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Gaze Following in Newborns

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Eye gaze has been shown to be an effective cue for directing attention in adults. Whether this ability operates from birth is unknown. Three experiments were carried out with 2- to 5-day-old newborns. The first experiment replicated the previous finding that newborns are able to discriminate between direct and averted gaze, and extended this finding from real to schematic faces. In Experiments 2 and 3 newborns were faster to make saccades to peripheral targets cued by the direction of eye movement of a central schematic face, but only when the motion of the pupils was visible. These results suggest that newborns may show a rudimentary form of gaze following.

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A number of studies have underlined the importance of gaze as a social cue for the understanding of human behavior. The sensitivity to a conspecific's eyes is highly adaptive (Baron-Cohen, 1995; Langton, Watt, & Bruce, 2000), and for this reason the special significance of gaze could have its roots very early in life. Infants as young as 2 months old are able to discriminate human facial features and show preferential attention to eyes over other components of the face (Hains & Muir, 1996; Lasky & Klein, 1979; Maurer, 1985). With regard to newborns, Freedman (1974) reported on a study by Jirari (1970) that showed that they prefer to follow a face containing six eyes than a face containing only two eyes. Batki, Baron-Cohen, Wheelwright, Connellan, and Ahluwalia (2000) demonstrated that newborns spend significantly more time looking at face with eyes open than at the same picture with the eyes closed. Most recently, we showed that newborn infants prefer to look at faces that engage them in mutual gaze and that, at least by 4 months of age, healthy human infants showed enhanced neural processing of mutual gaze (Farroni, Csibra, Simion, & Johnson, 2002). We concluded that there is sensitivity to eye contact from birth, and suggested that this is a vital foundation for later social development.

These studies show sensitivity to eye gaze from birth, but a further question about infants' sensitivity to eye gaze is whether they are able to use direction of eye gaze to influence their own behavior. Hood, Willen, and Driver (1998) showed in a group of infants ranging in age from 10 to 28 weeks that the perception of an adult's deviated gaze induces shifts of attention in infants in the corresponding direction. In their experiments they modified the standard Posner cuing paradigm (Posner, 1980) using as a central cue the direction of gaze of a woman's face, thus creating a computer-generated eye gaze shift. The reaction time to make a saccade to a peripheral target was measured under conditions in which the location of the target was either congruent or incongruent with the direction of gaze of a centrally presented face. Whether this result was specific to the eyes remains an open question. It is possible that certain properties of the eyes, which are also shared with other stimuli, are important to shift infants' attention. Recently, the perceptual basis of the mechanism that triggers an attention shift following perceived gaze was studied with the idea that human eyes have a unique morphology compared to other species (Kobayashi & Kohshima, 1997). Following this hypothesis, the eyes are special not because of the existence of a specialized mechanism, but because of their physical properties. For example, Ricciardelli, Baylis, and Driver (2000) showed that the contrast polarity of perceived eyes has a strong influence on gaze perception. Adult observers are significantly worse in judging gaze direction for images of human eyes with negative than with positive contrast polarity, even though negative images of eyes preserve the geometric properties of the eyes.

Motion is another important property of the eyes. Kobayashi and Kohshima (1997) concluded that because of the large ratio of exposed sclera in the eye outline, the movement of the pupils is enhanced, making it easier to detect the gaze direction of another individual. In a follow-up study to Hood et al. (1998), the results of Farroni, Johnson, Brockbank, and Simion (2000) supported the hypothesis that it is the motion of the pupils that directs 4-month-old infants' attention. Saccadic reaction times to look at a target were faster when the target appeared in the cued location than when it appeared in the opposite side, but only when the motion of the pupils was perceived. The lack of a congruency effect when the movement of the pupils was not visible suggests that the direction of the eyes per se does not have an effect in directing infant's attention. Although motion is an important cue for infants, it may become less important during development, such that in adults static presentation of averted gaze is sufficient for cuing. If this developmental trajectory is valid, it raises the further question of what cues, if any, can be used by newborns. We know that newborns prefer to look at the higher contrast part of the stimulus (Morison & Slater, 1985), in which case they could follow the dark pupils even when their movement is not visible. The question of whether or not dynamic gaze stimuli, with visible motion of the pupils, is necessary to detect the direction of gaze, and thus cue attention, is ripe for investigation. To answer this question a series of three experiments were carried out with newborns using schematic faces as stimuli to guarantee the best visibility of the eyes inside a high-contrast face stimulus.

We already know that babies are sensitive to direct versus averted gaze in realistic photographs (Farroni et al., 2002), but we do not yet know if they are able to make the same discrimination when the faces are schematic. The first experiment was run to investigate this question. The second experiment was carried out to test if gaze direction of a perceived face can be used as a cue in newborns' orienting when the movement of the pupil is visible. Finally, a third experiment was carried out to test the hypothesis that the newborn's ability to orient to another's gaze is dependent on the perceived movement of pupils.

EXPERIMENT 1

Recently, Farroni et al. (2002) showed that newborns looked significantly more at a face with direct gaze than at a face with averted gaze. The purpose of this experiment was to replicate the study of Farroni et al. and to extend the result to schematic face stimuli. Direct and averted gaze in schematic faces were compared by using the visual preference method with paired stimulus presentation.

Method

Participants. Twenty-six normal, healthy, full-term newborns were selected from the maternity ward of the Pediatric Clinic of the University of Padua. Three babies were excluded from the final sample for various reasons. One changed state during the experiment, and two babies showed a strong side bias (they turned more than 85% of the time in one direction).

