

Visual Search and Popout in Infancy

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ABSTRACT

Attentional selection enables efficient information processing by selecting relevant information and filtering out irrelevant information. For infants, attentional selection is critical because they are first constructing a knowledge base of the world. Visual search and texture segregation studies with adults have indicated that items that contain a unique perceptual feature automatically and selectively capture attention (i.e., popout), irrespective of the number of distracter items. In contrast, items that lack a unique perceptual feature are detected by serially allocating attention, resulting in longer search times as the number of distracters increases. Presumably, popout is due to an early preattentive processing stage that decomposes items in parallel into their primitive perceptual features, whereas serial search is accomplished by a later attentive processing stage. Research addressing infants' exhibition of visual search, popout, the functioning of the underlying attentive mechanisms, and development of the possible neural foundations is reviewed.

I. INTRODUCTION

Our world is populated by many visual objects and events, all of which are potential targets for our attention and processing resources. Because our processing resources are limited, we cannot attend to all possible objects and events simultaneously, but instead we allocate attention selectively to individual items. For infants, whose visual and mental processing was once described as "assailed by eyes, ears, nose, skin and entrails at once, feels it all as one great blooming, buzzing confusion" (James, 1890, p. 488) and who are first constructing a knowledge base, it is particularly necessary to possess mechanisms of selective atten-

tion. Thus, infants, as do adults, need to filter the information impinging on their sensory mechanisms to construct an organized knowledge base.

II. SEARCH, SEGREGATION, POPOUT, AND SELECTION MECHANISMS IN ADULTS

In adults, one particular set of mechanisms of attentional selectivity that have been investigated is preattentive versus attentive mechanisms, with the primary paradigms for their investigation being visual search (Treisman and Gelade, 1980) and texture segregation (Julesz, 1981). The functioning of these mechanisms has been formalized in two influential theories of adults' visual information processing in which an initial "preattentive" mechanism decomposes all stimuli in the visual array in parallel into their basic perceptual features (Julesz, 1981; Treisman and Gelade, 1980). The basic perceptual features have been hypothesized to include elongated blobs, orientations, width and length, size, color, motion, and elongated blob terminators—a list that agrees well with the properties that physiological evidence suggests are processed in parallel by the early visual system (Deco et al., 2002) (see Chapter 93). A later "attentive" mechanism selectively focuses processing resources serially to individual stimuli for the purpose of binding the features into a unified object percept and for object recognition (Julesz, 1981; Treisman and Gelade, 1980) (see Chapters 24, 65, and 90).

Behaviorally, these mechanisms have been explored with visual search and texture segregation paradigms and the phenomenon of popout. Popout can be described simply as the situation in which stimuli that are defined by a unique perceptual feature automatically and selectively capture attention (Treisman and Gelade, 1980) (see Chapters 17 and 68). That is, the

preattentive mechanism decomposes stimuli into their basic features and when a feature map indicates a stimulus unique for that property, then attentive processes are selectively allocated to that stimulus location. Consequently, regardless of the number of stimuli in the array, the time it takes to detect the stimulus with the unique feature remains relatively stable. In contrast, when a stimulus does not consist of a single unique identifying feature but is defined by a unique combination of features, it does not popout. Instead, the attentive mechanism allocates processing resources to each stimulus to detect the stimulus in the array with the unique conjunction of features (Treisman and Gelade, 1980) (see Chapters 17 and 43). Consequently, the time it takes to detect the stimulus with the unique conjunction increases as the number of stimuli in the array increases.

III. FEATURE SEARCH, SEGREGATION, AND POPOUT IN INFANCY

If "popout" is due to the early processing of features that are considered to be the building blocks of perception (Julesz, 1981; Treisman and Gelade, 1980), then popout might be evident early in development. Unfortunately, it is not possible to conduct manual reaction time studies with young infants as with adults, because infants do not have the motor control to press buttons to indicate detection. Instead, researchers have harnessed aspects of infants' existing behavior, including their looking (e.g., preferential looking, habituation-dishabituation, and novelty preference paradigms) and kicking (e.g., mobile conjugate reinforcement paradigm) behaviors, to assess their attentional and perceptual capacities. None of these paradigms, however, provides measures (e.g., reaction time) comparable to those obtained with adults, and they measure visual search and popout over larger time scales (seconds and even minutes) than assessed with adults, thereby making comparison of the underlying attentional and perceptual mechanisms difficult, as is discussed later in this chapter.

