UNIVERSITA' DEGLI STUDI DI PADOVA

Sede Amministrativa: Università degli Studi di Padova

Dipartimento di Psicologia dello Sviluppo e dei Processi di Socializzazione

SCUOLA DI DOTTORATO DI RICERCA IN SCIENZE PSICOLOGICHE

INDIRIZZO: PSICOLOGIA DELLO SVILUPPO E DEI PROCESSI DI SOCIALIZZAZIONE

XXI CICLO

OBJECT PERCEPTION IN EARLY INFANCY: THE ROLE OF ATTENTIONAL AND PERCEPTUAL PROCESSES

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Riassunto

Uno dei problemi fondamentali nello studio dello sviluppo cognitivo è quello di comprendere in che modo i bambini riescono a segmentare il flusso continuo di informazioni che ricevono dall'ambiente in unità percettive discrete e ad integrare tali unità in strutture percettive coerenti. Infatti, l'ambiente che ci circonda è generalmente costituito da un insieme complesso e strutturato di oggetti presenti simultaneamente nel campo visivo. Di conseguenza, fin dalle prime settimane di vita il nostro sistema visivo deve selezionare e integrare l'informazione proveniente dall'ambiente per percepire gli oggetti come separati e distinti. Il processo percettivo che permette di integrare le singole caratteristiche di un oggetto è indicato in letteratura con il termine figural binding. Il binding percettivo e l'attenzione selettiva sono due processi fondamentali per percepire gli oggetti come unità discrete. Il binding percettivo permette al sistema visivo di integrare le singole parti di un oggetto. L'attenzione selettiva permette di selezionare le informazioni rilevanti per la percezione di oggetti unitari e di focalizzarsi sui singoli oggetti all'interno della scena visiva. Negli adulti, tali processi operano in modo estremamente rapido ed efficace (Kellman & Shipley, 1991). Tuttavia, non è chiaro come il binding percettivo e l'attenzione selettiva interagiscono nel supportare l'integrazione delle diverse caratteristiche di un oggetto nei primi mesi di vita.

Lo scopo della mia tesi era quello di indagare il ruolo dei processi attentivi e percettivi nella percezione di oggetti alla nascita e nei primi mesi di vita, in situazioni sperimentali in cui sono state presentate sia figure reali che figure illusorie e in cui i bambini sono stati testati attraverso compiti di abituazione visiva e di ricerca visiva.

Nel primo studio, utilizzando la tecnica dell'abituazione, sono stati condotti tre esperimenti per indagare la capacità di bambini neonati di percepire una barra verticale parzialmente occlusa da una barra orizzontale costituita da contorni illusori quali quelli di Kanizsa. Sia la barra verticale che la barra orizzontale sono state presentate in movimento (Esperimenti 1, 2 e 3). Recentemente è stato dimostrato che, fin dalla nascita, i bambini sono in grado

di percepire un oggetto parzialmente occluso (i.e., completamento amodale, Valenza, Leo, Gava, e Simion, 2006), e di percepire una figura illusoria di Kanizsa (i.e., completamento modale, Valenza e Bulf, 2007). In questo studio la percezione dell'oggetto occluso era possibile solamente grazie al contemporaneo completamento amodale della barra verticale e al completamento modale dell'occusore illusorio. I risultati hanno dimostrato che, i neonati hanno percepito la barra occlusa e l'occlusore illusorio come oggetti unitari, dimostrando così che fin dalla nascita, almeno quando gli stimoli sono presentati in movimento, il nostro sistema visivo è in grado di utilizzare contemporaneamente i processi di completamento modale e amodale per integrare l'informazione visiva e, di conseguenza, percepire gli oggetti come unitari. Inoltre, questi risultati supportano l'ipotesi che l'informazione cinetica facilita la percezione di oggetti alla nascita, attirando l'attenzione del bambino verso gli elementi visivi che devono essere integrati per la soluzione del compito percettivo. In altre parole, i risultati dei primi tre esperimenti del presente lavoro di tesi suggeriscono che, oltre a processi di completamento percettivo, nella prima infanzia l'attenzione selettiva è un processo fondamentale per veicolare la percezione di oggetti unitari.

Utilizzando un sistema per la registrazione dei movimenti oculari (i.e., eye tracker), è stato verificato se una figura di Kanizsa catturava l'attenzione di bambini di 6 mesi di vita in un compito di preferenza visiva in cui la figura illusoria era presentata assieme ad una figura di controllo. L'eye tracker ha permesso di registrare la latenza della prima saccade verso i due stimoli, una variabile standard per misurare l'orientamento attentivo nei primi mesi di vita (Cohen, 1972). I risultati hanno dimostrato che i bambini hanno selezionato più velocemente la figura di Kanizsa rispetto allo stimolo di controllo, dimostrando che l'attenzione è stata catturata dalla figura di Kanizsa. Complessivamente, i risultati di questo primo studio hanno dimostrato che, nei primi mesi di vita, sia i processi di binding percettivo (Esperimenti 1, 2 e 3), che i processi di attenzione selettiva (Esperimento 4) supportano la percezione di un oggetto illusorio.

Nel secondo studio è stata indagata la relazione tra i processi di binding percettivo e i processi di attenzione selettiva nell'integrare le singole caratteristiche di un oggetto. Utilizzando l'eye tracker, adulti e bambini di 6 mesi di vita sono stati testati in un compito di ricerca visiva di una figura illusoria. Tale procedura è comunemente utilizzata negli adulti per indagare se il binding percettivo degli elementi induttori di una figura illusoria sono indipendenti dall'attenzione selettiva spaziale o se, al contrario, il binding percettivo richiede l'intervento dell'attenzione (Davis & Driver, 1994). L'utilizzo di un eye tracker permette di utilizzare gli stessi stimoli e la stessa procedura per gli adulti e i bambini e, di conseguenza, di confrontare direttamente il comportamento visivo nelle due diverse età. Ai partecipanti sono state presentate una figura illusoria e una figura reale inserite in un display di elementi distrattori (Esperimenti 5-9). La percezione della figura illusoria era possibile solamente grazie al binding degli elementi induttori. L'analisi dei movimenti oculari ha permesso di evidenziare che sia la figura illusoria che la reale catturavano automaticamente l'attenzione degli adulti (i.e. effetto pop out), dimostrando così che il binding percettivo degli elementi induttori di una figura illusoria non richiede attenzione selettiva spaziale. Al contrario, i bambini hanno mostrato un effetto pop out solo quando un target reale percettivamente saliente è stato presentato all'interno del display (Esperimento 7). Invece, quando la ricerca visiva ha implicato la selezione di un target illusorio (Esperimenti 7 e 9), o quando è stato presentato un display in cui il target reale era percettivamente più simile ai distrattori, i bambini hanno orientato l'attenzione all'interno del display in maniera casuale, dimostrando che nei primi mesi di vita il binding percettivo di una figura illusoria non opera in modo analogo agli adulti.

Complessivamente, i dati dimostrano che, sebbene i processi di binding percettivo (Espermenti 1-3) e di attenzione selettiva (Esperimento 4) supportino la percezione di una figura illusoria molto precocemente nel corso dello sviluppo, nei bambini di pochi mesi di vita il binding percettivo non opera in modo automatico come avviene negli adulti (Esperimenti 5-9). Questo risultato suggerisce che, nella prima infanzia, l'attenzione selettiva è un processo fondamentale per il binding percettivo delle caratteristiche di un oggetto, e che il modo in cui tale processo opera influisce sulla capacità del sistema visivo di raggruppare gli elementi di un oggetto in modo automatico, come dimostrato negli adulti.

Summary

One central issue in developmental cognitive science is to understand how infants detect the meaningful units in the flow of perceptual information and integrate these units into a coherent structure. Actually, at any given moment the infant is confronted with a visual field that must be differentiated into objects and from which one of these objects must be selected as the next focus of attention. Perceptual binding and selective spatial attention are two fundamental processes that help to perceive the outside world. Binding is necessary to link the different features of a single object. Selective attention serves to focus onto small subset of incoming information. The selection and binding of the various parts of an object in the correct combination pose little difficulty for adults, who readily report veridical object perception under most viewing conditions (Kellman & Shipley, 1991). It is still not clear however how exactly these two mechanisms operate and interact in early infancy.

Using real and illusory figures and habituation and visual search tasks, the purpose of this thesis was to study the role of perceptual and attentional processes affect object processing from birth to early infancy.

In Study 1, using the habituation technique, a first set of experiments has investigated whether newborns were able to link together spatially separated fragments to perceive the unity of a moving rod partly occluded by a moving Kanizsa-type illusory box (Experiment 1, 2 and 3). Recent evidence demonstrated that 1- to 3-day old babies can fill in spatial gaps when they are asked to perceive the unity of a partly occluded object (i.e. amodal completion, Valenza, Leo, Gava, & Simion, 2006), or when they are asked to perceive an illusory object composed from a number of spatially separate elements (i.e. modal completion, Valenza & Bulf, 2007). In the present study, both modal (illusory box) and amodal (occluded rod) visual completions had to be simultaneously used to solve the perceptual task. Results showed that newborns perceived the partly occluded rod and the illusory box as complete objects, providing evidence that, at least when motion information was used, newborn infants were able to utilize simultaneously modal and amodal completions to perceive object unity. These findings support also the hypothesis

that dynamic displays facilitate the solution of many perceptual tasks because motion triggers infant's attention toward the visual information that must be integrated. In other words, the results of the first three experiments reported in my thesis suggest that, beside perceptual binding, even attention has a crucial role in perceiving veridical object during early infancy.

Using an eye tracker system, in a subsequent experiment (Experiment 4) saccades latency, which is a standard variable to measure orienting of attention in infancy (Cohen, 1972), was measured to determine whether a Kanizsa illusory figure triggers 6-month-old infants attention over a control stimulus. Results showed that infants detected the illusory figure faster than the illusory one, showing that the Kanizsa figure was able to orient infants' visual spatial attention. Overall, this outcome demonstrates that both perceptual binding (Experiments 1,2 and 3) and selective spatial attention (Experiment 4) support the perception of an illusory figure in early infancy.

In Study 2, it was investigated the relation between perceptual binding and selective spatial attention, to determine how selective attention drives the binding of the single features of an object. Using an eye tracker system, adults' and 6-month-old infants' visual search behaviour was compared in a visual search task of an illusory figure. Visual search of illusory figures is usually used in adults' literature to assess whether the binding of different fragments of an illusory object is independent of selective spatial attention or, on the contrary, whether perceptual binding requires spatial attention to be performed (e.g., Driver & Davis, 1994). The eye tracker system allowed us to use the same stimuli and procedure for adults and infants and, as a consequence, to directly compare adults' and infants' visual behavior. Participants were presented with an illusory figure and a real figure embedded in a display of competing stimuli (Experiments 5-9). The illusory figure was clearly seen due to the visual binding of its inducing elements, although a large part of their contour was not present. The analysis of the visual scanning patterns showed that both the illusory figures and the real figures automatically trigger visual spatial attention in adults (i.e. pop out effect), providing evidence that adults' perceptual binding of separate elements to perceive an illusory object does not require spatial attention. In contrast to adult's data, infants show a pop out effect only when a high salient real target has to be detected (Experiment 7). Conversely, when an illusory target (Experiments 7 and 9) was used, or when the real target-distractors similarity was increased (Experiment 9), infants spread out their attention within the display in a casual manner, showing that in early infancy the binding processes involved in the perception of an illusory figure do not operate in an adult-like manner.

Overall these data demonstrate that, although perceptual (Experiments 1-3) and attentional (Experiment 4) processes in supporting the binding of an illusory figure are functional very early during the development, infants are not able to automatically bind an illusory figure when it is presented in among competing stimuli, as found in adults (Experiment 5-9). This outcome suggests that selective attention is determinant to affect the way in which perceptual binding operates during early infancy, leading to the ability to perform binding automatically, as found in the adults' visual system.

Introduction

One central issue in developmental cognitive science is to understand how infants detect the meaningful units in the flow of perceptual information and integrate these units into a coherent structure. To understand human speech, for example, infants must break down multiple continuous spaces of possible speech sounds – such as the continuum between /ba/ and /pa/ - into an inventory of discrete phonemes. Auditory and visual environments are alike in important ways: they both consist of overlapping inputs that must be differentiated and segmented.

At any given moment, the infant is confronted with a visual field that must be differentiated into objects and from which one of these objects must be selected as the next focus of attention. Actually, many of the objects are partly occluded by other, nearer surfaces, and it's routine for objects to go in and out of sight. The visual system, therefore, is adept at imparting structure to an incompletely specified visual array. To perceive an object, for example, an observer must register its missing portion using available information from the visible segments, including their shape, position, orientation, motion, relative distance, color and texture (Johnson, 2005). The selection and binding of the various parts of an object in the correct combination pose little difficulty for adults, who readily report veridical object perception under most viewing conditions (Kellman & Shipley, 1991).

How does this way of experiencing the word arise? Does the young infants possess similar percepts to adults, in that he or she is born with impressions of *segregated, coherent objects at various distances? Or does the infant's visual world consist of a series of disjoint, unrelated shapes that do not cohere into a sensible array until some period of development?*

These questions have long interested philosophers and psychologists. For example, James (1890) describes the neonate's perceptual experience as chaotic, characterized by a "blooming, buzzing confusion". This position was echoed by Piaget (1954) who proposed that, at birth, the infants' visual world consists of a patchwork of moving colors and shapes, as opposed to segregated, coherent objects. Perceptual organization was thought to emerge only gradually over the first two postnatal years, via direct manual experience with objects and coordination of visual, auditory and tactile information. Although Piaget's observations and descriptions have enjoyed strong support from repeated replications over the past several decades (for a review see Bremner, 1985; Marcovitch & Zelazo, 1999), his interpretation of infants' behavior has come under fire, mostly from researches that have used methods that are claimed to be more sensitive in tapping underlying cognitive construct.

Researchers who have used indices that do not depend on manual activity have provided strong evidence that Piaget underestimated the conceptual abilities of young infants (e.g. Baillargeon, Spelke, & Wasserman, 1985; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Kellman & Spelke, 1983). Actually, although young infants lack the capacity for free movement, their oculomotor system is largely functional shortly after birth, and infants make good use of it to learn about the world. Thus, the developmental origin of the ability to represent objects comes from experiments in which looking times are recorded to novel or ostensibly unexpected events. Many studies have provided evidence that infants shortly after birth are able to select and process different kinds of visual information to pursue a veridical object perception (e.g. Condry, Smith, & Spelke, 2001; Johnson, 2005; Valenza, Leo, Gava, & Simion, 2006). Such work has provoked a re-conceptualization of the infant as an active, organized information processor rather than a collection of passive and disorganized sensory receptors.

Starting to this theoretical framework, the present thesis will investigate when and how infants show the ability to parse and bind together different visual surfaces to perform a veridical object perception. Moreover, it will be investigated whether the perceptual binding of different fragments of an object is independent of selective spatial attention or, on the contrary, whether perceptual binding requires spatial attention to be performed. *In other words, the main purpose of this thesis is to study the perceptual and attentional processes that support the perception of coherent and unitary objects in complex visual scenes.*

The first part of my work will start reporting the developmental literature concerning the origin and development of infants' ability to perceive objects. In Chapter 1, infants' studies addressed to investigate how binding processes operate in supporting the visual completion of an object at birth and across the next several months will be reported. Two different tasks that are classically used to study the development of perceptual organization will be described: the ability to perceive partly occluded objects and the ability to perceive illusory objects. In Chapter 2, I will report the first study of my thesis aimed at investigating the role of perceptual binding and selective attention in newborns' ability to link separate fragments of an object through a spatial gap. Previous studies demonstrated that one- to three- day-old babies can fill in spatial gaps in a visible surface layout when they are asked to perceive the unity of a center-occluded object (i.e. amodal completion; Valenza, Leo, Gava & Simion, 2006), and when hey are asked to perceive an illusory object composed from a number of spatially separate elements (i.e. modal completion; Valenza & Bulf, 2007). Using the habituation technique, three experiments will be performed to confirm and extend these findings, investigating whether newborns are able to perceive the unity of a partially occluded rod when a illusory box is used (Experiment 1, 2 and 3). Both modal and amodal perceptual completion have to be simultaneously used to link edges across the spatial gap in the illusory box and the occluded rod respectively. Subsequently, the role of selective attention in the perception of an illusory Kanizsa figure in 6-month-old infants will be investigated in a classic preference task. More precisely, a Kanizsa square will be presented with a control stimulus that does not give rise to illusory contours (Experiment 4).