The 23 babies that completed the study met the screening criteria of normal delivery, a birth weight between 2,600 g and 4,000 g, and an Apgar score of at least 8 at 5 min. All were healthy and free of any known neurological or ocular abnormality. They were tested after the first 24 hr of life, the range of ages at time of test being from 24 to 120 hr postnatal ($M = 72$ hr). The testing took place during the hour preceding the scheduled feeding time, if the baby was awake and in an alert state. Informed consent was obtained from the parents.

Apparatus and stimuli. The infants sat on the adult's lap 30 cm distant from a translucent screen. The baby holder was not actively involved in the experiment, was unaware of the hypothesis being tested in the experiment, and was not one of the authors. The newborn's eye level was aligned to the center of the screen at the same level as the eyes of the schematic face. A video camera focused on the infants' face, allowing the experimenter to monitor their eye movements. Infants were shown two pictures of the same schematic face, one on the right and one on the left of the center of the screen. One of the faces had direct gaze and the other had averted gaze (left or right; see Figure 1). The faces subtended a visual angle of 41.0° × 31.5° and the external contour of the eyes 9.5° × 11.5° (e.g., life-size as viewed from 30 cm distance). The two stimuli were 8.5 cm apart. Every trial began with a center red flickering light-emitting diode (LED). The LED subtended a visual angle of 3° and, when turned on, blinked at a rate of 300 msec on and off. Spatial frequency composition in the eye regions was measured to confirm there was no significant difference in the energy between the two stimuli.

Procedure. Once the newborn was seated in front of the screen, as soon as she or he fixated the central LED, the experimenter (who watched the newborn's eyes via a video monitor system) initiated a trial and presented the faces on the screen. The faces remained on for as long as the infant fixated one of them (infant control procedure). When the infants shifted their gaze away from the display for more than 10 sec, the experimenter removed the faces and the center LED was turned on. In the next trial the location of the direct and averted gaze faces was re-

FIGURE 1 Example of stimuli presented in Experiment 1 during the preference task.

versed. Two trials were presented to the newborn with one left-to-right reversal. This procedure has previously been used with newborns (e.g., Valenza, Simion, Macchi Cassia, & Umiltà, 1996). Two pseudorandom presentation sequences were used in which half of the infants saw gaze averted to the right and half to the left. Videotapes of the baby's eye movements throughout the trial were subsequently analyzed by two coders blind to the location of direct and averted gaze faces. The coders recorded, separately for each stimulus and each trial, the number of orienting responses and the total fixation time (interrater reliability for 10% of the total participants, Cohen's $\kappa = 0.88$ for the duration of fixation and 0.99 for the number of orientations). The coders could see the corneal reflection of the stimulus face (to help establish fixation), but they could not see the details of the face and they were blind to the direction of the gaze.

Results

Preliminary statistical analyses showed no effects of stimulus order, averted gaze direction, or interactions between these factors. As a consequence, data for each condition (straight vs. averted gaze) were collapsed across these other factors.

Two separate parametric tests were performed to compare the average total fixation time for each stimulus (straight gaze vs. averted gaze) and the number of orientations in direction of each stimulus (see Table 1 for details). To avoid violating homogeneity of variance, all looking durations were logarithmically transformed for analysis. Newborns showed significantly greater total looking time at the straight gaze ($M = 132.3$ sec) than at the averted gaze ($M = 101.5$ sec), $t(23) = 2.2$, $p = .037$, but they did not orient more frequently to the direct gaze face ($M = 14.0$) than to the other ($M = 13.8$).

Discussion

Experiment 1 partially replicated the study of Farroni et al. (2002), but with schematic faces. The results demonstrated that newborns are able to discriminate the direction of gaze of a schematic face, and they prefer to look at direct rather than averted gaze. On initial consideration our results appear to confirm the proposal that there is a specific mechanism for detecting and perceiving the direction of eye gaze present from birth (Baron-Cohen, 1994). However, we believe that our results are also consistent with other interpretations. One alternative possibility is that spatial frequency differences around the eye regions are important. This seems unlikely because facial frequencies analysis of the all stimulus show only minor differences. Another possibility is that newborns preferentially attend more to the stimulus that is more similar to the general spatial arrangement of a face (Farroni et al., 2002; Johnson & Morton 1991). According to Johnson and Morton, subcortical circuits are activated by a primitive representa-

TABLE 1
Data Description of Experiment 1

Participant	Direct		Averted		Direct First Presentation		Averted First Presentation		Direct Second Presentation		Averted Second Presentation	
	Gaze (Sec.)	*No. of Trials*	*Gaze (Sec.)*	*No. of Trials*	*Gaze (Sec.)*	*No. of Trials*	*Gaze (Sec.)*	*No. of Trials*	*Gaze (Sec.)*	*No. of Trials*	*Gaze (Sec.)*	*No. of Trials*
1	64.86	8	187.12	14	20.88	2	91.60	6	43.98	6	95.52	8
2	126.14	13	71.54	11	84.70	3	33.02	4	41.44	8	38.52	9
3	79.66	2	68.08	4	71.76	1	50.04	3	7.90	1	18.04	1
4	35.24	5	29.76	5	18.76	3	22.00	4	11.00	2	16.48	1
5	188.26	21	68.52	10	172.76	16	41.78	2	15.50	5	26.74	8
6	207.30	10	176.50	12	145.94	6	52.22	4	61.36	4	124.28	8
7	148.66	24	104.30	21	108.42	11	27.16	9	40.24	13	77.14	12
8	128.58	18	58.54	19	36.34	7	35.52	8	92.24	12	23.02	10
9	100.14	11	65.02	6	52.88	7	13.44	2	47.26	4	51.58	4
10	52.96	15	185.66	27	9.42	6	132.52	19	43.54	9	53.14	8
11	127.84	7	198.62	27	92.22	6	147.32	24	35.62	1	51.30	3
12	64.78	8	84.82	16	34.14	5	61.40	10	30.64	3	23.42	6
13	153.92	10	42.92	6	65.94	4	42.24	5	87.98	6	0.68	1
14	167.92	2	166.50	12	131.90	1	88.24	6	36.02	1	78.26	6
15	169.49	20	50.80	12	78.72	7	30.88	7	90.77	13	19.92	5
16	136.80	13	132.08	17	32.46	5	96.52	11	104.34	8	35.56	6
17	87.86	28	94.34	31	65.76	15	31.22	16	22.10	13	63.12	15
18	110.10	26	53.60	13	37.70	14	13.76	5	72.40	12	39.84	8
19	244.16	19	91.40	13	75.98	9	41.14	8	168.18	10	50.16	5
20	158.94	22	78.64	14	100.48	13	11.32	6	58.46	9	67.32	8
21	162.34	25	53.26	15	104.92	14	3.38	2	57.42	11	49.88	13
22	132.24	6	94.26	4	82.76	3	41.3	1	49.48	3	52.96	3
23	195.26	9	178.24	9	68.76	2	24.12	2	126.50	7	154.12	7
M	132.3	14.0	101.5	13.8	73.6	7.0	49.2	7.1	58.5	7.0	52.7	6.7
SE	11.0	1.6	11.2	1.5	8.7	1.0	7.9	1.2	8.1	0.9	7.5	0.8