One of the first studies to suggest that popout occurs in early infancy was reported by Salapatek (1975), who used a preferential looking paradigm and presented infants with a patch of unique stimuli embedded in a field of dissimilar stimuli, for example, squares in horizontal lines (or vice versa). He found that 3-month-olds always oriented to the unique stimuli, whereas 2-month-olds did not, suggesting that 3-month-olds' but not 2-month-olds' attention was captured by the unique patch. This suggests that the

mechanism responsible for popout might develop around 3 months of age.

In the last 10 years or so, there has been considerable interest in this prospect and numerous studies have investigated popout in infants. In 1992, motivated by Salapatek's findings, two studies further investigated the development of popout of discrepant patches or textures (Atkinson and Braddick, 1992; Sireteanu and Rieth, 1992). Atkinson and Braddick found, in relative agreement with Salapatek (1975), that 4-month-old infants, but not 2- to 3-month-olds, oriented to a patch of oriented lines embedded in a texture of orthogonally oriented lines, suggesting that the ability to exhibit popout on the basis of orientation differences does develop around 3 months of age. However, when the patch of lines differed from the surrounding texture on the basis of size (and luminance), even the youngest infants exhibited popout.

Sireteanu and Rieth (1992) also found that infants as young as 2 months preferentially oriented toward the discrepant patch when it was defined by size, suggesting that it popped out. In contrast to Atkinson and Braddick (1992), however, Sireteanu and Rieth found that a discrepant patch defined by orientation was not preferentially oriented until approximately 12 months of age. The discrepancy between the two studies in the age at which popout of orientation-defined patches is exhibited may be due to methodological differences, including whether the homogeneous and discrepant areas of the texture were presented in two separate fields (Sireteanu and Rieth, 1992) or in one large field (Atkinson and Braddick, 1992), whether the oriented lines were the same length (Sireteanu and Rieth, 1992) or varied in length (Atkinson and Braddick, 1992), and whether the textures contained 16 lines (Sireteanu and Rieth, 1992) or 38 lines (Atkinson and Braddick, 1992). Regardless, these studies demonstrate that popout and the segregation of textures, at least those defined by size or luminance differences, is evident in infants as young as 2 months of age.

A number of other studies using different stimuli and paradigms have demonstrated popout in 3-month-old infants (Adler et al., 1998; Colombo et al., 1995; Rovee-Collier et al., 1992). Rovee-Collier et al. (1992), for example, used as a basis the finding by Julesz (1981) that a patch of +'s pops out for adults when it is embedded in a surrounding texture of L's, presumably because the +'s contain the unique perceptual feature of the line crossing. Rovee-Collier et al. used the mobile conjugate reinforcement paradigm in which 3-month-olds were trained to kick to move an overhead seven-block crib mobile that displayed either L's or +'s on every block side and then tested them 24 hours later with a mobile that consisted of either a

single unique L block among six + blocks or a single unique block of +'s among six blocks of L's. Previous research with this paradigm has indicated that infants will exhibit recognition of the test mobile only if the information presented on the blocks match (i.e., is familiar) the information infants remember were on the blocks during training; otherwise they exhibit discrimination. Rovee-Collier et al. found that infants' recognition performance was controlled by the familiarity or novelty of the unique characters on the single block regardless of whether the characters on the surrounding blocks were familiar or novel. For example, infants trained with a mobile that consisted of all L's and tested 24 hours later with a mobile that consisted of a single + among L's discriminate the test mobile even though it was predominately identical to the mobile with which they were trained. Thus, the single, unique + block controlled infants' recognition performance at test. This suggests that the unique character popped out from amid the surrounding dissimilar characters, similar to the findings of popout in visual search and texture segregation studies with adults.

Another fundamental outcome of preattentively decomposing stimuli into their basic features is that a search asymmetry exists in popout (Treisman and Gelade, 1980). That is, a stimulus that contains a unique feature will pop out from amid stimuli in which that feature is absent, whereas a stimulus in which that feature is absent will not pop out from stimuli in which that feature is present. For example, in adults, C's will popout from amid O's but not vice versa, presumably because the C's contain line terminators which are absent in the O's. Adler et al. (1998) and Colombo et al. (1995) have separately found evidence that suggests that search asymmetries are even exhibited in early infancy.