The second part of my thesis will consider the relation between selective attention and perceptual binding to perceive unitary objects in early infancy. Chapter 3 will contain documentation of developmental studies that have investigated how selective attention affects the detection of objects in visual environments. Subsequently, in Chapter 4, I will describe the connections between attentional and perceptual processes, taking into account recent studies that have tried to explore the relation between figural binding and attention during the perception of an object. Finally, in Chapter 5, the second study of my thesis regarding the relation between selective spatial attention and perceptual binding to link different fragments of an object will be described. The main goal of this study will be to investigate how selective attention affects perceptual binding in the perception of an illusory figure in 6-month-old infants and adults using an eye tracker system. Adults' (Experiments 5, 6, and 8) and 6-month-old infants' (Experiment 7 and 9) detection of a real and an illusory target will be tested in a visual search task. The use of an eye-tracker system will allow to directly compare infants' and adults' visual search strategies during the solution of the task. Many studies that measured the relation between eye movements and attentional processing in visual search tasks indicated that the assessment of eye movements can be used as an accurate measure of visual search mechanisms (Zelinsky & Sheiberg, 1997; McSorley & Findlay, 2003; Motter & Belky, 1998).

To summarize, the first study of my thesis contributes to verify under which conditions newborns are able to link together the spatially separate fragments of a single object in the correct combination (perceptual binding), revealing that the ability to parse and bind together different visual surfaces to perform a veridical object perception occurs very early during development and implies either perceptual or attentive mechanisms. Moreover, the second study outlines the role of selective spatial attention in performing a veridical object perception, providing evidence that spatial attention is determinant to affect the distribution of the infants looking behavior, and consequently, the way in which perceptual binding operates in the first months of life.

Chapter 1

Infants' perception of object unity

The ability to perceive an object when it is incompletely specified in the given stimuli is called visual completion. Visual completion has been divided into two types: modal and amodal (Michotte, Thines, & Crabbe, 1964, 1991). Modal completion refers to completion that produces a visible quality such as luminance or color. Amodal completion, refers to completion that does not produce visible quality. This type of completion occurs in occlusion situations. While modal and amodal completion have phenomenally different appearance, both of these processes support object perception by grouping segments separated in space. Amodal and modal visual completion supported the ability to perceive partly occluded objects and illusory objects in different ways, which are described in the next paragraphs.

1.1 Infants' perceptual completion of partly occluded objects

To accomplish perceptual completion of a partly occluded object an observer must register its missing portions using available information from the visible segments, a process called amodal visual completion. Such tasks usually pose little difficulty for adults, who readily report perception of edge continuity under many conditions (e.g., Kellman & Shipley, 1991). How do infants come to achieve perceptual completion?

Kellman & Spelke (1983) tested for perception of object unity with a paradigm that assumes a novelty preference after habituation to a rod-and-box display (Figure 1).

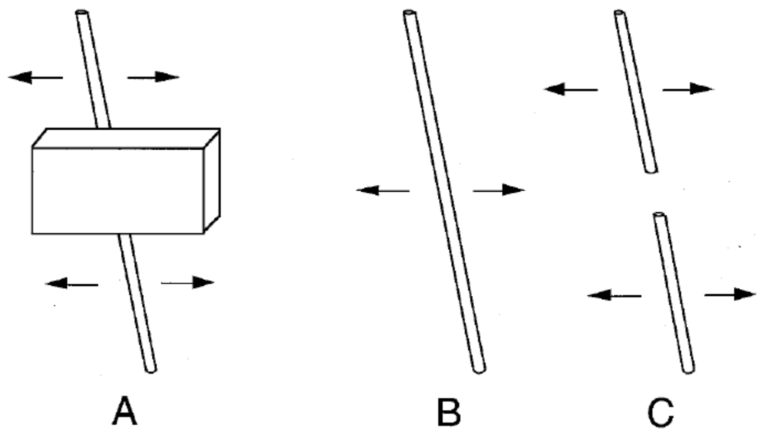

Figure 1: Displays presented to young infants in surface perception studies. (A) Rod-and-box display in which two visible rod parts are aligned and undergo common lateral motion. (B and C) Complete and broken rod test displays, respectively (Kellman & Spelke, 1983).

Four-month-old infants were familiarized with a moving rod whose center was occluded by a box. After the habituation to the moving rod, infants look longer at a non-occluded presentation of a broken rod, whose portions correspond to the visible portions of the rod presented during familiarization, than at a complete rod. Conversely, infants failed to show a test display preference after viewing a static rod-and-box arrangement. This result implies that, at least when motion information is available, infants experienced the partly occluded rod as more similar to the complete test stimulus, i.e. as a single, coherent object. More intriguingly, when infants viewed two dissimilar, nonaligned surfaces moving together behind an occluder, they provided evidence to perceive the unity of the rod (Figure 2).

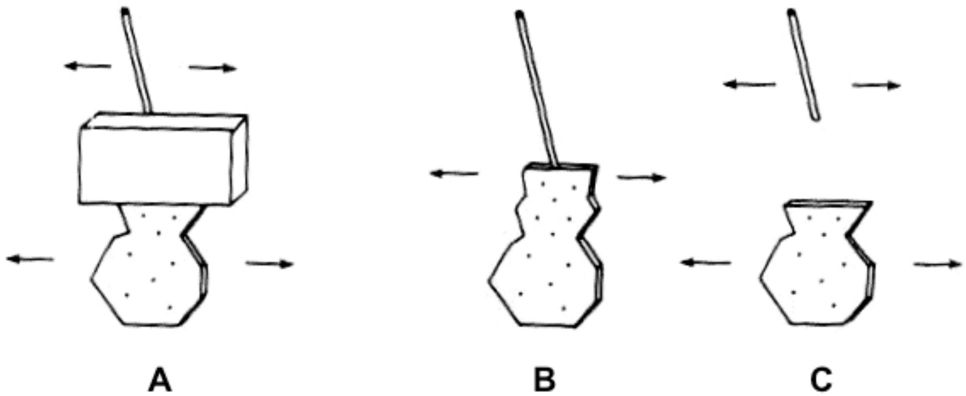

Figure 2: (A) A rod part and a dissimilar surface undergo common lateral motion. (B and C) Test displays: the rod part and the dissimilar surface are either connected or not connected (Kellman & Spelke, 1983).

In other words, infants' ability to perceive the partly occluded object was not affected by the simplicity or regularity of the rod's color, shape or texture, relying solely on common motion. Static information (such as alignment of the rod parts across the occluder) is insufficient to specify unity. Kellman & Spelke (1983) concluded that humans may begin life with the notion that the environment is composed of things that are coherent, that moves as units independently of each other, and that tend to persist, maintaining their coherence and boundaries as the move. Spelke (1990) has since proposed that the earliest kind of object perception can be characterized as reasoning in accord with fundamental physical principles. One of this is the principle of contact: visible surfaces that undergo a common, rigid motion tend to be connected (Spelke & Van de Walle, 1993).

Although Spelke (1985) puts forward the view that infants begin life with an innate conception of the underlying unity, persistence, and coherence of objects, researches with infants at birth demonstrated that newborns have sensory system sufficient to ascertain the boundaries and motions of many visible surfaces, but there is no evidence of any ability to detect more than what is directly visible (Slater, Morioson, Somers, Mattok, Brown, & Taylor, 1990). More precisely, when neonates were examined for perception of object unity in partly occluded objects, they showed a strong posthabitutation preference for a complete test display, implying that they did not perceive the occlusion. Thus, newborns did not act as like 4-month-old infants. However, there is an alternative interpretation of the age differences. It may be that perception of object unity is innately available to newborns, but that the test display that has been presented to them in the Slater et al.'s (1990) study did not contain sufficient information or cues for this ability to manifest itself. In other words, newborns' performance could be blocked by limits in their sensitivity to the information on which they operate. One possibility is that it is necessary for very young infants to appreciate that the occluded rod is in a different depth plane (behind) than the occluder, and that Slater et al.'s (1990) newborn infants did not detect this depth relationship. This possibility was investigated by Slater, Johnson, Kellman, & Spelke, (1994) who tested newborn infants in a condition where the gap between the occluder and the rod was large enough to be reasonably confident that they detected the separation. However, in Slater et al.'s (1994) study, a reliable preference on the test trials for the continuous rod was found, which is a preference in the same direction as that found earlier by

Slater et al., (1990). These findings suggest the time between birth and four months seems to be the period during which accurate responses to occlusion emerge.

This conclusion have been weakened by more recent researches addressed to investigate at what age infants can first perceive object unity, which is the developmental trend below the ability to perceive an object in absence of a direct perceptual support, and which are the mechanisms of development that underline the representation of an occluded object.

In the first study to explore this question, Johnson & Nanez (1995) demonstrated that 2-month-old infants exhibited no preference for either a broken or a complete rod test display after habituation to a rod-and-box display. This lack of a consistent preference indicates that perception of object unity may be emerge at about this time. That is, whereas 4-month-old infants prefer the broken rod (and thus infer the unity of the rod pieces) and neonates prefer the complete rod (and thus perceive the rod pieces as disjoint objects), 2-month-olds show a pattern of preferences in between these two types of response. In a follow-up investigation, 2-month-old infants were presented with displays in which information of unity was facilitated by enhancing the amount of the rod visible behind the occluding box (Johnson & Aslin, 1995). Three displays were used in which the proportion of occlusion was decreased (Figure 3): the height of the box was reduced and one or two gaps, respectively, were placed in the occluder such that portions of the rod were visible as it moved across the display. In this experiments, the 2-month-olds showed a strong and consisted preference for the broken rod following habituation, showing that the enhancement of the visual information available in the display could support perception of object unity. Thus, when the infants' immature visual system can pick up the visual information available in the display, infants were able to solve the perceptual task.

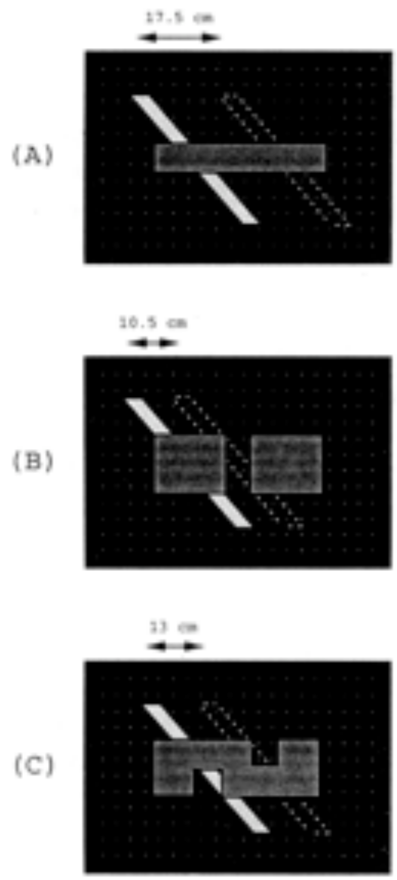

Figure 3: Displays used in Johnson and Aslin's (1995) study: (A) small-box display, (B) single-gap box display, and (C) double-gap box display. The extreme leftmost position of the rod in each display is shown as a solid figure, and the extreme rightmost position as a dotted figure.

This result is in line with the study of Kawataba, Gyoba, Inoue, and Ohtsubo (1999), in which 1 month-old infants were shown to perceive a grating behind an occluder when the spatial frequency of the grating matched the infants' visual system spatial contrast sensitivity (Figure 4). This results narrow the age range of development to 1 and 2 months after birth, implying that the shift toward the ability to perceive object unity is a very rapid developmental phenomenon.

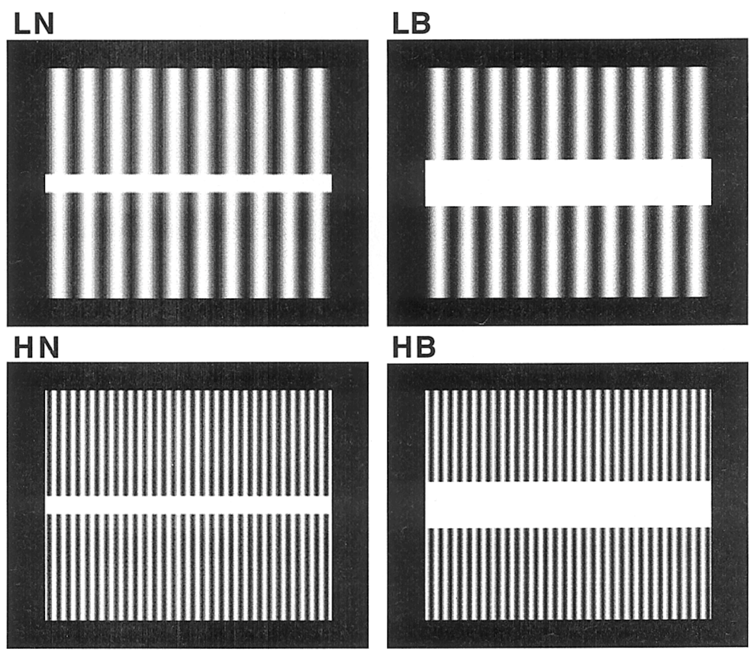

Figure 4: Kawataba et al. (1999) habituation displays comprise low spatial frequency grating and narrow occluder display (LN), low spatial frequency grating and broad occluder display (LB), high spatial frequency grating and narrow occluder display (HN), and high spatial frequency grating and broad occluder display (HB). One-month-old infants perceived the continuation of occluded grating in the LN display, but not in the LB, HN, and HB displays.

1.1.1 <u>The threshold model</u>

Overall, the outcome described in the previous study (Johnson & Aslin, 1995; Kawataba et al., 1999) have been interpreted as supporting the threshold model (Johnson & Aslin, 1996; Johnson, 1997) that describes the relationship between the sufficiency of visual information in the display and the efficiency of and infants' perceptual and cognitive skills. How does the model work?

In the experiment of Kellman & Spelke (1983) the objects used in tests for unity perception had edges that were aligned across the occluder. Only when the edges moved together did infants provide evidence of unity formation. There was no evidence of unity perception of aligned, static edges. Kellman (1993; 1996) proposed that sensitivity to alignment as a cue for unity follows a two-step process. The first process was denoted edge-insensitive (EI), and was proposed to be the only process available to infants younger than 6 months. The EI process specifies object unity by relying on motion, but not other cues such as the orientation of edges as they intersect with the occluder and the configuration or appearance of the partly occluded surfaces. The second process was denoted edge-sensitive (ES) and was proposed to become available to infants older that 6 months. The ES process exploits a range of cues, including edge orientation and alignment. Given that the ES process is unavailable to young infants, they would not be capable of unity perception based on visual information other than motion. Thus, Kellman (1996) predicted that 4-month-old infants would perceive unity in any display in which two visible rod parts undergo common motion.