tion of high-contrast elements relating to the location of the eyes and mouth (Conspec). A face with direct gaze may fit the spatial relation of elements in this template better than a face with gaze averted to the right or left. Clearly experiments need to be done to determine the basis of this preference in newborns. The next question that we investigated was whether eye gaze influences the direction and speed of newborns' eye movements.

EXPERIMENT 2

Farroni et al. (2000) used a real face image to demonstrate that an adult's averted gaze can induce shifts of attention in the corresponding direction because the direction of eye gaze can be used as an attentional cue. Their results showed that 4-month-old infants oriented more rapidly toward the location where the face stimulus looked (see also Hood et al., 1998). The purpose of Experiment 2 was to investigate whether the direction of gaze of a stimulus face can be used as a cue from birth. The procedure used was similar to that used in Experiment 1 of Farroni et al., with the only differences being that the stimulus face was schematic, and that the target was a dynamic bull's-eye pattern instead of different cartoons. The reason for these changes was to increase visibility of the stimuli to that most appropriate for newborn acuity.

Method

Participants. Fifty normal, healthy, full-term newborns were selected from the maternity ward of the Pediatric Clinic of the University of Padua. Thirteen babies were excluded from the final sample for various reasons. Twelve failed to complete testing due to a state change (they became too fussy or too drowsy, either just before the experiment began or during the experiment). With 1 baby, a technical error occurred. The 37 babies that completed the study met the screening criteria of normal delivery, a birth weight between 2,600 g and 4,000 g, and an Apgar score of at least 8 at 5 min. All were healthy and free of any known neurological or ocular abnormality. They were tested after the first 24 hr of life, the range of ages at time of test being from 24 to 120 hr postnatal (M = 72 hr). The testing took place during the hour preceding the scheduled feeding time, and if the baby was awake and in an alert state. Informed consent was obtained from the parents.

Apparatus and stimuli. The apparatus was the same as in Experiment 1. Newborns viewed a schematic face, which first blinked its eyes (switching between two video frames every 500 msec) and then looked either to the right or to the left. The gaze shift was followed by a peripheral target, a flickering bull's-eye, which appeared either on the same side as the stimulus gaze (congruent) or in the

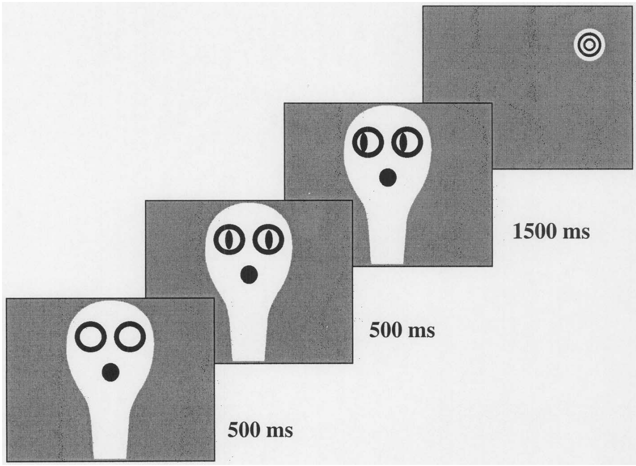

FIGURE 2 A schematic illustration of the sequence of events on a target trial (incongruent condition) in Experiment 2. Time extends from bottom to top.

opposite direction (incongruent; see Figure 2). The face-stimulus size was the same as in the previous experiment and the target was presented at 16.7° of eccentricity from the center of the screen.

Newborns were exposed to a pseudorandom sequence of trials with the target appearing equally often to the right and left with the proviso that there were no more than three consecutive trials in which the target appeared on the same side. In half of the trials the target appeared on the same side as the direction of eye gaze (congruent condition), and in half the direction of eye gaze and target location were opposite (incongruent condition).

Procedure. The procedure used was similar to that in Farroni et al. (2000). After the newborn was seated in front of the screen the testing session began with the presentation of a central schematic face blinking its eyes to capture the newborn's attention. As soon as the newborn fixated this stimulus, the experimenter (who watched the newborn's eyes via a video monitor system) initiated a trial by pressing a button. Trials began with the eyes of the stimulus face opened for 200 msec, before the pupils shifted either to the right or to the left (3° of visual angle, switching between two video frames created the illusion of movement) and remained oriented for a further 1,500 msec. After this period of averted gaze the face disappeared, and simultaneously a peripheral target was presented until the baby initiated an eye movement to either the congruent or incongruent location. Following this, a new trial was started by the reappearance of the blinking face. Each newborn viewed at least four trials of each type (congruent and incongruent).

