Developmental changes in inhibition of return from 3 to 6 months of age

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\textbf{Abstract}

The development of inhibition of return was examined in 3–6-month-olds using varied stimulus onset asynchronies. The 300 ms SOA condition revealed particularly interesting findings as it elicited facilitation in 4.5-month-olds, but inhibition in 6-month-olds. Implications for understanding the development of IOR are discussed.

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At approximately 6 months of age, infants demonstrate an attentional bias to novel locations as evidenced by the reduction of looking to a previously examined location. This tendency is called inhibition of return (IOR; Posner, Rafal, Choate, & Vaughan, 1985). IOR increases visual search efficiency by decreasing attention to locations that have already been examined (Posner & Cohen, 1984), which facilitates processing of new information in novel locations. Interestingly, by 6 months of age infants show IOR responses similar to those of adults, but the development of IOR preceding this point remains unclear. The current study contributes to the infant IOR literature by examining the developmental changes in facilitation and inhibition of visual attention that take place between 3 and 6 months of age.

A spatial cueing paradigm is used to elicit IOR with a brief presentation of a peripheral cue (see Fig. 1). Attention may be shifted to the cue either overtly, by moving the eyes, or covertly, by shifting attention without eye movement (Posner, 1980). IOR is determined by cue-target stimulus onset asynchronies (SOAs), or the elapsed time between the onset of the cue and the onset of the target. Spatial cueing paradigms result in two types of effects: facilitation and inhibition (i.e., IOR). A facilitative effect of the cue is typically observed with adults when the SOA is between 0 and 200 ms (Samuel & Kat, 2003). At these short SOAs, orienting is facilitated to the cued side, and RTs to that side are faster (Posner, Davidson, & Snyder, 1980). Facilitation is proposed to be observed at short SOAs because the cue captures attention, and if the target is presented within a very brief period of time, attention is still lingering at that location; therefore, the target is detected faster (Posner & Cohen, 1984). Conversely, IOR occurs at longer (200–3000 ms) SOAs (Samuel & Kat, 2003) because attention has shifted away from the cue before the target appears, resulting in a slower attentional shift back to the previously cued target (Posner & Cohen, 1984). The observed response pattern in adults of facilitation at short SOAs and IOR at long SOAs may hold for infants as well. However, because the precise SOAs that elicit facilitation and IOR in infancy have yet to be determined, it remains unclear.

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whether the time course of facilitation and IOR in infancy differs from that of adults. One purpose of the current study is to present SOAs that have not been used previously in order to better understand the time course of facilitation and IOR in infancy (see Table 1).

Because the methodology of the spatial cueing paradigm has differed across previous infant IOR studies, the age of emergence of IOR reported in the infant literature has remained unclear. Paradigms that elicit overt shifts of attention have reported evidence of IOR in newborns (Simion, Valenza, Umlita, & Barba, 1995; Valenza, Simion, & Umlita, 1994). Paradigms that lead to covert shifts of attention result in a general pattern of facilitation with infants of all ages at short SOAs and IOR at longer SOAs, but only with infants older than 4 months of age (Butcher, Kalverboer, & Geuze, 1999; Hood, 1993; Hood & Atkinson, 1991; Richards, 2000). This inconsistency concerning the emergence of IOR may be due to different dependent measures (i.e., RT versus direction of look) and/or differences in procedure (i.e., unilateral versus bilateral targets). The current study set out to examine the development of IOR in 3–6-month-old infants, using SOAs (200, 300, and 600 ms) which allow us to observe a developmental change from facilitation to inhibition. We presented unilateral targets to 3–6-month-old infants; thus RT was the dependent measure. Based on previous research, we expect infants to show facilitation at the shortest, 200 ms SOA. A 300 ms SOA has not yet been studied in infants and is on the borderline between observing facilitation and IOR in adults. Samuel and Kat (2003) found that a 300 ms SOA leads to IOR in adults, and because 6-month-olds show adult-like IOR, we predict that they will experience IOR at the 300 and 600 ms SOAs. However, we expect the 300 and 600 ms SOAs to result in facilitation in 3- and 4.5-month-olds because IOR is not consistently observed at these ages.

The sample consisted of 60 infants: 24 3-month-olds, 16 4.5-month-olds, and 20 6-month-olds. All were full-term and in good health. Sixty additional infants were omitted from analyses due to prematurity (6), fussiness or inattentiveness (43), or experimenter error/equipment failure (11). Infants sat in an infant seat 60 cm from a presentation screen. Prior to each trial, a flashing bull’s eye was presented centrally for 1500 ms to attract the infant’s attention. While the bull’s eye was still present, a cue appeared for 100 ms in the periphery to the right or left, after which the bull’s eye remained on for an additional 100, 200, or 500 ms. In some “neutral” trials, no cue was presented. Finally, the bull’s eye was removed and the target appeared in the periphery; the target remained on the screen until the infant made an eye movement or until approximately three seconds elapsed (Fig. 1). Both valid (cue and target on same side) and invalid (cue and target on different sides) trials were presented. Thirty-six trials were presented (15 valid, 15 invalid, and 6 neutral).