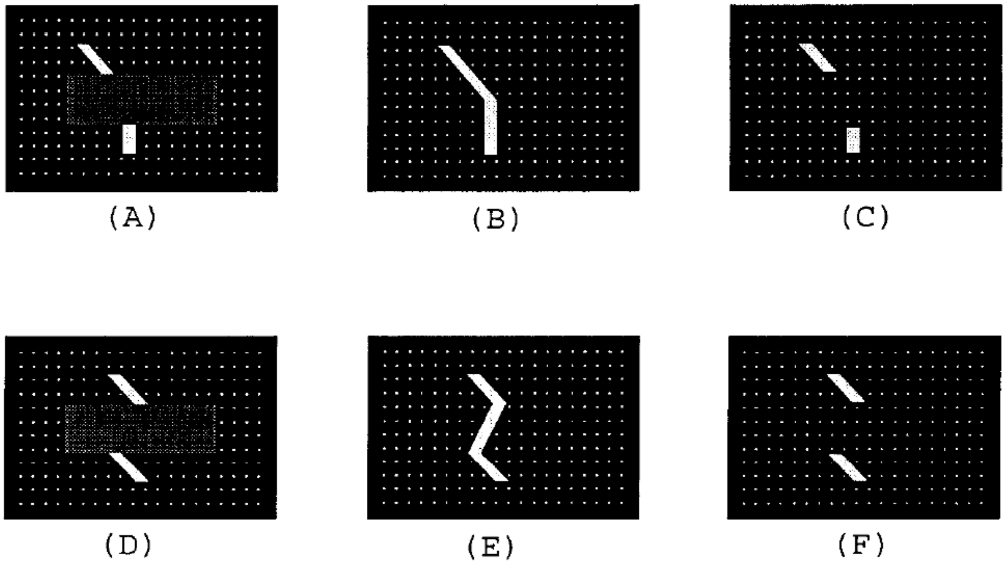

Figure 5: The displays used in Johnson & Aslin's (1996) study. A) Nonaligned, relatable habituation display, (B) Nonaligned, relatable complete rod display, (C) Nonaligned, relatable broken rod display, (D) Nonaligned, nonrelatable habituation display, (E) Nonaligned, nonrelatable complete rod display, and (F) Nonaligned, nonrelatable broken rod display.

Johnson & Aslin (1996) tested this hypothesis by habituating 4-month-old infants to rod-and-box displays in four conditions in which the rod parts underwent a common lateral motion. The first group of infants viewed a rod-and-box display against a textured background (a grid of dots), and subsequently exhibited a posthabituation preference for the broken rod. This result replicated the original findings of Kellman & Spelke (1983). The second group of infants viewed a rod-and-box display against a solid background with no texture elements, and showed no posthabitutation preference. The next condition used a misaligned rod display in which the rod parts were not aligned but were relatable, and the infants showed no test preference (Figure 5, A, B, C). Finally, a fourth group of infants viewed a nonalignement rod display in which the rod parts were neither aligned nor relatable (Figure 5, D, E, F), and they looked longer at the complete rod. This pattern of results provided evidence that infants in the first condition perceived the unity of the partly occluded rod. In contrast, percepts in the second and third conditions appear to have been indeterminate, and infants in the fourth condition seem to have perceived the rod parts as disjoint objects. Taken together, these findings indicate that unity perception does not appear to be driven exclusively by common motion. Rather, other cues, such as edge orientation and the presence of background texture, also support young infants' perception of object unity. Further experiments have revealed that also good form supports unity formation (Johnson, Bremner, Slater, & Mason, 2000).

To account for these results, Johnson (1997, 2000; Johnson & Aslin, 1996) proposed a threshold model, positing that unit formation process in young infants is multiply determined. The model suggests that a certain threshold of visual information is required for young infants to solve the object unity problem, in terms of orientation, depth, motion, shape, texture and color, rather than a single cue (motion). It may be that the threshold for perception of object unity is lower in older infants that in very young infants, and even lower in adults. That is, a threshold model would stipulate that insufficiency of cues may often be the best account of an apparent failure to perceive object unity in a particular display. In other words, perception of object unity may be a skill that, although fragile in its earliest form, is available to even very young infants if given adequate perceptual support (e.g. Kawataba et al., 1999).

To summarize, although early results seemed to indicate that infants relied on dynamic information alone and neglected configural information in perceiving object unity (Kellman & Spelke, 1983), more recent studies suggest that infants are able to use all the sources of information used by adults, including motion, contour alignment, and surface similarity (e.g. Johnson & Aslin, 1996). Where infants' perception are less clear that those of adults, this difference appears to reflect infants' lower sensitivity to these sources of information, in line with the threshold model (Johnson, 2000). A related consequence of infants' developing sensitivity is that studies of perceptual development must distinguish competence from performance (Condry, Smith, & Spelke, 2001). For example, when one finds, as Slater et al. (1990) did, that such infants at birth do not respond to a fully visible connected object as similar to a partly occluded one, however, one cannot conclude that this perceptual competence is absent. It is possible that the ability to binding the separate fragment of an object through a perceptual gap is present and functional at birth, but that newborns performance is blocked by limits on newborns' sensitivity to the information on which they operate (Condry et al., 2001).

Starting from this hypothesis, Valenza, Leo, Gava, and Simion (2006) tested the possibility that the failure of neonates to perceive object unity (Slater et al., 1990) could be due to the limitation in newborns' sensitivity to the visual information specifying unity. More precisely, Valenza et al. (2006) argued that the figural binding of the rod parts is masked in newborns' infants due to the poor perceptual skills that do not allow newborn infants to detect patterns of common motion over a spatial gap. Numerous studies provide evidence that the ability to track a moving stimulus improves in the first months of life (Johnson, 1990). When newborns track a moving stimulus, they perform a series of saccadic eye movements and tend to lag behind the movement of the stimulus, rather than predicting its trajectory. Conversely, by 2-3 months of age infants begin to show periods of smooth visual tracking and their eye movements often predict the movement of the stimulus in an anticipatory manner. If newborns were unable to detect object's common motion, they should have no preference between the test displays. For this reason, infants' latent object knowledge is expressed only later in development, when they become sensitive to the informative patterns of visual motions (Condry et al., 2001). To test this possibility, newborns were presented with a motion easily detectable by their immature visual system, i.e. a stroboscopic motion, a motion elicited by presenting the same object in temporally and spatially discontinuous positions. Stroboscopic motion, like other kind of motion, triggers attention, facilitated image segregation, and specifies surface boundaries (Tauber & Koffler, 1966; Yantis, 1995). The authors assumed that newborns infants could be facilitated to detect stroboscopic motion because this kind of motion does not require switching the gaze to track the trajectory of a moving stimulus, but only to make several saccades to keep the image of the target stable on the fovea. In other words, the stroboscopic motion does not require smooth pursuit. Results showed that newborns can link separate of a partially occluded object by detecting the common stroboscopic motion of the object' visible surfaces. Conversely, newborns failed to perceive a partly occluded rod as connected when it moves with a continuous translatory motion. Overall, this outcome provides evidence that newborns' failure to perceive the unity of a partly occluded object in past researches (Slater et al., 1990, 1994, 1996) may result from limits in infants' motion processing, rather than limits in object perception.

To summarize, the evidence to date on development of perception of object unity provides a clear evidence that mechanism for perceptual binding are functional even from birth, in absence of any visual experience, but infants' binding abilities increase in sensitivity and precision during the first months of life. The change in performance that occurs as an infant matures over the first 6 months of life appear to stem primarily from increases in sensitivity to motion information and spatial configuration over a spatial gap. This conclusion is in line with the threshold model: latent object knowledge precedes complete sensitivity to the visual information specifying unity, and when sensitivity emerge in ontogeny, object knowledge can be more fully expressed. These approach is confirmed by another line of research that attempted to study the origin and development of figural binding during infancy, i.e. the perception of illusory objects.

1.2 Infants' perceptual completion: the case of illusory objects

Illusory figures provide a second test case for examining the development of perceptual binding in infancy. Illusory figures are created by edged and lines that are perceived across areas where there are no luminance differences to indicate a contour. The best know example of illusory figures is provided by Kanizsa figures (1955; 1979), in which incomplete circular elements induce the perception of a triangle or a square. In these figures the illusion is created by the careful positioning of inducing elements, which are themselves luminance-defined figures perceived as being partly occluded by the illusory edges (Figure 6).

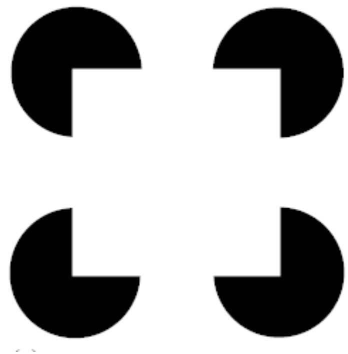

Figure 6: Kanizsa figure (1955, 1979).

When adults are shown such a figure, they typically report four characteristics: 1) the illusory figure seems brighter than the surrounding surface (apparent contrast); 2) a sharp border is perceived surrounding the area of brightness enhancement (illusory contours through modal completion); 3) the figure seems to be closer than the inducers, and seems to occlude them (apparent depth); 4) the inducers seem to be complete circles located behind the illusory figure (amodal completion). Illusory figures are useful for studying perceptual organization precisely because the perception of a coherent form depends crucially on the relationship among the inducing elements. Therefore it is possible to create control stimuli where the inducing elements are rearranged so as not to elicit perceptual grouping and consequently no perception of an illusory figure (Condry et al., 2001).

Using classical visual preference and habituation paradigms, developmental studies with human infants have explored the problem of when the modal completion of illusory figures emerges. Bertenthal, Campos, and Haith (1980) and Treiber & Wilcox (1980) suggest that this perception develops around 7 months of age. Using a visual habituation paradigm, Bertenthal et al. (1980) demonstrated that 7-month-olds but not 5-month-olds discriminate between a Kanizsa illusory square and a non-illusory control configuration produced by rotating half or all the inducing elements by 180° (Figure 7).

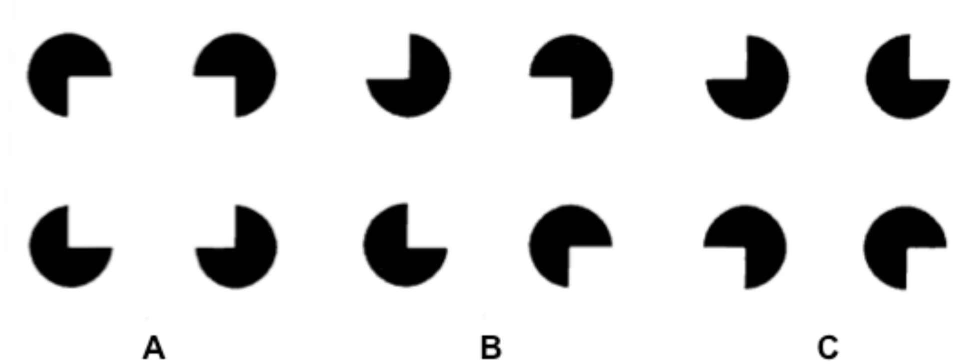

Figure 7: Stimuli generating subjective-contour perception (A) or not (B and C) (Bertenthal et al., 1980).

Accordingly, Treiber & Wilcox (1980) found that 1-4-month-old infants failed to discriminate between an illusory figure and a control stimuli.

Recent studies have further investigated illusory contour perception in infancy and provided further evidence of illusory contour perception in infants by 7-8 months of age. These studies, however, failed to find evidence for illusory contour perception in infants younger than 6 months. In a EEG study Csibra, Davis, Spratling, and Johnson (2000) investigated binding-related gamma oscillation in 6- and 8-month-old infants while they viewed static illusory objects. The brain activation elicited by a Kanizsa square was compared to that elicited by a control stimulus in which the inducing elements were arranged so as not to elicit perceptual grouping and consequently no percept of an illusory figure. In adult human brain, the recording of cerebral activity indicated a close link between binding processes of separately stimulus features and 40-hertz (gamma-band) oscillations generated by localized neural circuit (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1996; Muller et al., 1996). Results showed that 8-month-olds showed gamma burst similar to those of adults when perceiving illusory objects that require feature binding of spatially separate elements. This pattern of results was not found in 6-month-old infants. When considered together, these results suggest that infants less than 6 months of age have only a weak ability to perceive illusory contours.

Other studies, however, contradict these observations by providing evidence for an earlier onset of the ability to perceive illusory figures. Ghim (1990) found that infants aged 3-4 months were apparently capable of reacting to a Kanizsa square. Infants were shown to discriminate a pattern with subjective contours from patterns without subjective contours (Figure 8), but they did not discriminate among different patterns without subjective contours, demonstrating that babies were able to extract the global organization, that is, the configurational aspects of the illusory pattern instead of the featural information embedded in two-dimensional stimuli.

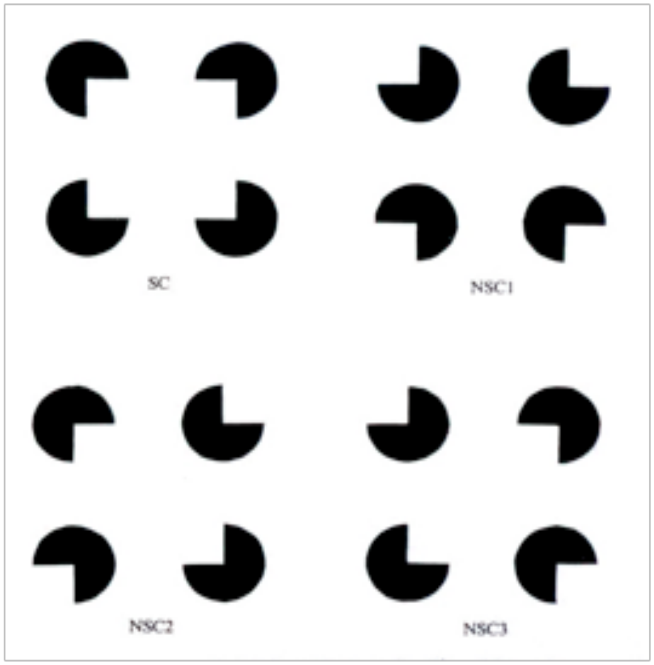

Figure 8: Four stimuli used in Ghim's (1990) experiments. The SC pattern produces subjective contours forming a square. The three NSC patterns do not produce subjective contours.

Similarly, Otsuka, Kanazawa, and Yamaguchi (2004) found that infants aged 3-4 months are capable of responding to a Kanizsa square if the ratio of the physically specified contour within the pattern to the total edge length is sufficiently large. Previous researches have shown that for adult observers the illusory-contour strength increases proportionally with the support ratio (Banton & Levi, 1992; Kojo, Liinasuo, Rovamo, 1993; Pillow & Rubin, 2002). Starting from this evidence, Otsuka et al. (2004) measured infants' preference for illusory-contour over non-illusory figures, varying the support ratio (Figure 9). When the support ratio was relatively high (66%), infants preferred illusory contours to the control stimulus by 3-4 months of age. In contrast, only 7-8-

month-old infants showed this preference when the support ratio was low (37%).

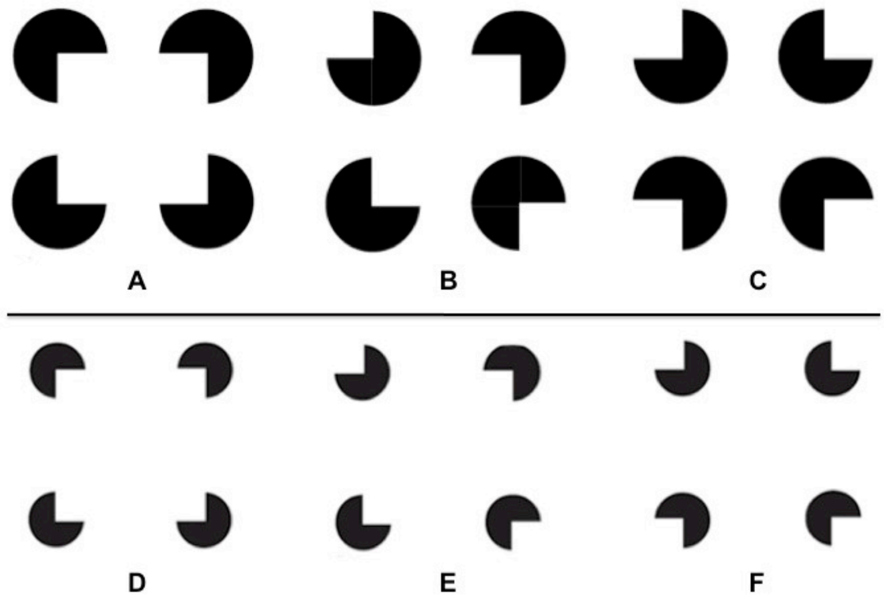

Figure 9: Stimuli used in Otsuka et al.'s (2004) study: (A and D) illusory-contour figures and (B, C, E, and F) non-illusory-contour figures. The support ratio of the illusory contours is 66% (A) or 37% (D).