Data analysis. Videotape of eye movements throughout the experiment was analyzed by two coders (using a video recorder and time code with half-frames) unaware of the trial type. They coded the onset and the direction of each saccade made by the participant after the cue onset (interrater reliability for the 10% of the total participants, Cohen's $\kappa = 0.85$ for the latency of saccades and 0.98 for the direction). Overall, 946 trials ($M = 25.6$ per newborn) were run, but 604 trials (64% of the total) were considered not scoreable. This was because (a) the baby was not central when the cue appeared (369 trials; 39%), (b) the baby was not central when the target appeared (217 trials; 23%), (c) the baby closed its eyes before the peripheral target was presented (10 trials), or (d) there was no eye movement to the target (8 trials). For the remaining 342 scoreable trials, the latencies (reaction times [RTs]) were measured by the half-frame (20 msec) from the video-recorded tapes and classified as target-driven saccades. These saccades occur at least 200 msec after the onset of the peripheral target (saccades with latencies under 200 msec are considered too fast to be target related; Haith, Hazan, & Goodman, 1988). If a newborn was not centered when the target appeared, the trial was coded as invalid.

Only the trials in which saccades were made directly to the target were included in the subsequent reaction time analyses. Saccades made to other locations were not included. To avoid violating homogeneity of variance, all latencies were logarithmically transformed for analysis. Of the scoreable trials for which reaction time was measured, 51% were for the congruent condition.

To examine any direct effects of the motion of the pupils of the schematic face on saccades made by the watching newborns, saccades made just after the onset of the averted gaze and before the appearance of the target were recorded and defined as cue-driven saccades. These saccades occurred during the interval between the onset of the gaze shift and 200 msec after the presentation of the target. They were compared to the saccades that occurred in the same interval but in the opposite direction. The rationale in recording these saccades was to examine the extent to which shifts of gaze in a schematic face directly elicit saccades in newborn viewers (see Table 2 for data details).

Results

Target-driven saccades. The average saccadic RT to respond to the target was calculated for each participant for the two conditions (congruent vs. incongruent). Saccades were faster in the congruent than in the incongruent condition, $t(36) = 2.25$, $p = .03$ ($M = 1{,}131$ msec, $SE = 68.17$, and $M = 1{,}327$ msec, $SE = 89.59$, respectively). This result shows that newborns are faster to make saccades to peripheral targets cued by the direction of eye gaze of a central face.

Cue-driven saccades. Overall, 339 saccades were made in total (195 in the cue direction and 144 in the opposite direction). Average number of saccades was

TABLE 2
Data Description of Experiment 2

	No. of Trials			Congruent		Incongruent			Cue-Driven to Cue		Cue-Driven Opposite	
Participant	*Submitted*	*Scoreable*	*% Valid*	*n*	*M RT*	*n*	*M RT*	*No. of Errors*	*n*	*M*	*n*	*M*
1	25	12	48.0	3	1,026.7	6	833.3	3	7	722.9	3	353.3
2	30	16	53.3	10	1,228.0	3	846.7	3	4	720.0	10	672.0
3	22	16	72.7	7	854.3	9	706.7	0	0	nc	1	nc
4	27	10	37.0	4	960.0	4	1,085.0	2	5	400.0	10	420.0
5	26	11	42.3	4	950.0	5	700.0	2	7	268.6	6	413.3
6	32	9	28.1	5	784.0	4	1,315.0	0	11	698.2	7	580.0
7	24	12	50.0	5	2,056.0	6	3,500.0	1	5	353.3	3	626.7
8	19	8	42.1	3	2,466.7	2	1,680.0	3	6	620.0	0	nc
9	23	8	34.8	3	513.3	4	1,290.0	1	6	780.0	3	393.3
10	15	6	40.0	2	1,330.0	3	933.3	1	5	600.0	2	830.0
11	22	9	40.9	6	1,403.3	3	1,486.7	0	7	331.4	5	544.0
12	20	13	65.0	4	805.0	4	680.0	5	3	366.6	1	nc
13	28	13	46.4	6	830.0	5	1,264.0	2	4	415.0	4	275.0
14	31	13	41.9	6	1,156.7	6	1,470.0	1	11	549.1	3	573.3
15	25	5	20.0	2	1,490.0	2	1,250.0	1	9	451.1	6	593.3
16	27	10	37.0	3	973.3	6	1,330.0	1	4	560.0	6	656.7
17	25	6	24.0	2	1,260.0	2	1,260.0	2	4	825.0	3	413.3
18	20	6	30.0	2	1,070.0	3	1,520.0	1	2	620.0	6	473.3
19	31	7	22.6	2	1,970.0	2	930.0	3	5	248.0	4	635.0