Video recordings of eye movements were scored frame-by-frame (33 ms intervals). Infants contributed 724 total trials. Of these trials, only the 586 correct trials (81%) were analyzed; the other 19% of trials were unusable trials based on standard criteria (e.g., Butcher et al., 1999). RTs that were greater than 2000 ms were removed, resulting in the removal of 8 trials (1%). Prior to analyses, similar trials were averaged within individual infants (e.g., average taken for all 200 valid conditions completed by one infant). Not all infants contributed to all cue conditions; therefore, missing values were replaced with the mean (75 trials; 12%); however, no more than two missing values were replaced for each individual infant. An alpha level of .05 was used for all statistical tests.

Results were analyzed using a mixed model analysis of variance (ANOVA), with SOA (200, 300, 600 ms) and Validity (valid, invalid) as within-subject factors and age (3, 4.5, 6 months) as between-subjects factor. The results revealed a main effect of SOA, \(F(2,114) = 5.5, p = .005, \eta^2_p = .088\), a main effect of Validity, \(F(1,57) = 4.584, p = .037, \eta^2_p = .074\), and an interaction of SOA \(\times\) Validity \(\times\) Age, \(F(4,114) = 2.527, p = .045, \eta^2_p = .081\). Because of the design of this study, the interaction must be analyzed prior to the main effects. Preliminary analyses revealed no differences in RT to the no cue conditions at the various SOAs, \(F(2,46) = 2.609, p = .084\); therefore, the average RT of the no cue conditions was calculated for each age group.

To examine the interaction further, separate one-way ANOVAs were conducted to examine Validity and Age effects separately at each SOA. At the 200 ms SOA, all age groups were significantly faster in responding to valid conditions (\(M = 405 ms, SD = 184\)) than invalid conditions (\(M = 510 ms, SD = 233\)), \(t(59) = 3.835, p < .001, d = .5\), which indicates facilitation at the 200 ms SOA for all age groups. The one-way ANOVA at the 300 ms SOA revealed a Validity \(\times\) Age interaction, \(F(2,57) = 7.939, p = .001, \eta^2_p = .21\). Follow-up tests showed no difference in RT for 3-month-olds in the 300 ms valid (\(M = 496 ms, SD = 295\)) and invalid (\(M = 620 ms, SD = 188\)) conditions, \(t(23) = 1.72, p = .099, d = .35\); therefore, 3-month-olds did not show either facilitative or inhibitory effects. The 4.5-month-olds were faster to respond in the 300 ms valid condition (\(M = 334 ms, SD = 199\)) than the...
### Table 1
Previous studies which examined IOR.

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<tr>
<th>Age</th>
<th>SOA</th>
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Note: Under each SOA, the results are shown separately for those studies that examined direction of look (DOL) and those that examined reaction time (RT). F: facilitation, I: inhibition, n.s.: tested but not significant; 1: Clohessy, Posner, Rothbart, and Vecera (1991); 2: Hood & Atkinson (1991); 3: Hood (1993); 4: Johnson et al. (1994); 5: Valenza et al. (1994); 6: Simion et al. (1995); 7: Butcher et al. (1999); 8: Johnson & Tucker (1996); 9: Richards (2000); 10: Nakagawa et al. (2003); 11: Current experiment; *: overt orienting.
300 ms invalid condition ($M = 559$ ms, $SD = 140$), $t(15) = 3.299, p < .005, d = .82$, which indicates that 4.5-month-olds showed facilitation at the 300 ms SOA. The 6-month-olds, however, showed the opposite response pattern from the 4.5-month-olds: they were faster to respond in the 300 ms invalid condition ($M = 459$ ms, $SD = 166$) than the 300 ms valid condition ($M = 640$ ms, $SD = 322$), $t(19) = 2.447, p = .024, d = .55$, which indicates that they showed IOR at the 300 ms SOA. Finally, no effects were seen at the 600 ms SOA condition for any age group, $p > .5$.

The purpose of this study was to examine the development of IOR between 3 and 6 months of age using three SOAs. As expected, all age groups showed facilitation at the shortest SOA. At the 300 ms SOA, 3-month-olds’ RTs did not reach significance, although they show a trend toward facilitation. These results with the 3-month-olds are not surprising, given that previous studies have found mixed results with SOAs close to 300 ms; Johnson and Tucker (1996) found non-significant results with a 200 ms SOA and Richards (2000) found facilitation with an SOA of 450 ms. Although it was surprising that facilitation was seen in the 3-month-olds at the 200 ms SOA, but not in the 300 ms SOA, results with the two older age groups were more consistent with the hypotheses.