Adler et al. (1998), using the mobile conjugate reinforcement paradigm (described above), trained 3-month-olds to kick to move a mobile that displayed either R's (feature-present) or P's (feature-absent). Twenty-four hours later, infants were tested with either a single P among R's or a single R among P's. Results indicated that recognition or discrimination was determined by the feature-present stimulus (R) regardless of whether it was the target (R among P's) or distracter (P among R's), suggesting that it popped out when it was the target whereas the feature-absent P failed to pop out when it was the target (see Table 34.1). For example, infants trained with a P mobile and tested 24 hours later with a mobile that consisted either of a single R among P's or of a single P among R's discriminate the test mobile because their recognition performance is controlled by the R, which does not match the P with which they were trained. This occurs because infants' attention was allocated to the feature-present stimulus in both cases, apparently popping out in the first case and receiving attentional allocation in the second due to the feature-absent stimulus failing to pop out.

Colombo et al. (1995), using a preferential looking task, presented 3- to 4-month-old infants with a homogeneous array of either O's or Q's paired with a heterogeneous array of a single Q among O's (feature-present condition) or with a single O among Q's (feature-absent condition). Results indicated the infants preferentially oriented their attention to the heterogeneous array only in the feature-present condition but not in the feature-absent condition. This asymmetry in infants' attentional allocation suggested that the feature-present target (Q) popped out from amid the feature-absent distracters (O's), whereas the feature-absent target (O) did not pop out from amid

TABLE 34.1 Summary of Results from Adler et al. (1998), Who Investigated the Perceptual Asymmetry of Popout in 3-Month-Old Infants

Train mobile	Test mobile	FAM or NOV	Recognition	Popout?
Feature-absent popout target				
R	Single P Among R's	NOV	Yes	No
P	Single P Among R's	FAM	No	No
Feature-present popout target				
P	Single R Among P's	NOV	No	Yes
R	Single R Among P's	FAM	Yes	Yes

Note. Shown are the training mobile, test mobile, familiarity (FAM) or novelty (NOV), and feature absence versus presence of the single popout target on the test mobile, whether recognition (or discrimination) was exhibited and, consequently, whether popout was indicated. From Adler, Inslicht, Rovee-Collier, and Gerhardstein, 1998.

Source. Reprinted, with permission, from Adler et al. (1998).

the feature-present distracters (Q's). Together, these two studies suggest that search asymmetries and the relevant preattentive and attentive mechanisms outlined in theories of adults' visual information processing are also evident in early infancy.

IV. PARALLEL SEARCH IN INFANTS

Collectively, the studies described above and others seem to indicate that very young infants, as young as 3 months, exhibit the phenomenon of "popout." This would further suggest that the preattentive mechanisms for selectively allocating early visual processing resources are functioning in early infancy. However, there are a couple of issues that have yet to be resolved by the infant "popout" studies that would provide definitive evidence for popout and preattentive processing in infancy. First, in adults, popout typically occurs on the order of milliseconds (e.g., Treisman and Gelade, 1980). In the infant studies, however, the paradigms used assess popout during test phases that last seconds (Colombo et al., 1995) and even minutes (Adler et al., 1998; Rovee-Collier et al., 1992). Thus, sufficient time exists in these studies for infants' behavior to be due to serial attentive processes rather than to preattentive popout.

A second issue that has yet to be addressed in the infant studies is that a key function of preattentive processing is that items in the visual world are processed in parallel. Quantitatively, in terms of popout, this means that the time to detect a target remains relatively unchanged as the number of distracter items increases. This contrasts with the effect of not presenting a popout target but only presenting distracter items, in which case the time to detect increases as the number of distracters increases. No infant study, due to the fact the paradigms used to date do not measure reaction time, has yet to examine whether processing of items in a visual array and popout occur in parallel, that is, that detection time is unaffected by the number of distracters.

Consequently, due to these two limitations of the infant studies, protracted test phase for assessing popout and failure to test for set size effects, whether infants actually exhibit the phenomenon of popout and a functioning preattentive mechanism as found in adults has yet to be definitively demonstrated. Recently, Orprecio and Adler (2003) measured the latency of 3-month-old infants' saccadic eye movements to visual arrays that either contained a popout target or did not. Because infants' eye movements to stimuli occur on the order of milliseconds, Orprecio and Adler reasoned that such a measure would be more comparable

in timing to the reaction time measure used to assess popout in adults and would be able to assess the effect of set size on detection time. Consequently, measuring infants' eye movements would allow for a more comparable assessment of pop-out in infants and be able to measure the functioning of the parallel preattentive mechanism (see Chapters 20 and 65).