20	29	7	24.1	3	720.0	2	780.0	2	3	406.7	3	646.7
21	28	9	32.1	3	800.0	4	2,065.0	2	2	640.0	2	770.0
22	29	9	31.0	3	633.3	5	1,304.0	1	6	436.7	3	493.3
23	18	6	33.3	2	1,040.0	2	1,460.0	2	3	493.3	3	220.0
24	41	17	41.5	10	1,118.0	4	1,090.0	3	9	615.6	8	312.5
25	29	8	27.6	3	1,193.3	3	1,920.0	2	7	440.0	7	320.0
26	34	10	29.4	4	1,430.0	3	1,080.0	3	5	832.0	8	930.0
27	26	8	30.8	3	860.0	4	915.0	1	5	108.0	0	nc
28	27	8	29.6	3	733.3	4	1,115.0	1	4	405.0	3	580.0
29	20	5	25.0	3	1,186.7	2	2,260.0	0	7	488.6	2	220.0
30	26	8	30.8	2	980.0	6	2,303.3	0	6	593.3	4	415.0
31	16	12	75.0	4	1,655.0	3	1,393.0	5	1	nc	1	nc
32	18	5	27.8	3	686.7	2	1,280.0	0	6	753.3	2	550.0
33	20	6	30.0	2	760.0	2	1,040.0	2	1	nc	0	nc
34	28	7	25.0	3	1,413.3	3	1,593.3	1	3	600.0	3	933.3
35	31	7	22.6	4	885.0	3	1,140.0	0	10	410.0	7	617.1
36	25	10	40.0	3	1,286.7	3	953.3	4	7	442.9	2	690.0
37	29	10	34.5	4	1,335.0	4	1,325.0	2	5	528.0	3	953.3
Total	946	342	1,366.2	141	41,843.6	138	49,097.6	63	195	17,722.6	144	17,104.0
M	25.6	9.2	36.9	3.8	1,130.9	3.7	1,327.0	1.7	5.3	521.2	3.9	551.7
SE			2.1	0.3	414.7	1.6	544.9	1.33	0.4	29.4	0.4	36.0

Note. RT = reaction time; nc = XXXXX.

calculated for each participant before the target appearance to compare the number of saccades directed to the same direction of the cue to the number of saccades in the opposite direction. A paired *t* test revealed a highly significant difference, $t(36) = 2.84$, $p < .007$, between the mean number of saccades in the direction of the cue and opposite to the cue ($M = 5.3$, $SE = 2.6$, and $M = 3.9$, $SE = 2.6$, respectively).

This result showed that newborns oriented more frequently toward the direction where the stimulus face looked before target presentation. Because participants contributed different numbers of cue-driven saccades, the percentage of eye movements made to the cue side was compared to chance. A *t*-test analysis confirmed a significant difference, $t(36) = 2.63$, $p = .01$ ($M = 58.7$ vs. $M = 41.2$; $SE = 3.3$). No difference in the average RT of the saccades toward the cue or opposite was found (both with a mean latency of 500 msec).

Discussion

The results of Experiment 2 are consistent with the hypothesis that gaze cuing can be elicited shortly after birth. The analysis of the target-driven saccades shows that newborns are faster to make saccades to a peripheral target cued by the direction of eye gaze of a central face. This result replicates previous findings (Farroni et al., 2000; Hood et al., 1998) obtained with older infants, and shows that in newborns the direction of eye gaze produces a spatial cuing effect. However, because newborns' saccadic reaction time is much slower than that in older infants, it could be argued that the target-driven effect merely results from late cue-driven saccades. Analysis of the cue-driven saccades revealed more frequent saccades in the direction of the cue than saccades in the opposite direction. This result shows following of the cue before the target appearance. Therefore, the target-driven effect could potentially have been caused by the cue-driven one. For this reason we analyzed the frequency distribution with all the raw data to ensure that the target-driven saccades were not, in fact late cue-driven saccades (see Figure 3). This analysis revealed a clear bimodal distribution due to separate effects of the cue and the target.

EXPERIMENT 3

Like older infants, newborns are sensitive to motion, and gaze cuing effects could be due to a strong sensitivity to the direction of movement of the pupils, rather than to their processing of the final position of averted gaze (see Farroni et al., 2000). Thus, the results obtained in Experiment 2 could be due not to perceived eye direction, but to motion, suggesting that the basis for eye gaze cuing from birth could be cuing by direction of motion. Alternatively, the higher contrast part of the stimulus may be crucial for newborns, in which case they could follow the dark pupils even when movement is not visible. The third experiment was carried out to investigate