All these investigations pertain to static subjective contours. Further studies provide evidence that young infants are able to perceive an illusory contour if the subjective pattern is embedded in a dynamic display (Curran, Braddick, Atkinson, Wattam-Bell, 1999; Johnson & Mason, 2002; Kavsek & Yonas, 2006; Otsuka & Yamaguchi, 2003). For example, using a preferential looking technique, Ostsuka & Yamaguchi (2003) infants preferred an illusory Kanizsa figure to a non-illusory control stimulus under static and dynamic conditions (Figure 10).

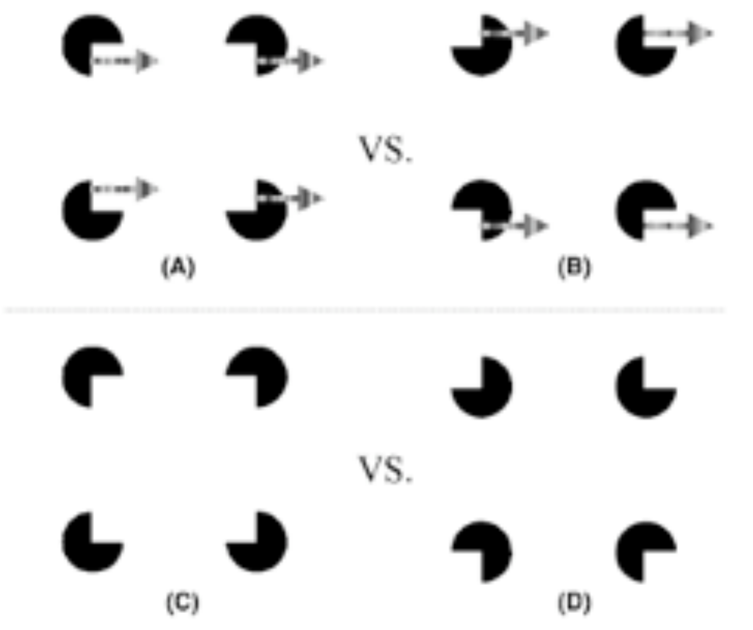

Figure 10: Stimuli used in Otsuka and Yamaguchi's (2004) study. Top figures illustrate the figures of the moving condition (A and B). Bottom figures illustrate the figures of the static condition (C and D).

Under the moving condition, the cut-off sectors of the inducing elements underwent lateral translation. This movement caused the inducing discs to be accreted and deleted. To an adult observer, the illusory contours under the moving condition looked like an illusory square moving back and forth laterally in front of the inducing disks. Infants were shown to preferred moving illusory contours to non-illusory contours by 3-4 months of age, and only 7-8-month-old infants preferred static illusory condition. These findings demonstrated that motion information promotes infants' perception of an illusory Kanizsa figure.

More intriguingly, Johnson & Mason (2002) explored perception of kinetic illusory contours by 2-month-old infants in sparse random-dot displays depicting an illusory shape against a background (Figure 11). Infants were habituated to a shape specified by accretion and deletion of background texture and relative motion, and exhibited a novelty preference when presented with luminance-defined familiar and novel shapes. These findings reveal an early capacity to perceive illusory shape solely from kinetic information.

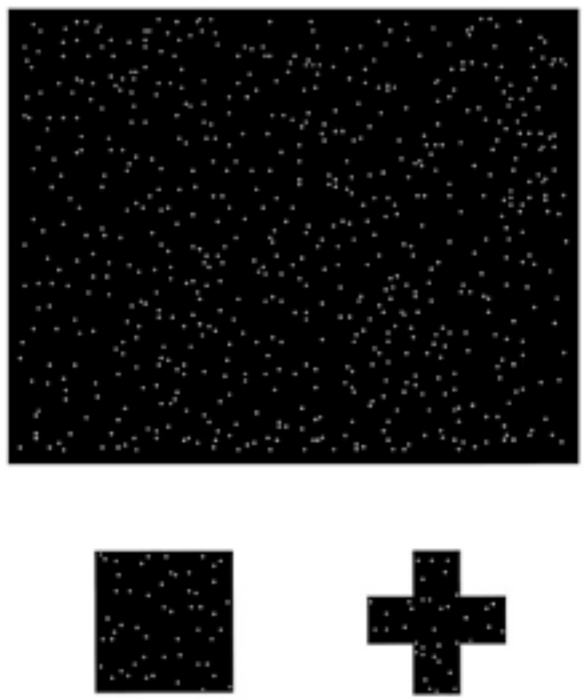

Figure 11: Displays used in Johnson and Mason's (2002) study. When the illusory shapes were stationary they were camouflaged and therefore invisible, because both shapes and background were composed of the same sparse texture.

Altogether, these outcomes are consistent with a recent view that maintains that perception of illusory contours is not an all-or-nothing process that appears suddenly, but is an ability that undergoes a gradual development starting within the first weeks of life (Kavsek, 2002). Actually, at least under particular condition, such as a high support ratio or kinetic conditions, the ability to perceive illusory contours is already present at 2-3 months of age. It is worth noting that motion information is a crucial and reliable factor in enhancing the perception of illusory contours in the first weeks of life, even though it is the only cue available in the display to solve the perceptual task (Johnson & Mason, 2002). This conclusion is not surprising because motion has been shown to be an important source of information for many other perpetual abilities in the first months of life. For example, research conducted over the past few decades has found that young infants' depth perception follows a specific developmental trend (Kellman & Arterberry, 1998). For example, research conducted over the past few decades has found that young infants' depth perception follows a specific developmental trend (Yonas & Granrud, 1985). Sensitivity to kinetic depth information appears to emerge first by 1 month of age (Náñez, 1988), followed by sensitivity to binocular disparity around 4 months of age (Braddick, Atkinson, Julesz, Kropfl, Bodis-Wollner, Raab, 1980; Granrud, 1986; Yonas Arterberry, Granrud, 1987), and sensitivity to pictorial depth cues that emerges between 5 and 7 months (Granrud, Haake, & Yonas, 1985; Granrud e Yonas, 1984; Granrud, Yonas, & Opland, 1985; Yonas, Granrud, Arterberry, & Hanson, 1986; Yonas, Granrud, & Pettersen, 1985).Moreover, as pointed out before, newborns are able to perceive a rod partly occluded by a box as connected when the rod moved laterally behind the occluder with a stroboscopic motion easily detected by the newborns' immature visual system (Valenza et al., 2006).

In line with this data, Valenza & Bulf (2007) investigated the role of motion in newborns' perception of illusory figures. Starting from the data obtained for the partly occluded objects (Valenza et al., 2006), newborns were assumed to be able to manifest the ability to perceive illusory contours at least when a stroboscopic motion easily detected by their immature visual system is used. In order to investigate whether newborns infants are able to use a pattern of stroboscopic motion to perceive illusory figures two experiments were conducted. In the first experiment it was tested whether motion information exerted a facilitating effect on the extraction of illusory contours at birth. Using a visual preference test, a Kanizsa figure in which incomplete circular elements induce the perception of a square will be presented together with a control non-illusory figure produced by 180° rotating the incomplete circular elements (Figure 12).

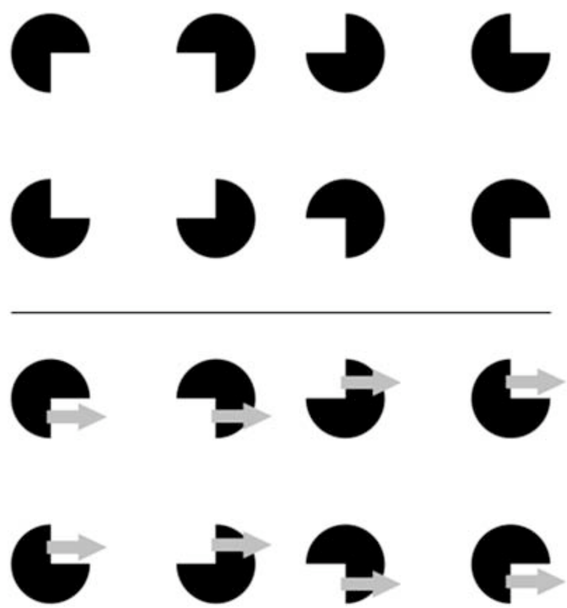

Figure 12: Stimuli used in Valenza and Bulf (2007). Top figures illustrate figures presented under static condition. Bottom figures illustrate figures presented under moving condition.

The two stimuli will be presented either in static or kinetic condition. Results showed that newborns manifest a preference for the illusory Kanizsa figure anly in the kinetic, but not in the static condition. In the second experiment it was investigated whether motion information alone could be use to perceive an illusory figure. Newborns were habituated to a moving random-dot shape that was matched with the background in terms of texture, color and luminance. Thus, the recovery of the illusory shape was possible relying only on kinetic information. Results showed that newborns manifested a novelty preference when presented with luminance-defined familiar and novel shapes. Altogether, these findings provide evidence that motion enhances and sometimes is sufficient to induce newborns' perception of illusory contours.

Overall, the developmental trend of illusory object perception parallel the results obtained in the developmental studies on partly occluded objects. More precisely, the ability to bind together a number of separate fragments to perceive an illusory figure stem from intrinsic properties of the human perceptual system and that the system for illusory object perception is operative even at birth but heavily constrained (Valenza & Bulf, 2007). This ability showed a clear progression across the first several postnatal months, most probably due to the growing of sensitivity to the source of information available in the displays (Condry et al., 2001).

1.3 Conclusions

In the present chapter, two different tasks concerning the development of perceptual binding have been explored: the perception of partly occluded and illusory objects. The perception of partly occluded objects is supported by the amodal completion of the rod's part that is not directly visible through the visual input, while Kanizsa illusory figures' perception relies on both the modal completion of the illusory contours and the amodal completion of the inducing elements, which are perceived as complete circles partly occluded by the illusory figure.

The studies reviewed in the present chapter provide evidence that the ability to link a real gap imposed by an occluder and the ability to link a virtual gap in an illusory contour display show a very similar developmental trend, improving rapidly during the first months of life as consequence of the growing of sensitivity to visual information that specify objects and their arrangements. Although heavily constrained, these abilities have been shown to be operative since birth.

Nevertheless, although infants' amodal completion of a partly occluded object is well established, the observation that infants are capable of performing modal completion processes in a Kanizsa illusory figure does not imply that they perceive a depth stratification in the illusory display. Evidence regarding young infants' ability to perceive the perception of the inducing elements in an illusory figure, or to perform both modal and amodal completion of an illusory figure in the same display is scarce, and it will be described in Chapter 2. No evidence for an illusory figure's depth stratification through amodal completion was provided at birth.

The research that will be described in Chapter 2 starts from this lack and it will try to investigate whether newborns were able to use both modal and amodal completion simultaneously to extract the depth order of visual surfaces in a rod and box display in which the box was defined by an illusory figure.

Chapter 2

Newborns' perception of partly occluded objects:

The role of modal and amodal completion

As it is extensively described in Chapters 1, the human visual system is predisposed from birth to perceive surfaces as belonging to coherent objects, and not as a collection of fragments that undergo continual changes in appearance. This ability has been provided presenting young infants with partly occluded objects (amodal completion) and illusory objects (modal completion).

Nevertheless, previous infants' studies have investigated modal and amodal completion separately. In contrast, often in real visual scenes veridical object perception requires that both modal and amodal completion are performed simultaneously in order to segregate single objects in complex visual scenes that contain multiple objects. Actually, to perceive a world of unitary objects, a mature visual system is adept at going beyond the fragment information that is directly available on the retina. Both modal and amodal completion built representation of complete contours, objects, and surfaces, acting on fragmentary input. This is the case of the visual completion of an illusory Kanizsa figure. Although a Kanizsa illusory figure is only partially specified, an adult observer can complete contours of a white figure lying in front of black circles (modal completion), and complete black circles as partly occluded objects in depth, behind the white illusory square (amodal completion).

Subsequently, studies that have examined adults' and infants' ability to perform modal and amodal completions simultaneously will be described.

2.1 Modal and amodal completion in adults

Studies with adults provided several common properties between modal and amodal completion.

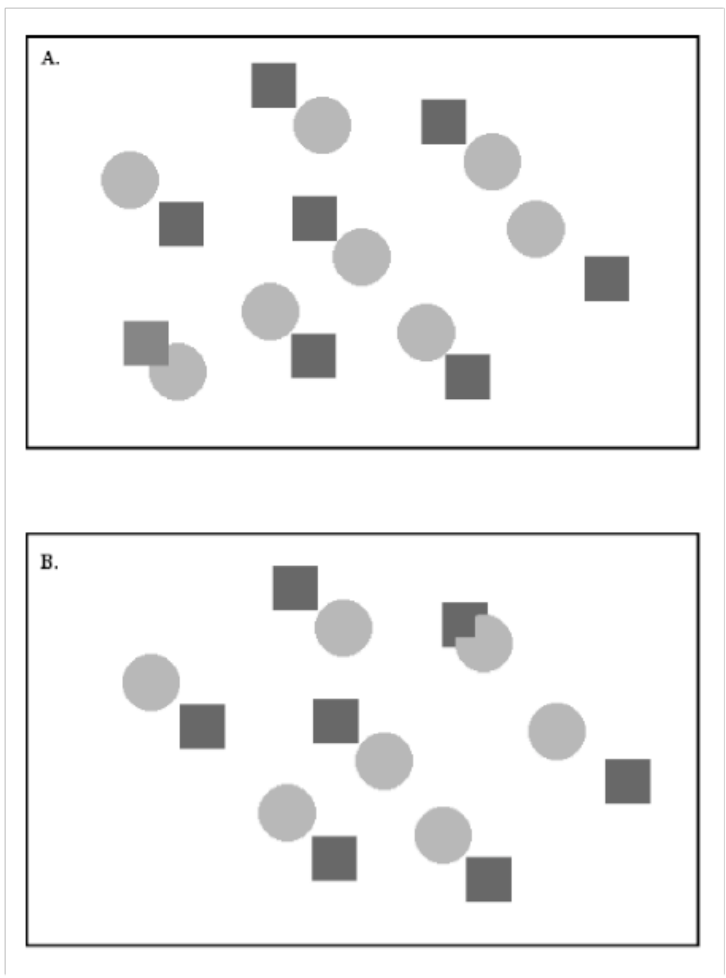

Figure 1: Search displays used in Rensink and Enns (1998). The task is to determine the presence or absence of a notched circle. The visual search is much harder in (A) (where the notched circle appears to be partly occluded in the notching region by the abutting square) than in (B).

For example, psychophysical studies with adults showed that both modal and amodal completion occur early in the visual processing. Rensnik & Enns (1998) examined whether amodally completed representation is used in visual search task. In their study, participants searched for a notched square among complete ones (Figure 1). Rensink & Enns found that a notched square fragment was easily detected when it was not occluded, but that the search task became difficult when the notched square was occluded, and hence was allowed amodal completion. Similarly, using a similar visual search task, Davis & Driver (1998) found that the Kanizsa subjective figures can induce amodal completion of a notched circle in this speeded task (Figure 2).