Specifically, Orprecio and Adler (2003) presented infants with visual arrays in which the popout target (+) was either present or absent and in which the number of distracter items (L's) varied (see Fig. 34.1), and infants' latency to make an eye movement to the target in the target-present condition and to one of the distracters in the target-absent condition was measured. Furthermore, to assess whether popout occurred in parallel, the effect of increasing set sizes on infants' eye movement latencies was measured. The results indicated that infants' saccade latencies remained unchanged in the target-present conditions as set size

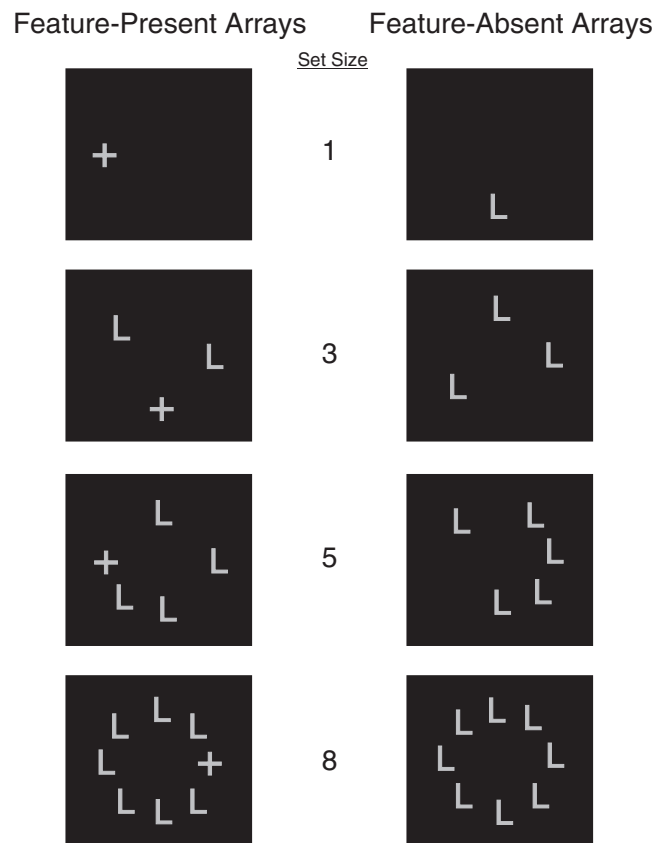


FIGURE 34.1 Example of the visual search arrays used by Orprecio and Adler (2003). Shown are target-present and target-absent search arrays with set sizes of 1, 3, 5, and 8. The stimuli in the array shown to infants were actually red in color. On those trials when a target was present it could randomly occur in either the 3, 6, 9, or 12 o'clock location, and the distracters randomly occurred in any of the remaining locations.

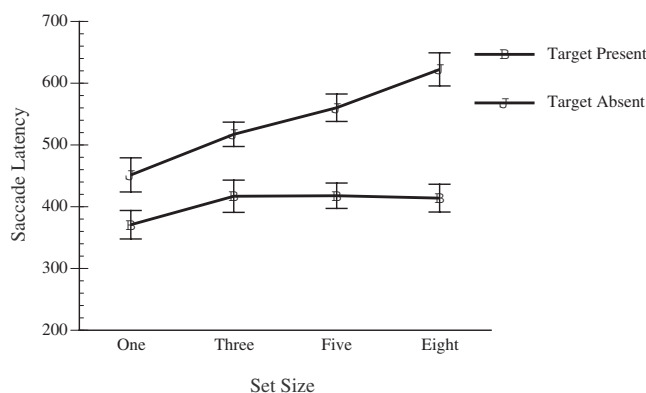


FIGURE 34.2 Infants' saccade latencies to visual search arrays when the target (+) was present among distracters (L's) and when it was absent as a function of the array set size. Results indicate popout and a parallel search function when the target was present and a serial search function when the target was absent.

increased from 1 to 3, 5, and 8 items, whereas their saccade latencies increased linearly in the target-absent conditions as set size increased (see Fig. 34.2). These results are identical to what is typically found in studies of visual search in adults (Treisman and Gelade, 1980) (see Chapter 65). Moreover, they indicate that infants as young as 3 months of age do exhibit "popout" on a millisecond scale, that it is unaffected by the number of distracters, and that it is likely due to a functioning parallel preattentive processing mechanism.