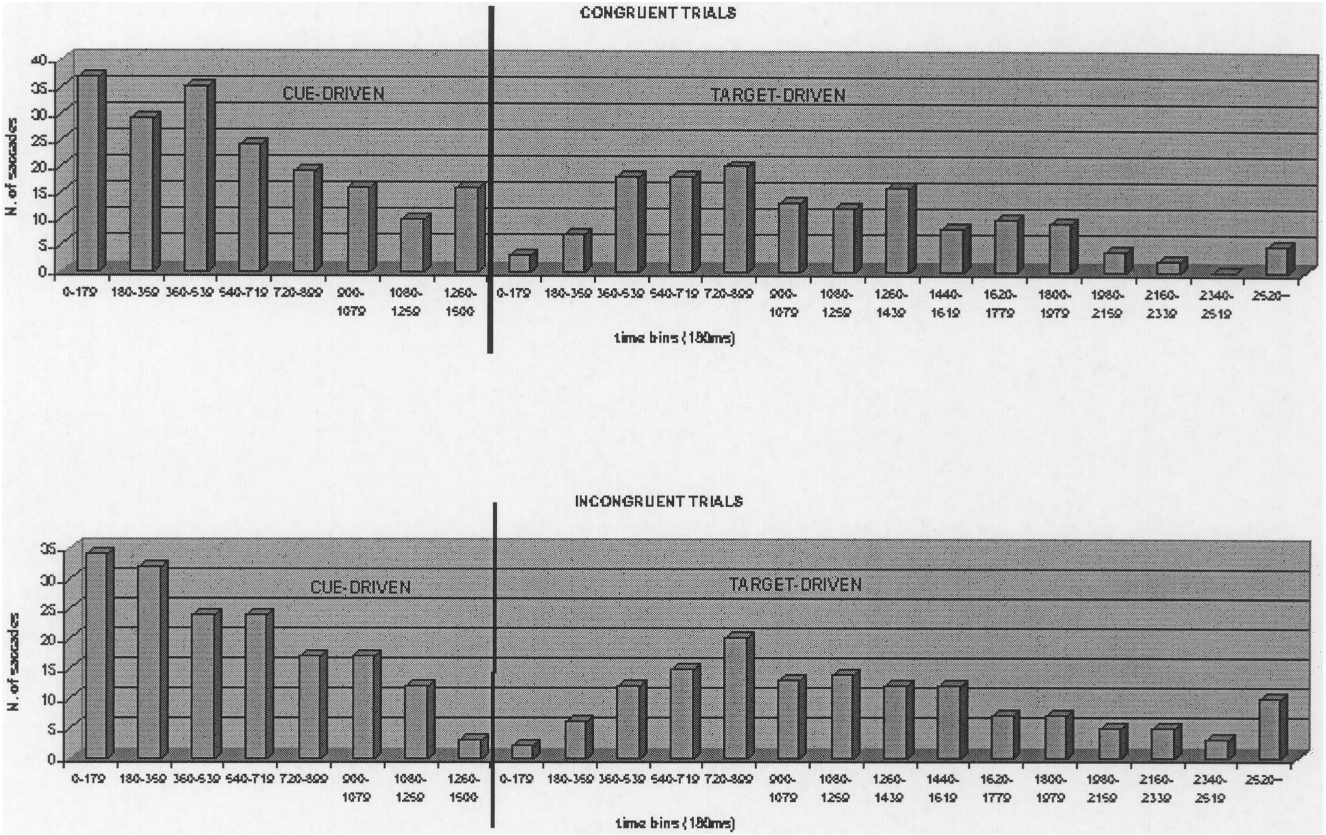

FIGURE 3 Number of saccades in 180-msec time bins for all 37 participants over the whole trial in the congruent and incongruent condition in Experiment 2. The left-hand side of the figure shows the number of saccades before target presentation. The right-hand side shows those recorded after target presentation.

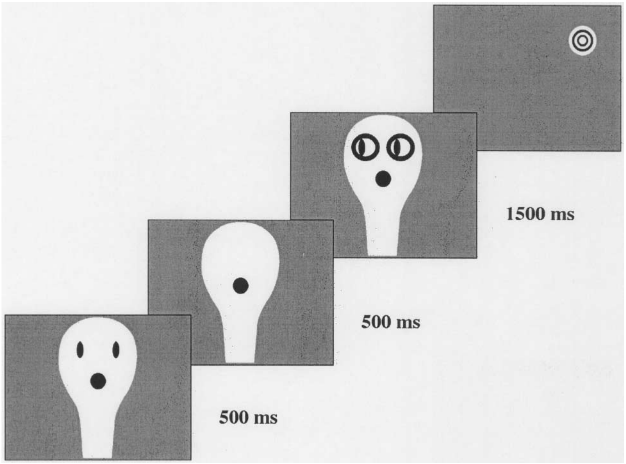

FIGURE 4 A schematic illustration of the sequence of events in a trial (incongruent condition) in Experiment 3. Time extends from bottom to top.

these hypotheses. Specifically, we sought to determine whether when the motion of the pupils is not available as a cue, gaze direction can still cue orienting.

In this experiment, the (apparent) movement of the pupils was not visible due to the following sequence of events. At the start of the trial, during the pupils' blinking cycle to attract the baby's attention, the eyes appeared without the contour of the sclera so that just the pupils appeared to blink (see Figure 4). The rationale for removing the sclera was to avoid any possible perception of movement of the pupils. In Farroni et al. (2000), Experiment 3, the averted gaze was presented immediately after the eyes-closed part of the cycle. They also used a longer eyes-closed part (1,000 msec) of the blinking cycle so that when the eyes opened, they were already looking left or right, and there was no apparent movement of the pupils. With schematic images it was not possible to use the same procedure used as in Farroni et al. The only way to avoid the illusion of the motion of the pupils was to remove the surrounding frame (the sclera).

Method

Participants. Fifty normal, healthy, full-term newborns were selected from the maternity ward of the Pediatric Clinic of the University of Padua. Twenty-two babies were excluded from the final sample for various reasons. Fifteen changed state just before the experiment began, or during the experiment, and did not revert to an awake state within a reasonable amount of time. For 7 babies, a technical error occurred.

The 28 babies that completed the study met the screening criteria of normal delivery, a birth weight between 2,600 g and 4,000 g, and an Apgar score of at least 8 at 5 min. All were healthy and free of any known neurological or ocular abnormality. They were tested after the first 24 hr of life, the range of ages at time of test being between 24 and 120 hr postnatal. The testing took place during the hour preceding the scheduled feeding time, if the baby was awake and in an alert state. Informed consent was obtained from the parents.

Apparatus and stimuli. The apparatus and the procedure were the same as in Experiment 2. The only difference was that newborns were shown an image of a schematic face, which first blinked (its pupils appear and disappear) and then shifted gaze either to the right or to the left. This was followed by a peripheral target, a flickering bull's-eye, which appeared either to the same side where the face looked (congruent) or in the opposite direction (incongruent; see Figure 4). The stimulus and target size were the same as described in Experiments 1 and 2. Newborns were exposed to a pseudorandom sequence of trials with the target appearing equally often to the right and left, with the same restrictions as in Experiment 2. Half of the trials were congruent and half were incongruent.

Data analysis. Overall, 882 trials (M = 31.5 trials per newborn) were run, but 638 (72% of the total trials) were considered nonscoreable because (a) the baby was not central when the cue appeared (390 trials; 44%), (b) the baby was not central when the target appeared (234 trials; 26%), (c) the baby closed its eyes before the peripheral target was presented (13 trials), or (d) there was no eye movement to the target (1 trial). Videotape of eye movements throughout the experiment was analyzed by two coders unaware of the trial type (interrater reliability for 10% of total participants, Cohen's $\kappa = .80$ for the latency of saccades and .97 for the direction). Of the scoreable trials for which reaction time was measured, 55% were for the congruent condition (see Table 3 for data details).