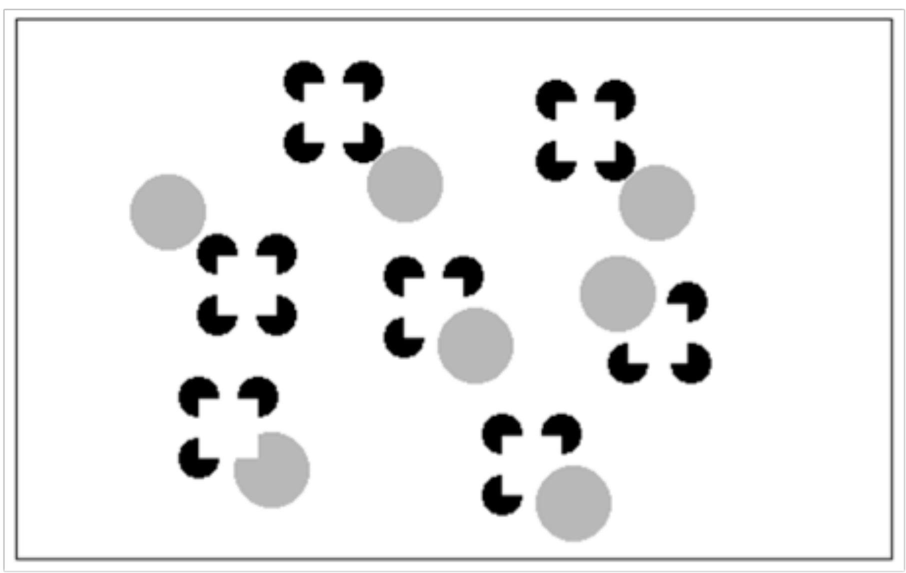

Figure 2: Search displays used in Davis and Driver (1998)

In their study, search for a notched-circle target became difficult when the notched target was arranged so that it formed a component element of the

Kanizsa square, and could be amodally completed. These results suggest that both modal and amodal completion occur rapidly in visual processing. Several research further examined the time course that is needed for modal and amodal completion to take place (Rauschenberger & Yantis, 2001; Sekuler & Palmer, 1992; Guttman & Kellman, 2004; Ringach & Shapley, 1996), providing evidence that both modal and amodal completion occurs rapidly within 100 to 200 milliseconds in visual processing and helps object recognition. In addition, it has been shown that the strength of modal and amodal completion depends on the same stimulus parameter. Shipley & Kellman (1992) examined the effect of relative position and orientation of the edge on the perceived strength of modal and amodal completion. They found that contour alignment has a nearly identical effect on observers' ratings of illusory contour strength and of the perceived unity of a partly occluded object. This common property between modal and amodal completion is taken as suggesting that there is a common mechanism underlying both modal and amodal completion (Kellman & Shipley, 1991; Shipley & Kellman, 1992; Kellman, Yin, & Shipley, 1998).

2.2 Modal and amodal completion in infants

In the developmental literature, only few studies have examined the ability to perform modal and amodal completion simultaneously (Johnson & Aslin, 1998; Condry, Smith, & Spelke, 2001; Cisbra, 2001; Otsuka, Kanazawa, & Yamaguchi, 2006). Condry et al. (2001) examined whether 4- and 7-month-old infants were able to perceive the amodal completion of inducing elements in a Kanizsa illusory square. To perceive the inducing elements as complete black circles, infants had to perceive the illusory contour (modal completion) and bound the black circles in depth (amodal completion). Thus, both modal and amodal completion had to occur. Infants were habituated to either an illusory square with incomplete discs as inducing elements or to a non illusory display in which all four inducing elements were rotated upward, and then they were tested with a single, semicircular inducing element or a single complete disc (Figure 3).

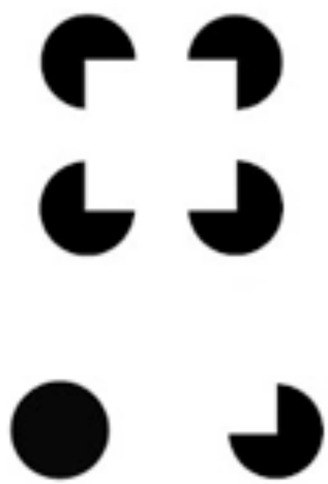

Figure 3: Search displays used in Rensink and Enns (1998).

At 7 months of age, infants habituated to the illusory square preferred the single inducing element during the test phase, whereas infants habituated to the non illusory display showed a preference for the complete disc, suggesting that they bound the inducing elements as complete circles when they were habituated to the illusory square. Conversely, 4-month-old infants showed no preference between the test displays. These results showed that from 7 months of age infants perceive the inducing elements in the illusory display as continuing behind the illusory Kanizsa figure, providing evidence that infants can use modal and amodal completion simultaneously. In accordance with this, Csibra (2001) found that 8-month-olds but not 5-month-olds perceive the apparent depth in the Kanizsa figure as adults do. Eight- and five-month-old infants were presented with scenes that included a Kanizsa square and further depth cues provided by the accretion and deletion pattern of a moving duck (Figure 4).

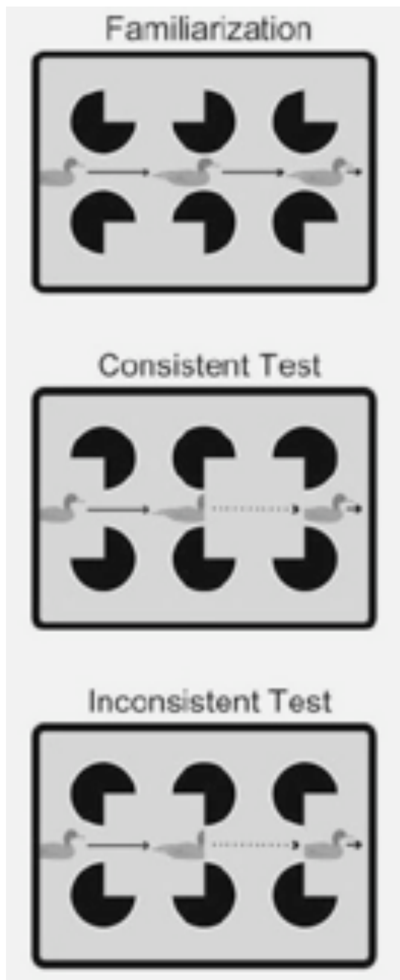

Figure 4: Stimulus events during the familiarization and test phases of Csibra's (2001) study. Solid arrows indicate visible motion, dotted arrows indicate implied motion.

The 8-month-old infants looked significantly longer at the scene when the two types of occlusion cues were inconsistent than when they were consistent with each other. This outcome provides evidence that they interpreted the Kanizsa square as a depth cue. In contrast, 5-month-olds did not show this difference. Altogether, these finding demonstrated that 8-month-olds but not 5-month-olds perceive the illusory figure as a real object that can act as an occluder. Similarly, Otsuka et al. (2006) examined the development of modal and amodal completion in 3-4 and 5-6 months of age, using a display composed of a partially overlapping circle and square. The display induced either modal or amodal completion depending on the color (Figure 5). Infants were familiarized with either the modal or the amodal display.

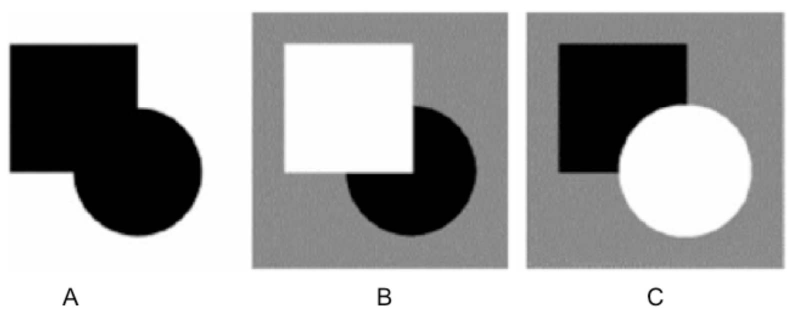

Figure 5: Modal display (A) and amodal displays (B and C) used in Otsuka et al.'s (2006) study.

After the familiarization, infants were tested on their discrimination between a complete figure and a broken figure. If infants could perceptually complete the figures during the familiarization phase, they were expected to show a novelty preference for the broken figure. After familiarization with the modal display, infants aged 3 to 6 months showed a preference for the broken figure, whereas only 5-6-month-olds showed this preference after being familiarized with the amodal display. These results suggest that modal completion develops by 3-4 months of age, whereas amodal completion develops by 5-6 months of age, in line with Condry et al.'s (2001) and Csibra's (2001) studies.

However, it has to be underlying that all these studies investigated the ability to perform amodal completion in an illusory figure using static objects. When infants were provided with motion information, this ability was shown even before the 7 months of age. As underlined in Chapter 1, motion information enhances infants' ability to link together the separate fragments of an object (e.g., Valenza et al., 2006). Using dynamic displays, Johnson & Aslin (1998) investigated the contribution of illusory contours to the perceptual completion processes in a partly occluded object. A first group of 4-month-old infants were presented with a black rod and black box, moving back and forth out-of-phase relative to one another, against a random-dot-texture background (Figure 6A).

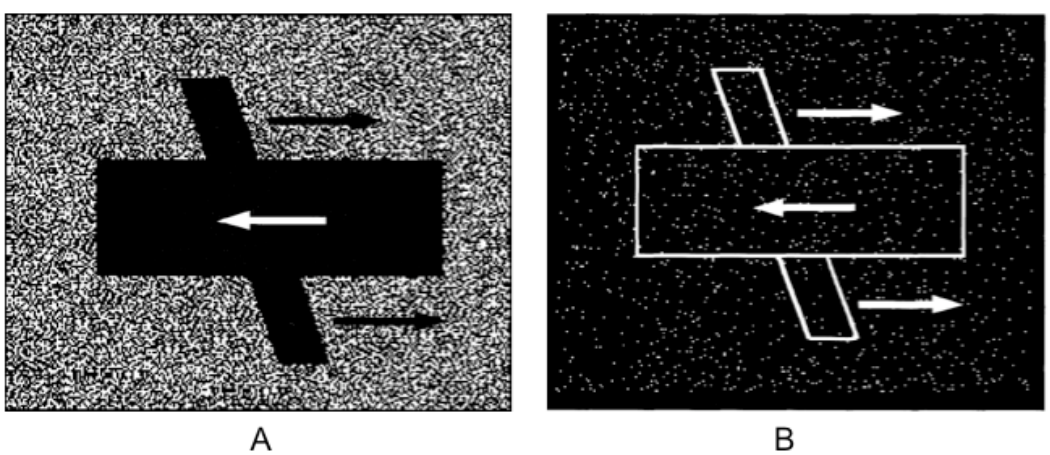

Figure 6: Displays presented to 2-month-old infants in Johnson and Aslin's (1998) study.

As a result of the lack of texture, there was no direct information for depth ordering, nor occlusion, and perception of complete box and rod parts across the intersection. This connectedness was given only by illusory contours (modal completion), which allowed the visual system to infer the depth ordering of the rod and box and infer the existence of the hidden portion of the rod (amodal completion). A second group was presented with a sparse-surface-texture display (Figure 6B) in which surface boundaries were specified by kinetic illusory contours, i.e. illusory contours given by motion (Kellman & Cohen, 1984). Differently to the black rod and box display, only the dynamic information provided the extraction of the rod and box spatial relations through the extraction of illusory contours. During the test phase, infants were presented with a broken and complete rod. Longer looking at the broken rod after habituation would imply perception of the unity of the rod. Results showed that 4-month-old infants prefer the broken rod in both displays, demonstrating that young infants perceive the segregation in depth of surfaces whose boundaries are given by illusory contours.

The outcome further confirm that 2-month-old infants are able to pursue both modal and amodal completion simultaneously, at least when dynamic displays are used.

2.3 Study 1

Starting from this evidence, the present study was aimed at investigating whether newborns are able to use modal and amodal completion simultaneously to perceive a partly occluded object. Under particular conditions, i.e. when a motion information is available, newborn babies were already shown to be able to fill in spatial gaps when they are asked to perceive partly occluded object (i.e. amodal completion, Valenza et al., 2006), and illusory objects (i.e. modal completion, Valenza & Bulf, 2007). Thus, it is plausible to hypothesized that newborns could rely on both modal and amodal completion to perceive object unity in an occlusion perceptual task.

Newborns were tested with a rod and box display, in which a Kanizsa-type illusory box was used. The illusory box was obtained by the careful positioning of the two incomplete circles (pacmen), which induced the perception of Kanizsa-type illusory contours. Since the box boundaries were specified only by illusory contours, the perception of the occluded portion of the rod depended on both modal (illusory box) and amodal (occluded rod) visual completion. Using a habituation technique, three experiments were performed.

Newborns were habituated to a moving rod partly covered by a real moving occluder (illusory condition, Experiment 1), or to an illusory moving occluder (real condition, Experiment 2). The illusory box was induced by the two pacmen, while the real occluder was defined by a black outline contour. Moreover, newborns were habituated to a control display in which the inducing pacmen of the illusory box were rotated by 180°, in order to create a control figure that is composed by the same pacmen as the Kanizsa-type illusory box, but did not give rise to illusory contours (control condition, Experiment 3). In all experiments, during the test phase, newborns were presented with a complete and a broken version of the rod.

Experiment 1

The goal of the present experiment was to investigate whether newborns were able to perceive a partly occluded object in a rod and box display in which the occluding box was defined by real contours (real condition). The experiment was a replication of the Valenza et al. (2006) study on newborns' perceptual completion of partly occluded objects, in which a display that minimized the demands of the newborns' visual system to solve the perceptual task was created. More precisely, Valenza et al. used a display in which the occluding box was a relatively narrow static filled in gray rectangle placed of a black background, and in which only the rod underwent a stroboscopic motion (Figure 7A).

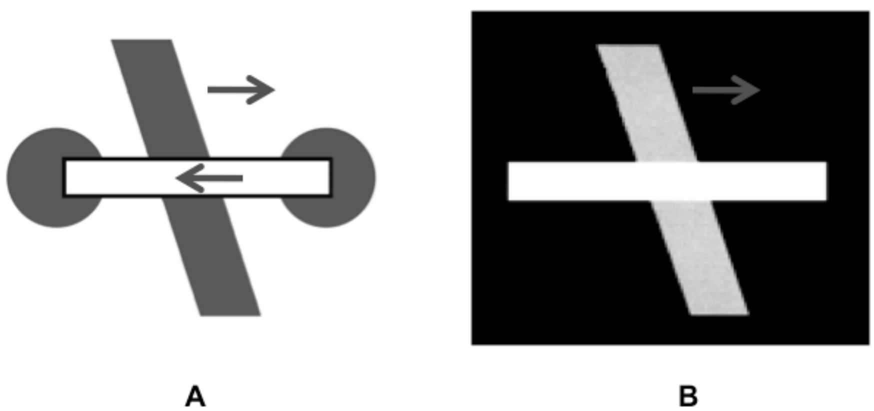

Figure 7: (A) Rod-and-box display used in the present experiment. (B) Rod-and-box display used in Valenza et al. (2006).

These perceptual constrains were shown to be crucial, facilitative conditions to elicit the ability to perceive a partly occluded object at birth. Experiment 1 was aimed at investigating whether these results could be extended to the real display presented in the present study, which differed from the original display used by Valenza et al. (2006) in many ways. Accordingly to Valenza et al.' (2006) display, the occluding box used was made relatively narrow, and a dynamic information, i.e. stroboscopic motion, was used. Nevertheless, differently to Valenza et al. (2006), the rectangle was defined by a black outline contour on a white backgorund, and two gray pacmen was placed on each extremity of the box. Moreover, the rod and the box underwent an out-of-phase motion (Figure 7B). These differences were introduced in order to make a direct comparison with the illusory Kanizsa-type dispaly used in Experiment 2.