V. CONJUNCTION SEARCH IN INFANTS

The two-stage models of early perceptual processing (Julesz, 1981; Treisman and Gelade, 1980) posit that when an item is not defined by a single unique feature but is defined by the conjunction of two or more features, its detection does not occur via the parallel preattentive mechanism (first stage) and, consequently, it does not pop out. Instead the item defined by a conjunction of features is detected by an effortful serial search conducted by the attentive mechanism (second stage). As a result, detection time increases as the number of distracter items increases (Treisman and Gelade, 1980). In early infancy, in contrast to feature search and popout, there have been few studies investigating conjunction search.

In one study, Bhatt et al. (1999) used the novelty preference paradigm to compare the ability of 5.5-month-old infants to detect a discrepant texture (red X's) embedded in a surrounding texture (blue X's and green O's) when they differed by a single unique

feature (red) versus their ability to detect a discrepant texture (blue O's among blue X's and green O's) when it was defined by a conjunction of features (blue and O). Bhatt et al. familiarized infants to texture arrays consisting solely of distracter items and tested infants with the familiarized texture paired with a texture array that contained the discrepant embedded texture. They found that infants exhibited a novelty preference when the embedded texture was defined by a single unique feature but not when it was defined by a conjunction of features. This finding suggests that 5.5-month-old infants exhibit preattentive popout but are unable to conduct an attentive serial search. Another study by Gerhardstein and Rovee-Collier (2002), which measured 1- to 3-year-olds' reaction time to touch the location of the target item on a computer screen, found that these older infants and children were able to detect the target when it was defined by a conjunction of features, and their reaction time as a function of the number of distracters was consistent with a serial attentive search. Together, these studies indicate that, unlike preattentive processing and popout, which are exhibited as early as 3 months of age, attentive processing and serial search may not be available until the end of the first year.

VI. DEVELOPMENTAL ASPECTS OF THE NEUROBIOLOGY OF PREATTENTIVE AND ATTENTIVE MECHANISMS

Together, the infant studies indicate that preattentive mechanisms and popout are present in young infants, whereas attentive mechanisms and serial search may come online near the end of the first year. This provides developmental support for the hypothesis that preattentive and attentive mechanisms are distinct processing modules. If they are distinct mechanisms, perhaps they are also distinct neurally, in which case the developmental trends for the exhibition of preattentive and attentive processing in the visual search situation should mirror developmental trends in the maturation of neural mechanisms.

Johnson (1993) has proposed a theory of neural development, particularly as it relates to visual attention, in which attentional processing and behavior in the first few months of life is controlled primarily by the subcortical superior colliculus pathways, but around 3 months of age the cortical pathway through the frontal eye fields (FEFs) comes online. Considering that substantive research has established that neurons in FEFs show activity during presentation of a popout search array that discriminates the popout target from

the distracters even in the absence of eye movements (Thompson et al., 1997) (see Chapters 21 and 22) and that the areas of the visual cortex from which it receives projections process the primitive perceptual units (Deco et al., 2002) (see Chapter 93), it is consistent that popout, which relies on the processing of these primitive perceptual units, would be evident at 3 months of age.

Johnson (1993) further proposes that around 6 months of age, there is rapid development of the parietal cortex, which has been hypothesized to be involved in the ability to disengage from stimuli, a capacity that would seem to be critical to serially search through the stimuli in a visual search array (see Chapters 7 and 24). Consequently, the ability to serially and attentively search an array may be significantly hampered until the parietal cortex is more functionally mature at 6 months, perhaps accounting for why 5.5-month-olds were not able to search for a conjunction target but 1- to 3-year-olds could.

VII. CONCLUSIONS

A key factor in efficiently processing information from our world is the ability to select relevant information while filtering out irrelevant information. Selection and filtering of information are even more critical for the infant who is first constructing his or her knowledge base about the world. One set of mechanisms that has been proposed to accomplish this attentional selection is preattentive versus attentive mechanisms. These mechanisms are manifested behaviorally in adults to visual search arrays as popout versus serial search. In this chapter we reviewed developmental research that indicated that popout is exhibited as early as 3 months of age, whereas serial search is not exhibited before approximately 6 months of age. This developmental trend is consistent with theories of neural development in which the FEF pathway, which has been hypothesized to be involved in popout, is functionally mature by 3 months of age, and the parietal cortex, which is involved in attentional disengagement and therefore may be involved in serial search, is functionally

mature around 6 months of age. Regardless, the primitive preattentive mechanism for automatic attentional selection of unique stimuli in the visual world is available very early in infancy, whereas the more intentional attentive mechanism is not available until the second half of the first year.

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