Results

Target-driven saccades. The average saccadic RT was calculated for each participant for the two conditions (congruent vs. incongruent). A paired t-test analysis was conducted and no difference between congruent and incongruent saccades was found, $t(27) = 0.32$, $p = .75$. Newborns are not faster to make saccades to a peripheral target cued by the direction of eye gaze of a central face (M = 1,103 msec, SE = 107.28, in the congruent trials; M = 1,057 msec, SE = 94.29, in the incongruent trials).

To compare the effects in Experiments 2 and 3, a repeated measures multivariate analysis of variance was performed, with the between-subject factor of Experiment (2 or 3), and the within-subjects factor of condition (congruent or

TABLE 3
Data Description of Experiment 3

	No. of Trials			*Congruent*		*Incongruent*			*Cue-Driven to Cue*		*Cue-Driven Opposite*	
Participant	*Submitted*	*Scoreable*	*% Valid*	*n*	*M RT*	*n*	*M RT*	*No. of Errors*	*n*	*M*	*n*	*M*
1	24	4	16.7	2	850.0	2	930.0	0	5	404.0	2	300.0
2	28	7	25.0	2	420.0	3	1,020.0	2	5	672.0	5	724.0
3	40	10	25.0	5	992.0	2	660.0	3	9	604.4	6	456.7
4	30	10	33.3	2	1,050.0	3	426.7	5	7	142.9	8	300.0
5	32	6	18.8	3	1,680.0	2	1,550.0	1	5	296.0	7	402.9
6	47	4	8.5	2	490.0	2	1,080.0	0	3	73.3	10	380.0
7	37	8	21.6	2	690.0	4	1,650.0	2	3	613.0	15	525.0
8	27	8	29.6	4	1,460.0	4	665.0	0	11	634.5	3	526.7
9	28	4	14.3	2	220.0	2	1,380.0	0	4	655.0	6	456.7
10	25	8	32.0	3	980.0	2	960.0	3	10	296.0	3	640.0
11	32	8	25.0	2	320.0	3	1,553.0	3	8	787.5	7	314.0
12	37	10	27.0	3	1,373.0	5	1,056.0	2	13	329.0	8	282.5
13	43	8	18.6	2	1,200.0	3	1,080.0	3	10	406.0	9	420.0
14	27	8	29.6	2	1,250.0	2	730.0	4	8	527.5	3	586.7

15	25	7	28.0	3	573.0	2	1,380.0	2	5	520.0	2	590.0
16	20	5	25.0	3	1,560.0	2	810.0	0	7	446.0	2	230.0
17	23	8	34.8	3	2,107.0	3	1,033.0	2	6	643.0	5	660.0
18	39	11	28.2	4	1,695.0	3	1,420.0	4	4	285.0	7	151.0
19	31	6	19.4	2	940.0	3	980.0	1	7	231.0	2	720.0
20	31	6	19.4	3	1,320.0	2	1,170.0	1	12	703.0	3	453.0
21	46	23	50.0	10	1,188.0	6	2,366.7	7	9	593.3	10	838.0
22	25	6	24.0	2	700.0	2	310.0	2	8	455.0	5	328.0
23	40	5	12.5	2	2,480.0	2	250.0	1	8	480.0	7	280.0
24	30	6	20.0	3	2,033.3	2	2,060.0	1	5	576.0	5	532.0
25	25	7	28.0	2	530.0	3	400.0	2	10	428.0	6	893.3
26	19	7	36.8	4	1,385.0	2	1,090.0	1	7	386.0	3	320.0
27	42	8	19.0	2	540.0	3	1,040.0	3	11	309.0	12	545.0
28	29	13	44.8	4	860.0	3	553.3	6	4	530.0	4	420.0
Total	882	221	714.9	83	30,886.3	77	29,603.7	61	204	13,026.5	165	13,275.4
M	31.5	7.7	25.0	3.0	1,103.0	2.8	1,057.3	2.2	7.3	465.2	5.9	474.1
SE			1.7	0.3	107.2	0.2	94.3	0.3	0.5	33.3	0.6	34.9

Note. RT = reaction time.

incongruent). To avoid violating homogeneity of variance, all latencies were logarithmically transformed for analysis. Neither the condition main effect, $F(1, 63) = 0.71$, $p = .40$, nor the interaction between experiment and condition, $F(1, 63) = 1.2$, $p = .28$, were significant, whereas the between-subject factor of experiment showed a significant effect, $F(1, 63) = 5.96$, $p = .02$. This result shows that in Experiment 3 newborns were faster overall than in Experiment 2 (M = 1,080, SE = 100.78 vs. M = 1,228, SE = 78.88). Two subsequent separate analyses of variance between experiments were done on congruent and incongruent RTs, reavealing a significantly longer RT for the incongruent response in Experiment 2 than in Experiment 3, $F(1, 63) = 4.2$, $p = .04$. One interpretation of this result is that to make a saccade in the opposite direction of the cue in the first experiment represents a cost for the newborns. The same analysis with 4-month-old infants (Farroni et al., 2000) gave the same result. In Farroni et al., for the comparison between the experiment with the visible movement of the pupils and the one in which the movement was not present, the between-subject factor of experiment was significant due to RTs in the incongruent trials being significantly faster in the experiment with no visible movement than in the experiment with the visible movement.

