs. 2a and 2b;

$M_{two} - M_{one} = 0.25 \log s, p \leq .0005$, Bonferroni corrected). Separate analyses by experiment confirmed that the outcome-by-condition interaction did not occur for 10- and 12-month-olds who saw heads right-side-up only (Experiments 1 and 2, respectively), $F(1, 17) = 2.64, p = .12, \eta_p^2 = .1$, and $F(1, 17) = 0.65, p = .43, \eta_p^2 = .03$, but this interaction did occur for those who saw heads oriented differently (Experiments 3 and 4, respectively), $F(1, 17) = 9.67, p \leq .0064, \eta_p^2 = .36$, and $F(1, 17) = 10.1, p \leq .0055, \eta_p^2 = .37$.

DISCUSSION

Our results show that a contrast between two different faces presented in different orientations is sufficient for both 10- and 12-month-olds to count two objects, but that when the same faces are both presented upright, the contrast between them is not sufficient for infants of these ages to count two objects. Indeed, when two faces have different orientations, infants succeed in individuating them at 10 months, an age when they generally fail to individuate objects on the basis of property contrasts, and when the faces have the same orientation, infants fail to individuate them at 12 months, an age when they generally succeed in similar tasks.

We interpret infants' success when one face was upright and the other inverted by postulating that the brain encodes upright and inverted faces differently. Such success strengthens the parallel between brain-activation data and infant-counting results. It was known that changing the directional properties of faces changes the response in the brain's face and object areas; we have now shown that changing the directional properties of faces also changes infants' abilities to count objects. Indeed, infants appear to treat inverted faces as objects, not as humans, as if they belonged to a different natural category.

It is even more surprising that although infants are attracted by faces from birth (Johnson & Morton, 1991) and can clearly distinguish different upright human faces at 6 months (Pascalis, de Haan, & Nelson, 2002), even as late as 12 months they fail to use these abilities to "count" two different objects. This suggests that infants respond first to faces as a category (Kanwisher, 2000; Tong et al., 2000), and not to subordinate-level distinctions among faces (Gauthier, Tarr, et al., 2000).

Still, what could explain this surprising failure to exploit information well within the reach of a 12-month-old? Magnetoencephalographic (MEG) and ERP evidence in humans (Bentin & Deouell, 2000; Eimer, 2000; Liu, Higuchi, Marantz, & Kanwisher, 2000) and single-neuron recordings in monkeys (Sugase, Yamane, Ueno, & Kawano, 1999) suggest that face processing has a temporal course. The brain first encodes the categorical facelike nature of the stimulus, and only later the differences between faces. Possibly, then, the immature brain assigns indexes for object tracking on the basis of the first signal allowing category discrimination, and subsequent encoding of face differences cannot modify index assignments.

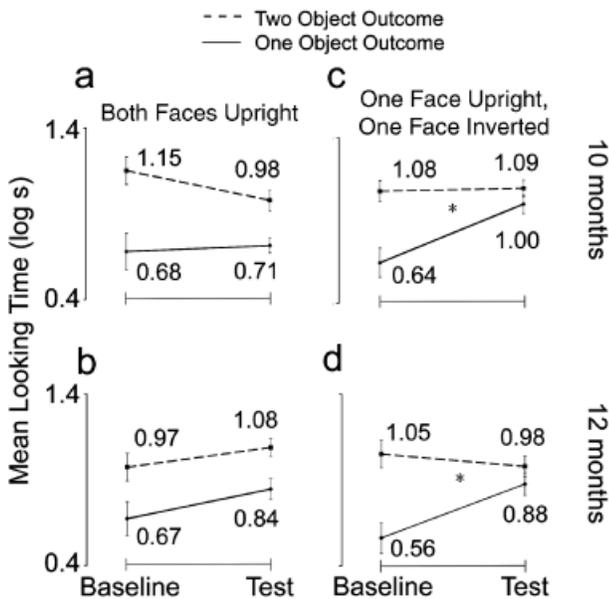


Fig. 2. Results of the four experiments, showing average looking time (log seconds) for 10-month-olds (a) and 12-month-olds (b) looking at puppets with upright faces (Experiments 1 and 2) and 10-month-olds (c) and 12-month-olds (d) looking at puppets with differently oriented faces (Experiments 3 and 4; $n = 18$ in all experiments) after removal of the occluder. Asterisks indicate significant interactions between outcome (one or two objects) and condition (baseline or test). Bars represent standard errors of the means.

Another possibility is that early counting by properties does not involve any implicit or explicit counting. The increase in looking time at a “surprising” scene may be a by-product of the activation of brain networks maximally responsive to properties of natural classes. When properties in a scene activate distinct networks, the disappearance of one of those properties from the scene creates a mismatch between the state of the brain and the state of the world. Increased looking at a surprising scene may be the result of such a mismatch, as if an active brain network were waiting for its matching, but absent, stimulus. Such a hypothesis is consistent with recent findings that surprise at the absence of an expected object after removal of an occluder increases gamma-band activity in infants (Kaufman, Csibra, & Johnson, 2003).

In either case, our results show that before the age of 1 year, a template of the human face has a functional role in object individuation. For infants, faces are not only interesting stimuli, but also instruments for sorting humans from other things. Although our results cannot be used to assess whether such a functional role depends on a special face mechanism (Kanwisher et al., 1997), expertise (Gauthier, Skudlarski, Gore, & Anderson, 2000), or a combination of both (Johnson & Morton, 1991), they do show that any expertise integrates with higher cognitive functions early in development.

Acknowledgments—The present work was supported by a Friuli Venezia Giulia Research Grant. L.L.B. conceived the experiments with J.M. and E.F., carried them out and analyzed them with E.F., and wrote the article. We thank James Cutting and Susan Carey for insightful comments on the first draft and Michele Nathan for her careful reading of the final manuscript.

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(RECEIVED 11/24/03; REVISION ACCEPTED 5/24/04)