Of note is the difference in response between 4.5- and 6-month-olds at the 300 ms SOA, which previous studies have suggested would be on the borderline between eliciting facilitation and IOR. Based on previous research (Samuel & Kat, 2003), it was expected that 6-month-olds would show IOR, while the younger infants would show facilitation. The results were consistent with this hypothesis in the 4.5- and 6-month-old age groups and also corroborate data from Nakagawa et al. (2003), who found facilitation in 4-month-olds and IOR in 9-month-olds at a 700 ms SOA. However, the present study shows the developmental change from a facilitative response to an inhibitory response at a shorter SOA (300 ms), which is on the borderline between observing facilitation and IOR in adults. In addition, the present study shows the change from facilitation to inhibition with a younger age group (6-month-olds). A 300 ms SOA is short enough to elicit the earlier emerging response of facilitation in 4.5-month-olds, but long enough to induce a relatively more mature inhibitory response in 6-month-olds. Thus, the developmental transition that occurs between these two ages presumably involves changes in processes such as speed and efficiency of visual information processing, as well as speed of attentional orienting.

Interestingly, the results did not show any significant effects for any age group at the 600 ms SOA. It was not expected that 3-month-olds would show an inhibitory effect, but it is puzzling that no facilitative effect was observed. Likewise, 4.5-month-olds showed neither facilitation nor inhibition. The results from previous studies are mixed at a 700 ms SOA. The 6-month-olds also showed no effect at the 600 ms SOA, which is consistent with the findings of Johnson and Tucker (1996) with 6-month-olds with an SOA of 700 ms. As Table 1 shows, results from 6-month-olds are variable and somewhat inconsistent across all SOAs. The current data add to our understanding of the development of IOR, but do not yet clear up every apparent discrepancy on its developmental timetable (Table 2).

Some of the previous IOR inconsistencies may be accounted for by variations in procedures, which may be more than minor technical differences, but instead may result in important differences in results across studies. First, paradigms in which infants are required to make overt shifts of attention tap into different processes than those which require infants to make covert shifts of attention. Thus, it is difficult to make direct comparisons between IOR studies that use overt and covert shifts of attention. A second methodological variation that could affect results is that the dependent measure varies across studies. While studies that present unilateral targets only measure the RT to respond to the target, studies that present bilateral targets generally also examine direction of look. RT may not be an optimal dependent measure for detecting differences between valid and invalid trials, especially when testing younger infants, who may show slower responses across the board. Direction of look (with bilateral targets) may be a preferable measure for showing sensitivity to attentional biases away from a previously cued location. At a minimum, Table 1 in conjunction with the current results demonstrates that further work is needed to reveal the extent to which findings from studies of overt and covert orienting are tapping into similar attentional processes.

Placing the results of the present study in the context of other studies (summarized in Table 1), our data suggest that IOR emerges between 4.5 and 6 months of age when using a covert orienting paradigm that employs RT (rather than direction of look) as the dependent measure. The developmental course of IOR is still unclear, as only one group of researchers has studied IOR in newborns, and few studies examine IOR before 3 months of age. Additionally, there are unanswered questions with respect to the time course of facilitation and IOR. The field would certainly benefit from additional studies employing both overt and covert tasks within-subject, to see the extent to which those two paradigms are tapping into similar processes. Despite these methodological questions, however, the current findings provide solid evidence for the early emergence of facilitative and inhibitory attentional processes that are believed to underlie efficient visual search. They also provide interesting evidence of a developmental shift in attentional orienting: we observed that the same condition (300 ms SOA) resulted in facilitation for one age group and inhibition for another. Considered along with other studies, if it is

<table>
<thead>
<tr>
<th>Age</th>
<th>200V Mean (SD)</th>
<th>200V Median</th>
<th>300V Mean (SD)</th>
<th>300V Median</th>
<th>600V Mean (SD)</th>
<th>600V Median</th>
<th>No Cue Mean (SD)</th>
<th>No Cue Median</th>
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<tbody>
<tr>
<td>3 mos.</td>
<td>446 (192)</td>
<td>594 (280)</td>
<td>496 (295)</td>
<td>620 (188)</td>
<td>546 (300)</td>
<td>570 (306)</td>
<td>627 (252)</td>
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<tr>
<td>4.5 mos.</td>
<td>345 (186)</td>
<td>470 (122)</td>
<td>334 (199)</td>
<td>559 (140)</td>
<td>545 (265)</td>
<td>470 (138)</td>
<td>548 (312)</td>
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<tr>
<td>6 mos.</td>
<td>404 (167)</td>
<td>442 (218)</td>
<td>640 (322)</td>
<td>459 (166)</td>
<td>531 (160)</td>
<td>505 (304)</td>
<td>501 (266)</td>
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</table>

Table 2
RT means (standard deviations) for valid and invalid trials at each SOA across ages.
indeed the case that newborn infants show IOR-like responses when orienting overtly, but IOR is not seen following covert shifts of attention until between 3 and 6 months of age, then longitudinal studies examining both covert and overt orienting in the same infant sample would prove most enlightening regarding both the time course of the emergence of IOR and its implications for other domains of attentional processing.

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References