Cue-driven saccades. Overall, 369 saccades were made (204 in the direction of the cue and 165 in the opposite direction). Average number of orientations was calculated for each participant before the target appearance to compare the number of cue-driven saccades to the number of saccades opposite to the cue. A paired t test revealed no significant difference, $t(27) = 1.74$, $p > .05$, between the mean number of saccades in the direction of the cue and those opposite to the cue (M = 7.5, SE = 2.7, and M = 6.0, SE = 3.3, respectively). This result showed that newborns did not orient more toward the direction of the stimulus gaze. Because some participants contributed different numbers of valid trials, the percentage of eye movements to the cued side was compared against chance. The t test analysis revealed a significant difference, $t(27) = 2.12$, $p < .043$, between the mean percentage of saccades in the direction of the cue and opposite to the cue (M = 56.6 vs. M = 43.3; SE = 3.1). This result demonstrates that, in fact, newborns tend to follow the higher contrast part of the stimulus eyes even when the movement of the pupils is not visible. Nevertheless, the pupil location is not used as a cue to direct his or her orienting to the target.

GENERAL DISCUSSION

In Experiment 1 we replicated and extended the previous finding that newborns are sensitive to direct eye contact. In Experiments 2 and 3 we extended this finding further to show that the direction of motion of eye pupils can guide looking behavior. Taken together, these observations suggest a surprising degree of competence in the perception and processing of eye-related information by newborns, and this may be an important foundation on which more sophisticated social cognitive abilities are later constructed.

Although the implications of these results are potentially important, we urge caution in their interpretation for several reasons. First, our newborns had between 24 and 120 hr within which to gather experience about faces. There is little doubt that during this time they had opportunities to view both direct and averted gaze, as well as shifts of gaze. The successful use of schematic faces in this study, however, means we can be confident that they have not observed these displays previously, especially because newborns are unable to generalize learning from real objects to two-dimensional representations. In other words, they are showing apparent sensitivity to eye gaze in face-related stimuli unlike those they may have previously been exposed to (Slater & Quinn, 2001). A second reason for caution comes from the relatively small visual angle between the face and the targets. This was arranged to maximize our chances of obtaining a positive result, but is unlikely to be reflected in the real world. A third area of caution surrounds the basis for the cuing effect. Although we ruled out that the target-driven cuing effect observed in Experiment 2 was directly driven by the motion of the pupils (cue-driven saccades), it is nevertheless possible that the pupil motion merely sensitizes the right or left visual field. When the target is subsequently presented, the oculomotor threshold for making a saccade into one visual field is reduced. Previous work has established that the basis of eye gaze cuing in infants of 4 months and older is, in all likelihood, different from that in adults (Mansfield, Farroni, & Johnson, 2003). It remains to be established whether the basis of the effect in newborns is the same as that in 4-month-olds (Farroni, Mansfield, Lai, & Johnson, in press), and whether it is eye gaze specific.

The finding in Experiment 3 that newborns, like slightly older infants, are not cued by static presentations of eye gaze direction suggests that the mechanisms we have observed are simpler than those hypothesized to be innate by Baron-Cohen (1994). Specifically, we have established that newborns are (a) sensitive to direct gaze, and (b) influenced by the direction of motion of elements in an array. Further experiments will determine whether newborns, like 4-month-olds, require mutual gaze to precede the motion of face-related elements to show cuing (Farroni et al., in press). Even if this turns out to be the case, these mechanisms are not specifically tuned only to detecting the direction of eye gaze. Despite the lack of specificity in these mechanisms, however, their operation within the natural environment of the infant may have similar consequences to the more specifically dedicated mechanisms hypothesized by Baron-Cohen.

The results obtained in these experiments also have potential implications for other theories of the development of face processing, which vary from the view that newborns are equipped with specific face-processing and recognition abilities (Slater & Quinn, 2001) to the view that face-processing abilities have to be acquired through perceptual learning (Gauthier & Nelson, 2001). In particular, Johnson and Morton (1991) proposed a two-process theory in which an initial bias for newborns to orient toward faces (Conspec) constrains the early visual input to developing cortical circuitry that, through this experience, will become specialized for faces in later life (Conlern). We believe the results obtained in this study are compatible with a slightly modified version of this model. Specifically, Johnson and Morton suggested that the basis of Conspec was a crude representation of the high-contrast areas relating to the eyes and mouth. Using computer simulations, Bednar (in press) demonstrated that this simple representation can account for nearly all the available empirical data on newborns' preferences for realistic and schematic face stimuli. Farroni et al. (2002) suggested that this simple representation may also account for newborns' preferential orienting to realistic faces with direct gaze, because this stimulus contains the most symmetric arrangement of high-contrast elements in the basic configuration of the face. If this view is correct, it extends and refines the functions originally attributed Conspec in a number of ways. First, by preferentially orienting to faces with direct gaze this may help bootstrap the emergence of a number of social-cognitive abilities, including eye gaze cuing, in addition to biasing early experience toward faces (Farroni et al., 2002). Second, by ensuring foveation of faces with direct eye gaze, Conspec may help determine which cortical regions develop specialization for faces (Johnson, in press). For example, the fusiform face area may become established because it receives input from the fovea (Malach, Hasson, Avidan, Lerner, & Levy, in press).

Johnson and Morton (1991) stated that, in addition to the Conspec and Conlern mechanisms, visual preferences in infancy were determined by several other sources, such as spatial frequency. If the preceding interpretation of newborns' preferences for faces with direct gaze is correct, then we can add cuing of orienting by directed motion to the list of other mechanisms influencing visual orienting during the first year. Although gaze cuing may become eye specific by adulthood, motion cuing remains responsible for the effects observed at least until 4 months of age (Farroni et al., in press). However, if future experiments can demonstrate that direction of motion cuing in newborns is eye specific, then a revision of Johnson and Morton's theory will be required.

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