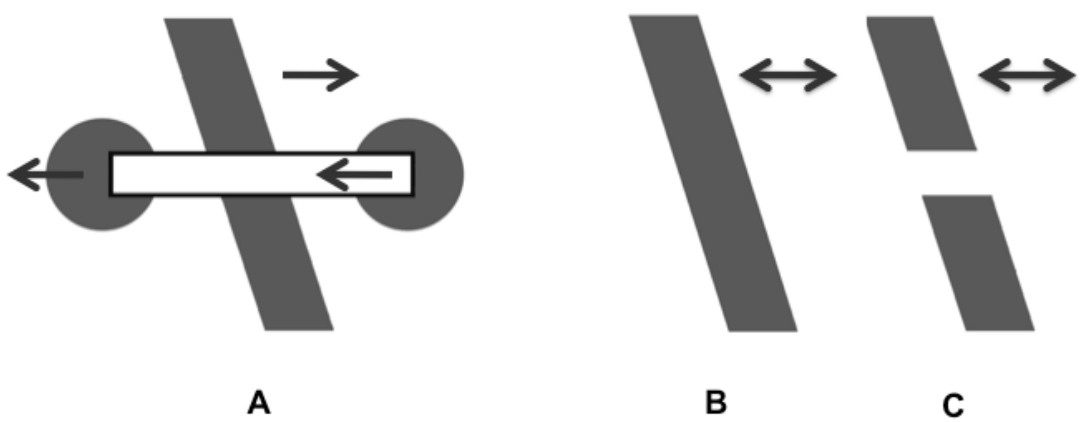

Figure 8: (A) Rod-and-box display presented in Experiment 1. The rod and box moved back and forth out-of-phase relative to one another, undergoing a stroboscopic motion. (B) Complete-rod display. (C) Broken-rod display.

Using an infant controlled procedure, newborns were habituated to the rod and box display. During the test phase, two moving unoccluded paired stimuli were presented: a complete rod and a broken rod with a gap at the place where the occluding rectangle was placed during the habituation phase (Figure 8). Both the complete and broken rod test displays moved with the same stroboscopic motion as the habituation display. If infants perceived the center-occluded rod as one connected object, they should look longer at the broken display. If they perceive the occluded rod as two separate surface fragments, they should look longer at the complete display.

Method

Partecipants

Participants were 23 healthy and full-term 1- to 3-day-old infants recruited at the maternity ward of the Paediatric Clinic of the University of Padova. Three infants were tested but excluded from the sample because they changed their state during testing (n = 4), or because they showed a position bias during the preference test phase (n = 1). So, the final sample consisted of 18 newborn infants, aged 10-132 hr (mean age = 44 hr). All of them met the screening criteria of normal delivery, a birth weight between 2770 and 4380 gr., and a 5 min Apgar score between 9 and 10. Infants were tested only if awake and in alert state. Informed consent was obtained from their parents.

Stimuli

During the habituation phase two identical rod and box displays were presented. The distance between the two rod and box displays was 7.1 cm (13.6°) side by side. Each stimulus consisted of a partly occluded rod located behind a rectangular box. The rod measured 11.8 cm in high (22.5°) and 2.5 cm

(4.8°) in length, and was oriented 25° clockwise from the vertical axis. The box measured 11.5 cm in length (22°) and 1.8 cm in high (3.4°), and it was outlined by a 2 mm thick black contour (0.4°). In order to make a direct comparison with the habituation display of the illusory condition (Experiment 2), two incomplete gray (32 cd/m^2) circular elements were placed at each extremity of the occluding box. The elements measured 4 cm (7.6°) in diameter. Both the rod and the box underwent an out-of-phase stroboscopic motion, consisting of two successive changes of the stimulus position. The distance between the positions of both the rod and the box in each frame was 2.5 mm (0.5°) on the right, and 2.5 mm (0.5°) on the left from the centre of the vertical axis of the display. Thus, the total amount of displacement of the moving rod and box was 5 mm (10°). As one frame of the box flashed on and off at the right of the central axis, the other frame flashed off and on at the left. Each frame was onset shortly after the other was offset, but stopped in the same position for a short period of 700 ms. The stroboscopic motion of the box leaded to the perception of an increase or decrease of the area of the incomplete circular elements. At the same time, the rod underwent the same pattern of motion, but out-of-phase. To an adult observer, this kinetic stimulus led to the perception of an out-of-phase rod and box that jumped back and forth around the central vertical axis of the display.

The test displays, presented without the occluder, were a complete and a broken rod moving with the same stroboscopic of the rod and box in the habituation phase. The broken rod corresponded exactly to the visible portions of the rod presented during the habituation phase.

Apparatus

The newborn sat on experimenter's lap, in front of a black panel, at a distance of about 30 cm. The panel had two square holes where the black screens of two computer monitors appeared. The horizontal midline of the images was aligned with a red flickering LED that was located in the centre of the panel, between the screens. The LED was used to attract the infant's gaze at the start of both the habituation and preference test phases, subtended about 2° of visual angle and, when turned on, blinked at a rate of 300 ms on and 300 ms off. Plain white curtains were drawn on both sides of the infant to prevent interference from irrelevant distractors.

Procedure

Testing began with the central flickering LED. As soon as the infant's gaze was properly aligned with the LED, the habituation was began by a second experiment that watched the infant's eyes by means of a video-monitor system and pressed a key on the computer keyboard. This automatically turned off the central LED and activated the onset of the stimuli. Habituation was established by recording the duration of individual fixations. The observer recorded the duration of each fixation on each stimulus by pressing a push button that was connected to the computer. Because during the habituation phase the same stimulus was presented on the left and the right side, the amount of looking time was recorded irrespective of the side. The habituation phase was terminated when the habituation criterion was reached, that is when from the fourth fixation the sum of any three consecutive fixations was 50% or less than the total of the first three (Slater, Morison, & Rose, 1985). When the habituation criterion was reached, the stimuli were automatically turned off and the central flickering LED was turned on.

As soon as the infants' gaze was realigned to the LED, the preference test phase began. Each infant was given two paired presentations of the test stimuli, i.e. the complete and the broken rod. During each presentation, the initial left-right order of presentation was counterbalanced across subjects. The central LED flickered between the first and the second presentation but did not flicker when the test image was shown. A presentation lasted until each stimulus had been fixated at least once and a total of 20 s of looking fixation had been accumulated. The experimenter recorded the duration of infant's fixations on each stimulus by pressing two different push buttons depending on whether the infant looked at the right or left position.

Results

Habituation score. All the infants reached the criterion of habituation. The average of looking time to habituate to the stimuli was 49.01 s (SD = 14.46), and the average number of trials to reach the criterion was 11 s (SD = 3.57).

Preference score. The number of fixations and the total looking time were calculated. The number of fixations toward the broken rod (M = 10, SD = 2.8) was significantly higher than the number of fixation toward the complete rod (M = 7, SD = 2.7), paired-samples $t(17) = 2.69$, $p = 0.16$, two-tailed. Moreover, they looked longer to the broken rod (M = 27.68 s, SD = 12.05 s), than to the complete rod (M = 18.11 s, SD = 8 s), paired-samples $t(17) = 2.11$, $p = 0.05$, two-tailed. In order to test whether newborns were able to perceive the occluded rod as a single object in the rod and box display to which they were habituated, a novelty preference score (percentage) was computed. Each infant's looking time at the broken rod during the two test phases was divided by the total looking time to both test stimuli over the two presentations, and subsequently converted into a percentage score. Hence, only score above 50% indicated a preference for the broken rod. To determine whether the novelty preference score was significantly different from the chance level of 50%, a one-sample *t* test was applied. Preference score for the broken rod was significantly above chance (M = 59%, SD = 18%), $t(17) = 2.17$, $p = 0.044$, two-tailed, indicating that newborns look significantly longer at the broken rod during the test phase.

Discussion

Evidence indicates that, when a stroboscopic motion was used, newborns were able to amodally complete the partly occluded rod as a unique object under the occluding box. This result confirms and extends the data of Valenza et al. (2006) to the slightly different stimulus' conditions contained in the display presented in this study, in which the occluding row was defined by an outline contour and two incomplete circles were placed at each extremity of the box, and in which an out-of-phase bow and rod stroboscopic motion was used. Starting from the result obtained in Experiment 1, Experiment 2 was carried out to verify whether newborns' ability to perceive a partly occluded object is present even when an illusory box occluded the rod.

Experiment 2

Experiment 2 was designed to investigate whether newborns were able to fill in the spatial gap of a partly occluded rod when an illusory Kanizsa-type box was used (Figure 9).

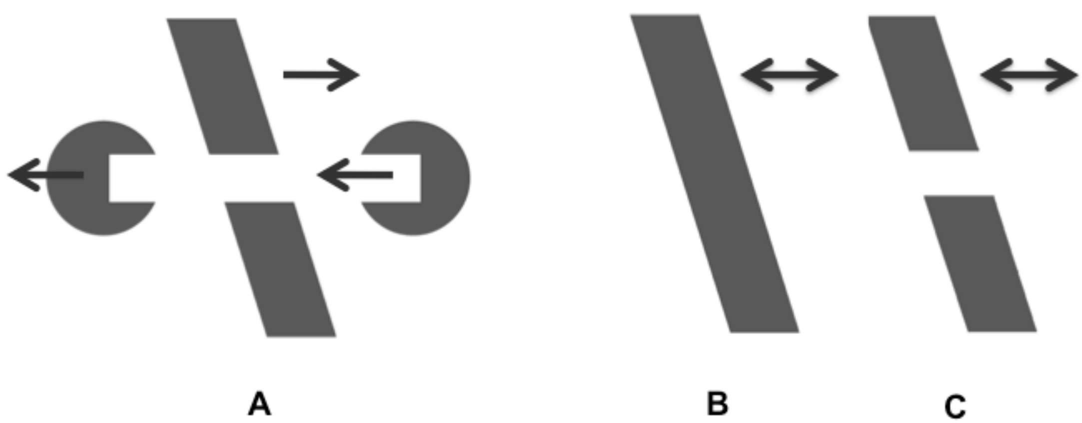

Figure 9: Sample of the stimuli presented in Experiment 2. (A) Habituation display. (B and C) Test displays. Perception of the coherence of the rod and box dependes on both modal and amodal completion.

Intriguingly, since the display is physically composed of just four spatially separated fragments, the visual information that defines the partly occluded display is extremely underspecified: no luminance, color or contrast physical gradients allow the visual system to define the contour of the box and, consequently, the gap that separated the two portion of the rod could be only filled in relying on the perceptual appearance of the illusory box. Thus, the depth order of the visual surfaces and the perception of the occlusion were only defined by the ability to perform simultaneously a modal completion of the illusory box and an amodal completion of the rod.

As in Experiment 1, after habituation to the rod and box display that underwent an out-of-phase stroboscopic motion, newborns were tested with a complete and broken rod test displays, which again underwent a stroboscopic motion. If newborns perceived the rod as connected under the illusory box, they should looked longer to the broken rod.

Method

Partecipants

Participants were 26 healthy and full-term 1- to 3-day-old infants recruited at the maternity ward of the Paediatric Clinic of the University of Padova. Nine infants were tested but excluded from the sample because they changed their state during testing (n = 2), or because they showed a position bias during the preference test phase (n = 7). So, the final sample consisted of 17 newborn infants, aged 10-74 hr (mean age = 41 hr). All of them met the screening criteria of normal delivery, a birth weight between 2560 and 4150 gr., and a 5 min Apgar score between 9 and 10. Infants were tested only if awake and in alert state. Informed consent was obtained from their parents.

Stimuli

The stimuli were the same used in Experiment 1, with the exception that the occluding box was illusory. The illusory box was created by the careful positioning of the two incomplete circular elements.

Apparatus and procedure

The apparatus and procedure were identical to those used in Experiment 1.

Results

Habituation score. All the infants reached the criterion of habituation. The average of looking time to habituate to the stimuli was 58.10 s (SD = 20.10), and the average number of trials to reach the criterion was 12 (SD = 5.26).

Preference score. The number of fixations and the total looking time were calculated. Newborns oriented equally toward the broken (M = 8, SD = 2.6), and the complete rod (M = 6, SD = 2.2), paired-samples t (16) = 1.55, p = 0.14, two-tailed, but they looked longer to the broken rod (M = 24.37 s, SD = 5.55 s), than to the complete rod (M = 18.56 s, SD = 6 s), paired-samples t (16) = 2.12, p = 0.05, two-tailed. In order to test whether newborns were able to perceive the occluded rod as a single object in the rod and box display to which they were habituated, a novelty score (percentage) analogous to that calculate in Experiment 1 was computed. Each infant's looking time at the broken rod during the two test presentations was divided by the total looking time to both test stimuli, and subsequently converted into a percentage score. The mean preference score for the broken rod was 57% (SD = 13%), and differed significantly from the chance level of 50%, one-sample t (16) = 2.16, p = 0.046.

Discussion

After habituation to the centered occluded rod, newborns showed a reliable preference for the broken rod over the complete rod, providing evidence that they were able to perceive a partly occluded rod even though the occluding box was illusory. Thus, the data demonstrated that newborns were able to rely simultaneously on both the modal completion of the illusory box and the amodal completion of the rod to solve the perceptual task.

In order to create a control condition for the illusory rod and box display, in Experiment 3 newborns' were presented with a display that was constructed with exactly the same elements of the rod and box display used in the present experiment, but that did not provide any cue for occlusion or depth.

Experiment 3

The goal of the present experiment was to test newborn perception in a control condition in which the inducing pacmen of the illusory box were rotated by 180°. This gave rise to a control figure that was composed by the same pacmen as the Kanizsa-type illusory box, but did not give rise to illusory contours (Figure 10).

Figure 10: Sample of the stimuli presented in Experiment 3. (A) Habituation display. (B and C) Test displays.

After habituation to the control display, during the test phase newborns' were presented with a complete and a broken rod. Since the control display did not contain any information about occlusion or perception of surfaces in depth, it was hypothesized that newborns could look longer to the complete rod, indicating that they had perceived two separate portions of the rod during the habituation.

Method

Partecipants

Participants were 18 healthy and full-term newborns recruited at the maternity ward of the Paediatric Clinic of the University of Padova. Four infants were tested but excluded from the sample because they changed their state during testing (n = 2), or because they showed a position bias during the preference test phase (n = 2). So, the final sample consisted of 14 newborn infants, aged 10-84 hr (mean age = 41 hr). All of them met the screening criteria of normal delivery, a birth weight between 2215 and 4065 gr., and a 5 min Apgar score between 9 and 10. Infants were tested only if awake and in alert state. Informed consent was obtained from their parents.

Stimuli

The stimuli were the same used in Experiment 2, with the exception that the occlusion effect provided by the Kanizsa-type illusory box was disrupted by rotating the inducing elements 180° around their planar axes. This allowed to obtain a control non-illusory Kanizsa figure that was exactly the same as the illusory one, but that did not give rise to illusory contours. The lack of illusory contours prevented any possibility of a link between the two pieces of the rod.

Apparatus and procedure

The apparatus and procedure were identical to those used in Experiment 1.

Results

Habituation score. All the infants reached the criterion of habituation. The average of looking time to habituate to the stimuli was 58.56 s (SD = 20.10), and the average number of trials to reach the criterion was 13 (SD = 3.55).

Preference score. The number of fixations and the total looking time were calculated. Newborns oriented equally toward the broken (M = 7, SD = 3.6), and the complete rod (M = 8, SD = 3.2), paired-samples t (13) = 1.07, p = 0.3, two-tailed, but they looked longer to the complete rod (M = 27.95 s, SD = 10.27 s), than to the broken rod (M = 18.94 s, SD = 6.49 s), paired-samples *t* (13) = 2.23, *p* = 0.044, two-tailed. A preference score (percentage) analogous to that calculate in Experiment 1 and 2 was computed for the broken rod. Each infant's looking time at the complete rod during the two test presentations was divided by the total looking time to both test stimuli, and subsequently converted into a percentage score. The mean preference score for the complete rod was 41% (SD = 15%), and differed significantly from the chance level of 50%, one-sample *t* (13) = 2.18, *p* = 0.049.

Discussion

The result of Experiment 3 demonstrated that newborns looked longer at the complete rod than at the broken rod, showing that they did not pick up any occlusion or depth information in the control display. Since the display presented in the present experiment was composed of exactly the same elements as the display presented in Experiment 2, these data allowed to conclude that the perception of the object unity in Experiment 2 was due to the careful positioning of the element within the display and to the ability of the newborns' perceptual system to link together the separate fragments in the correct combinations.

Experiments 1, 2 and 3: a comparison

To compare the preference score for the broken rod from Experiment 1, 2, and 3, a one-way ANOVA with one between-participants factor, experiment (1, 2, and 3) was conducted. The analysis reached statistical significance, F(2, 46)

= 5.94, p = 0.005. A post-hoc comparison showed a difference in the preference score for the broken rod between the illusory condition (57%) and the control condition (41%), $t(29) = 3.09$, $p = 0.004$, and between the real condition (59%) and the control condition (41%), t(30) 0 3.01, $p = 0.005$, but not when the percentages were compared in the real condition (59%) and the illusory condition (57%), $t(33) = 0.44$, $p = 0.66$.

Conclusions of Experiments 1-3

Previous studies have demonstrated that newborns are able to link together spatially separated visual surfaces when they were asked to perceive an illusory object (Valenza & Bulf, 2007), or when they are asked to perceive a partly occluded object (Valenza et al., 2006). The current study confirms and extends these findings, providing a link between newborns' ability to used both modal and amodal completion for a veridical object perception.

Newborns were presented with a rod and box dynamic display in which the occluder was a Kanizsa-type illusory figure (illusory condition) (Experiment 2). The solution of the perceptual task relied on the use of both modal and amodal perceptual completion. Newborns' performance in the illusory condition was compared to their performance with a display in which the box was defined by real contours (real condition) (Experiment 1), and with a display in which the box was a figure that did not contain any depth information (control condition) (Experiment 3). Newborns have been shown to perceive the partly occluded rod as a complete object in the real and illusory condition, but not in the control condition.

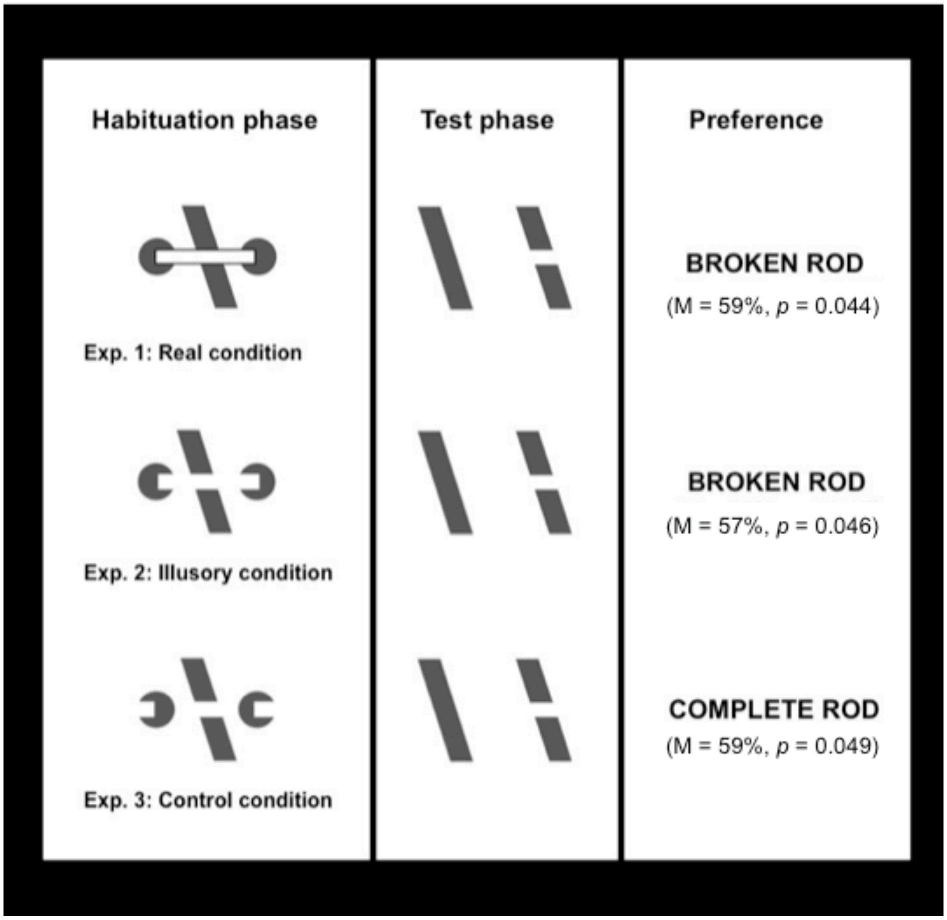

Figure 11: Summary figure with the results of the three experiments. The *p* values refer to the preference for the broken rod (Exp. 1 and 2) and the complete rod (Exp. 3) using a one-sample *t* test.

The result obtained in the illusory condition demonstrated that newborns were able to utilize simultaneously modal and amodal completion to pursue a veridical object perception (Figure 11). This outcome further confirms adults' (Rauschenberger & Yantis, 2001; Sekuler & Palmer, 1992; Guttman & Kellman, 2004; Ringach & Shapley, 1996; Kellman & Shipley, 1991, 1992; Kellman et al., 1998) and infants' (Johnson & Aslin, 1998; Condry, Smith, & Spelke, 2001) findings that modal and amodal completion could support contemporarily object perception by grouping segments separated in space.

The necessity to use both modal and amodal completion to solve the perceptual task was due to the complex and extremely underspecified visual display presented to newborns in the illusory condition. Despite the display physically contained just four separate elements, the binding processes allowed newborns to perceive a set of coherent objects placed in different depth planes.

Before conclude that the human visual system is adapted form birth to perceive unitary, coherent objects by the integration of the visual information available from the sensory input, it is relevant to stress that the use of a dynamic target stimulus might have facilitated the solution of the perceptual task triggering newborns' attention. This consideration is not surprising because there are strong reasons to suspect that motion is an important source of information for many other perceptual abilities in the first months of postnatal life (Kellman & Arterberry, 1998). For example, research conducted over the past few decades has found that young infants' depth perception follows a specific developmental trend (Yonas & Granrud, 1985). Sensitivity to kinetic depth information appears to emerge first by 1 month of age (Náñez, 1988), followed by sensitivity to binocular disparity around 4 months of age (Braddick et al., 1980; Granrud, 1986; Yonas et al., 1987), and sensitivity to pictorial depth cues that emerges between 5 and 7 months (Granrud, Haake, & Yonas, 1985; Granrud e Yonas, 1984; Granrud, Yonas, & Opland, 1985; Yonas, Granrud, Arterberry, & Hanson, 1986; Yonas, Granrud, & Pettersen, 1985). Similarly, it is well documented that motion plays a relevant role in inducing object perception in young infants (e.g., Kelman & Spelke, 1983; Johnson & Aslin, 1995; Johnson & Náñez, 1995, 1996; Jusczyk, Johnson, Spelke, & Kennedy, 1999) and newborns (Valenza et al., 2006).

If the use of dynamic information have triggered newborns' attention facilitating modal and amodal completion of a partly occluded object, it can be concluded that the ability to achieve a veridical object perception at birth is very weak and heavily constrained, and depends on perceptual cues that newborns are able to detect. Indeed, early in development, before sufficient visual experience has occurred, bottom-up salience is very important in directing visual attention and motion information would contribute to this bottom-up guidance.

The consideration that motion is a key cue to trigger newborns' attention to the relevant elements of the visual display that have to bind together, suggests that, besides perceptual binding, selective attention is crucial to select single objects in visual scenes where multiple elements are available. The more proficient infants become at selectively information pickup in support of visual binding, the more likely it is that they will be able to detect and utilize that information in perceptual tasks.

Starting from this point, a lack of Experiments 1, 2 and 3 is that they do not take into account the possible role of selective processes in performing perceptual binding of the illusory rod-and-box display. More precisely, the experiments previously reported leaved unresolved a fundamental problem: which is the role of selective attention in perceptual binding of spatially separate elements in the illusory display? Usually, the dependent variable to measure orienting of attention in infancy is to record which of two stimuli is detected faster by infants (Cohen, 1972). Cohen (1972) postulated that two distinct sets of processes are at work in infants' visual attention, i.e. attention-holding and attention-getting. The former is more cognitive, and involves more active information processing. The measure of attention holding is the duration of fixations to the stimulus, such as recorded in the habituation procedure. The latter is more reflexive, and is more an automatic orienting to an abrupt change in the periphery, and is measured by the latency of turning to the stimulus.

Using an eye tracker system, Experiment 4 was designed to investigate whether an illusory figure triggers selective attention in young infants. Both the total fixation time and the latency to orient to the illusory figure were measured.

Experiment 4

The goal of Experiment 4 was to test whether an illusory figure triggers visual attention over a non illusory stimulus in 6-month-old infants in a static condition. The non illusory figure was obtained by rotating the inducing elements of the Kanizsa figure by 180° around their planar axis, to give rise to a control stimulus composed of exactly the same elements of the Kanizsa figure, but that did not give rise to illusory contours. This is a standard solution used to investigate infants' preference for illusory figures. When the Kanizsa figure is perceived, it contains three-dimensional information, whereas the rotated pattern has only individual elements. Thus, the preference for the illusory over the non illusory figure has been explained as a detection of a three-dimensional information driven by the perceptual binding of the inducing elements in the illusory figure, but not in the non illusory one (Otsuka & Yamaguchi, 2003). Infants' preference for a Kanizsa figure in such displays is well established in developmental literature, either in static conditions (e.g., Otsuka & Yamaguchi, 2003), and in dynamic conditions (Otsuka Kanazawa, & Yamaguchi, 2004; Valenza & Bulf, 2007).

However, to our knowledge, no studies have investigated if selective attention operates in the perceptual binding of the inducing elements in an illusory Kanizsa figure in infancy. To this end, in the next experiment, an eye tracker system was used to register infants' saccadic eye movements. Many studies have demonstrated an intimate link between saccadic eye movements and selective attention in the selection of targets (e.g., Adler, Bala, & Krauzlis, 2002; Crawford & Muller, 1992; Hoffman & Subramaniam, 1995; Klei, 1980; Kowler, Anderson, Dosher, & Blaser, 1995). For example, Hoffman & Subramaniam (1995) found that target detection prior to eye movement initiation is superior when target and saccade location coincide than when they do not, suggesting that the allocation of spatial attention is an important element for generating a saccadic eye movement. Similarly, Kowler et al. (1995) found that attention could not be allocated to one location while at the same time preparing to make a saccadic eye movement to a different location. Given the linkage between eye movement and attentional allocation, saccades' latency is a reliable measure to examine the deployment of selective attention in a visual display.

The eye tracker allowed to measure the amount of looking time toward the illusory and non illusory figure, as classically done in the previous developmental studies already described, and to register the latency of the first saccade directed toward both stimuli, a variable that is usually associated to the deployment of visual attention. If the Kanizsa figure was able to trigger infants' visual attention, infants were expected to select the illusory figure faster than the non illusory stimulus.

Method

Participants

Nineteen 6-month-old infants participated in the study. Six-month-old infants instead of newborns were tested in the present experiment, because of the difficulty to calibrate newborns' eyes with the eye tracker system. Moreover, conversely to newborn infants, 6-month-old infants have been shown to be able to perceive an illusory Kanizsa figure in static conditions (Otsuka et al., 2004). Three infants were observed but excluded from the sample because of general fussiness (1) or position bias (2). So, the final sample was composed by 16 infants (mean age = 187 days, range = 180-196) composed the final sample. All infants were born at full term, in good health, with no visual, neurological or other disorders. Infants were recruited from a database of new parents, and parents were contacted by letter and telephone. Infants were tested only if they were awake and in an alert state.

Stimuli

Infants were presented with a Kanizsa figure and a non illusory control stimulus (Figure 12). All figures were composed of four black incomplete circular elements (3 cd/m^2) against a white background. The elements measured 7 cm (7°) in diameter and each element was situated 3.5 cm (3.5°) from each adjacent element, so that the illusory Kanizsa square was 10.5 cm X 10.5 cm (10.5°). The distance between the stimuli was 4.5 cm (4.5°) side by side. To ensure that infants were able to perceive the illusory figure a relatively high support ratio was used. The support ratio, defined as the ratio of the physically specified contours to the total edge length, determinates the illusory-contours strength: the larger the ration, the stronger the illusion. Otsuka et al. (2004) provided evidence that, in a static condition, 6-month-old infants showed a preference for a Kanizsa figure over a control stimuli when the support ration was high (66%), but not when it was low (37%). Thus, a support ratio of 66% that has been shown to support 6-month-old infants perception has been used in the present study.

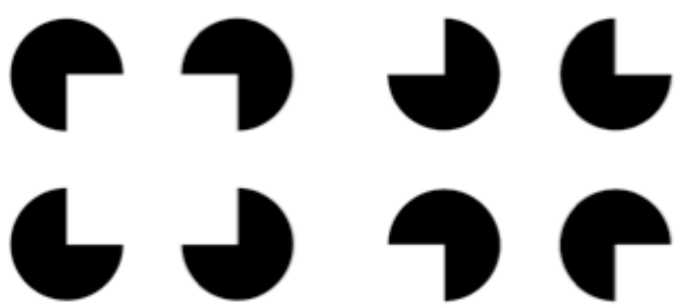

Figure 12: Sample of the stimuli presented in Experiment 4.

Apparatus

The stimuli were presented through the software E-Prime 1.1. A remote, pan-tilt infrared eye tracking camera (Model 504, Applied Science Laboratories [www.a-s-l.com], Bedford, MA) using bright pupil technology, placed directly below the stimulus screen, recorded the infant's eye movements at a temporal resolution of 50 Hz. Infrared light emitted from diodes on the camera was reflected back from the infants's retina through the pupil producing a backlit, white pupil and from the corneal surface of the eye. An experimenter guided the eye tracking camera by means of a remote control, so that the eye of the infant was always in focus. The image of the eye on a television monitor rendered this procedure easier. Plain curtains were hung on the both side of the testing area to prevent interference from irrelevant stimuli. Behind the curtains were two computers, one that generated the stimuli and one that controlled the eye-tracker camera and collected the eye-movement data. To coordinate the eye movement data with a specific stimulus display, the stimulus-generating computer sent a unique, time-stamped numerical code via a parallel port to the data-collecting computer indicating the onset of the stimulus display and indicating the type of stimulus-display. The digital data indicating the fixation locations and change of locations of the eye and therefore the eye movements themselves were calculated from relation between the centroid of the pupil and the corneal reflection by use of the Applied Science Laboratories' algorithm.

Procedure

Each infant was placed in an infant seat at a distance of 60 cm from the computer screen. Before beginning the experimental trials, the eye tracker was calibrated by having the participant look at stimuli (animated cartoon with a musical soundtrack) successively presented at three different locations on the stimulus monitor (center, top left, and bottom right) and recording the eye tracker values for the eye fixation location. All subsequent eye data were calculated through these calibration values.

An experimental trial began with the presentation, in the middle of the screen, of a central fixation point (a colored moving clown). As soon as the participants looked at the central fixation point, the stimuli automatically appeared on the monitor and the central fixation was removed. Each stimulus pair was presented for 8 seconds. All infants were submitted to four trials, in which the left versus right position of the two stimuli within each pair were counterbalanced within two regions of interest (ROI) previously selected by the experimenter. The ROI, square shaped, virtually surrounded the outer edges of the illusory and the control stimulus, and measured 18 cm X 18 cm (18°).

Results

Overall total looking time

To investigate whether the illusory Kanizsa square was preferred over the control stimulus, a paired-sample *t* test was performed on infants' mean looking fixation time toward the two stimuli. The comparison was statistically significant, t (5) = 2.58, p = 0.021. Infants looked longer at the illusory figure (M =, 10.36 s SD = 4.3 s) than at the non illusory one (M = 7.89 s, DS = 3.4 s). In addition, preference scores (percentages) for the illusory over the non illusory stimulus was calculated. Each infant's mean looking time at the illusory Kanizsa figure was divided by the looking time to both stimuli and converted into a percentage score. Preference scores for the illusory figure were significantly above the chance level of 50% (M = 57%, SD = 10%), one sample $t(15) = 2.68$, $p = 0.017$. Finally, examination of the data for individual infants revealed that 13 of 16 infants looked longer at the illusory figure (binomial test, $p = 0.009$).

These findings demonstrate that 6-month-old infants exhibit a spontaneous visual preference for an illusory Kanizsa figure over a non illusory control stimulus composed of exactly the same elements as the illusory figure, but that did not give rise to illusory contours. This outcome replicate and confirm the results obtained in previous young infants' studies regarding the visual preference for an illusory figure to a non illusory one (Otsuka & Yamaguchi, 2003; Otsuka et al., 2004; Valenza & Bulf, 2007).

Saccades' latency

The mean latency of the first saccade to select both the illusory and the non illusory figure was measured. Infants' were faster to select the Kanizsa illusory figure (580 ms), than the non illusory figure (669 ms). A paired sample *t* test revealed that this difference was significant, $t(14) = 3.11$, $p = 0.008$.

Discussion

Results showed that 6-month-old infants looked longer at the Kanizsa figure, providing evidence that they preferred the illusory stimulus over the non illusory one, replicating the data of Otsuka et al. (2004). More intriguingly, results provided evidence that, when the latency of the first saccades was measured, infants detected the illusory figure faster than the non illusory control stimulus, showing that the Kanizsa figure triggered infants' deployment of visual attention. Overall this outcome suggests that 6-month-old infants were able to bind together the inducing element of the Kanizsa figure to perceive a coherent, unified object, and that the perceptual binding of the elements determined a faster selection of the Kanizsa figure over the control stimuli, triggering the deployment of visual attention.

2.4 Conclusions

Study 1 provided evidence that newborns showed a veridical object perception when they were asked to perform the perceptual binding of spatially separated elements in an illusory rod-and-box display (Experiment 1, 2 and 3). Moreover, 6-month-old infants have be shown to orient their attention toward an illusory figure faster that toward a control stimulus in visual preference task, providing evidence that the illusory figure was able to trigger young infants' visual attention (Experiment 4).

Although this pattern of data allowed to conclude that both perceptual binding and selective attention support the perception of an illusory object during early infancy, the use of visual habituation (Experiment 1, 2 and 3) and visual preference (Experiment 4) techniques did not disentangle the question of how perceptual binding and selective attention interact to support objects perception in infants. This issue has been investigated in adults using visual search tasks. In a typically search task, an observer must determine the presence of a stimulus in an array of multiple stimuli, instead of compare two simultaneously presented stimuli, as in classical infants' habituation and preference paradigms. Since our processing resources are limited and we are constrained in the amount of visual information that can be processed at any particular moment, specific items in space must be selected as targets in order for visual processing and behavior to proceed efficiently (Treisman, 1964). For example, to spot a friend in a crowded airport, we must selectively scan the visual scene to find and indentify our target (friend) among multiple distractors (other people). In this case, selective attention supports the selection of certain stimuli for processing while potentially interfering stimuli are ignored, a candidate skill in controlled visual exploration in complex scenes.

The second part of my thesis (Chapter 3, 4 and 5) will concern with the relations between selective attention and perceptual binding in determining objects perception in adults and young infants.

Chapter 3

Visual pop out in infants and adults

William James (1890) wrote that attention was ‘taking possession by the mind, in clear and vivid form, of one of what seem several simultaneously possible objects’ (p. 403). This conceptual view of attention stems from the fact that our visual world contains many simultaneously available objects that are possible inputs for visual and cognitive processing and for guiding behavior. Attention is not a single entity, but the name given to a set of processes. Regarding the multifaceted nature of attention, three main components have been identified: selection, vigilance, and control. In a broad sense, all three components of attention serve the purpose of allowing for and maintaining goal-directed behavior in the face of multiple, competing stimuli.

The present chapter will concern with the selectively component of visual attention in adults and early infancy. Developmental research in young infants provides an important complement to work with adults in the understanding of the mechanisms of visual selection. Many attentional and perceptual systems are immature, or nonfunctional, in the young infant. The immaturity of these systems, corresponding behavioral characteristics, provides some information about how these system are expressed in adults.

Selective attention has been described as one or more mechanisms that determine what information from the external environment enters a system for subsequent processing (Craik, Govoni, Naveh-Beniamin, & Anderson, 1996;

Treisman, 1992). For infants, selective attention mechanisms would seem to be crucial for filtering and making sense of their visual world with which they have little or no experience as they pursue the construction of a knowledge base (Adler & Orprecio, 2006; Dannemiller, 2005).

As extensively reported in Chapter 1 and 2, a growing number of studies suggests that since birth the human visual system perceives a world of coherent, unified objects, integrating the visual information in many viewing conditions. Although these results suggest that infants show a veridical object perception very early during the development, the role of selective attention in integrating the various parts of an object remains unclear. In fact, the most widely used habituation-dishabituation and novelty- and familiarity-preference paradigms for studying aspects of infants' perceptual and cognitive development exploit over attention (i.e. fixation) as their primary measure. In these studies, however, only a single stimulus is typically presented during initial stimulus processing, so attentional selection is not required as there is no competition from other stimuli. Consequently, although these studies have considerably expanded our knowledge of infants' perceptual processing capacities, they have shed little light on the development of attentional mechanisms responsible for selecting a target amidst competing stimuli.

To directly explore the development of mechanisms of selection during initial allocation of attention, a number of studies have examined infants' ability to selectively attend to one stimulus that is superimposed on a second stimulus (Bahrick, Walker, & Neisser, 1981), to shift attention between two simultaneously presented stimuli (Atkinson, Hood, Wattam-Bell, & Braddick, 1992), to disengage visual attention from one stimulus to attend to a second, subsequently presented stimulus (Farroni, Simion, Umiltà, & Dalla Barba, 1999) and to inhibit a shift of attention back to a stimulus that they had previously selected and allocated attention (Valenza, Simion, & Umiltà, 1994). Many studies have also examined the pop out effect during infancy, in which infants' attention is captured by a stimulus that is surrounded by dissimilar but simultaneously presented stimuli (Bhatt, 1997).

In this chapter two classical models regarding the way in which selective attention operates to support adults' object perception will be reported. Moreover, in order to illustrate the role of attention in finding objects in complex arrays of multiple objects, studies on the pop out effect in adults will be reviewed, as well as the developmental literature that suggests that very early in the development infants show the ability to exhibit pop out,

3.1 What is the object of selective attention? Two classical models

The majority of evidence regarding the role of selective attention in objects' perception comes form standard models on visual attention, e.g. the space-based view of attention (Posner, 1980) and the feature integration theory of attention (Treisman, 1988).

3.1.1 *Space-based view of attention*

The space-based view of attention derives support from experiments that show that focal attention shifts from one location to another, selecting particular regions in visual space. Stimuli within these selected regions are processed more efficiently that stimuli that fall into no-selected regions (Umiltà, 2001). Thus, the space-based view of attention characterized attention in spatial terms, as a spotlight, which could move about the visual field, focusing processing resources on whatever fell within that spatial region – be it an object, a group of objects, part of one object, or even nothing at all (e.g. Eriksen & Eriksen, 1974; Posner, 1980). In other words, as the attentional spotlight moves around the visual environment it engages with the various objects in the scene.

Evidence for spatial selection comes from spatial cueing studies (e.g., Posner, 1980). Posner's basic paradigm can be summarized as follows. The detection stimulus can be presented in one of two spatial locations, indicated by two empty boxes (Figure 1). The participant was instructed to press a key as fast as possible upon stimulus detection, regardless of location of the stimulus, and to fixate a central mark, above which a plus sign or an arrow pointing to the right or to the left might appear. If the plus sign was presented, the detection stimulus was equally likely to occur to the left or right of fixation (neutral trials). If an arrow was presented, it was much probable that the detection stimulus occurred on the indicated side (valid trials), than on the other side (invalid trials). The valid cue to the location where a target would appear speeded the response to that target, and slowed responses when the cue was invalid and the target appeared elsewhere. In other words, differences in response time to a stimulus at expected and unexpected position in the visual field have been taken as a measure of the efficiency of detection due to the orienting of attention towards the expected position.

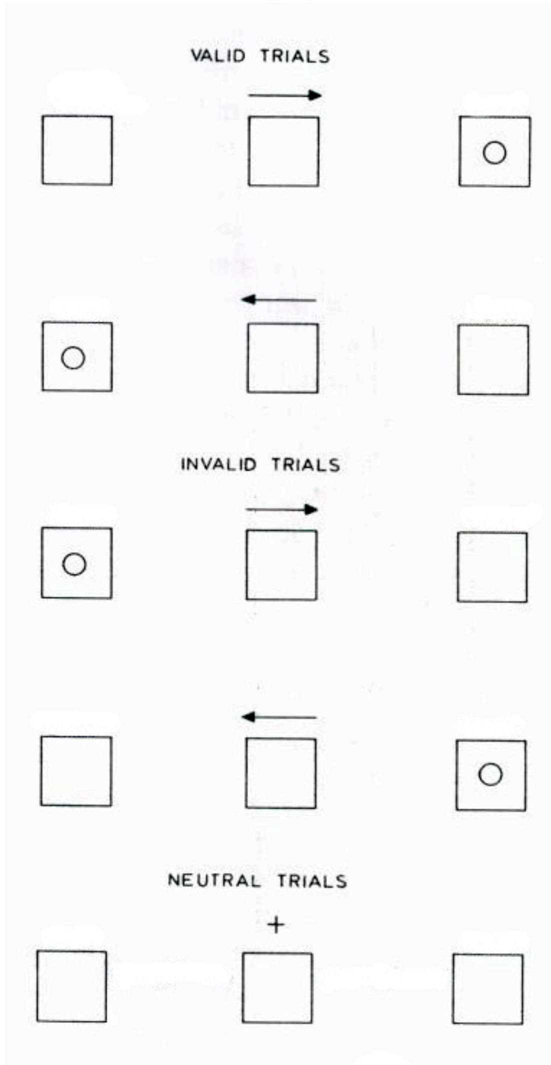

Figure 1: Schematic drawing of Posner's (1980) basic paradigm.

A similar experiment was conducted by Downing & Pinker (1985), this time cueing one of ten boxes with a partially valid cue. Detection of the targets was fastest in the cued box, and slowed monotonically as the distance between the cued box and the actual target location increased on invalid cues trials.

These types of results suggested that attention was being deployed as a spatial gradient, centered on a particular location and becoming less effective as the distance from that location increased. These studies exemplified some evidences supporting the space-based view of attention, claiming that attention does not select objects or their features but, instead, is directed to regions of visual space, which may be empty or occupied by objects.

3.1.2 The feature-integration theory of attention

Treisman (1988) proposed that to perceive coherent objects in our visual world, the visual information is articulated into parts or features followed by the integration of this information into holistic representation.

This model, known as 'the feature-integration theory of attention' (Treisman, 1988; Treisman & Gelade, 1980), suggests that in an initial preattentive stage of processing, objects are decomposed into their basic perceptual features. As a consequence of the initial decomposition of stimuli into their basic features, attentive processes are selectively allocated to a stimulus unique for a particular feature, which 'pops out' from the visual display. Thus, the attentional-capture phenomenon of pop out can be described as the situation in which stimuli that are defined by a unique perceptual feature automatically and selectively guide attention (Treisman, 1988; Treisman & Gelade, 1980; Treisman & Souther, 1986).

A later attentive stage selectively focuses processing resources to individual stimuli for the purpose of binding the features into a unified object percept. Thus, when confronted with a visual scene, the visual system does not deal with coherent and unified objects, but the visual information is first articulated into parts or features, and only successively attention operates to bind these features in whole objects.

This theory was developed entirely from behavioral data collected from adults using visual search tasks. The visual search tasks allow to investigate how selective attention operates when an item has to be found in an array of competing stimuli.

3.2 Visual search tasks and pop out in adults

Investigations of how visual selective attention operates to find an object in a complex array of multiple objects have usually been performed using visual search tasks. In a visual search task, the observer must typically determine as quickly as possible the presence of a prespecified target among a varied number of homogeneous distractors (Treisman & Gelade, 1980). The efficiency of the search can be assessed by varying the number of distractors (the set size) and measuring reaction time (RT). When attention can be deployed to the target despite the number of distractors items, the slope of the resulting RT X set size function will be near zero, showing a pop out effect of the target. If the target is differentiated from the distratcors by a unique feature, the observer detected the oblique target consistently and rapidly, and reaction times were unaffected by the number of distractors in the display. In this case, because the observer does not need to employ focal attention to detect the target (i.e. the target is detected in parallel across the visual display), the stimulus features differentiating the target from non-targets are assumed to be detected by early preattentive stage of visual processing. In contrast, when the stimulus is defined by a unique combination of features, it does not pop out. In this case, the RT increases as a function of the number of distractors, a result interpreted as evidence that the observer is using focal attention and a serial scanning of the visual display to identify the target (Treisman & Sato, 1990). For example, the latency to find a green T among red Ts, in which the target is defined by a difference in a basic feature (i.e., color) is independent of the number of distractors (the target pops out), but the latency to find a green T among green Xs and brown Ts is directly proportional to the number of distractors, since the target is defined by a conjunction of features (i.e., form and color). (Figure 2).

The functioning of these mechanisms has been formalized in two influential theories of adults' visual information-processing that have proposed two-stage models. In an initial preattentive stage of processing, stimuli in the visual array are decomposed into their perceptual features (Julez, 1984; Treisman, 1988). The basic perceptual features have been hypothesized to include orientations, width and length, size, color, motion – a list that agrees well with the properties that physiological evidence suggests are processed in parallel by the early visual system (Deco, Pollatos, & Zihl, 2002; Livingstone & Hubel, 1981). A later attentive stage selectively focuses processing resources to individual stimuli for the purpose of binding the features into a unified object percept (Treisman, 1988).

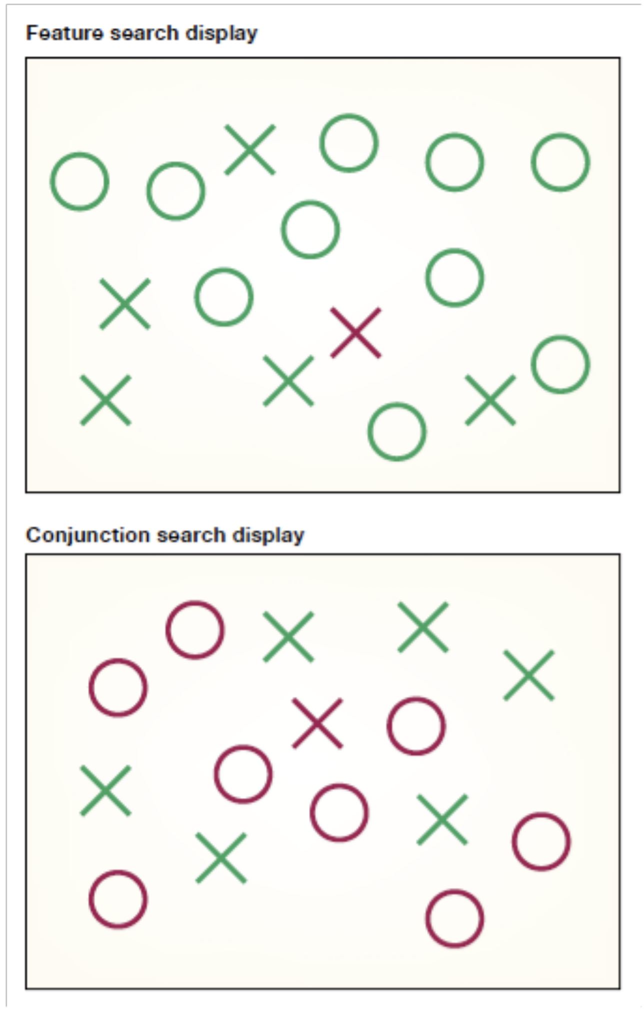

Figure 2: Examples of displays used in visual search studies. Detection of a red X among green distractors is easy when color or shape alone can be used to discriminate the target fro distractors, whereas detecting the red X among green Xs and red Os is more difficult.

Though there continues to be considerable interest in understanding the nature of the preattentive and attentive mechanisms (Wolfe, 1994), the parallel-serial dichotomy is not accepted universally. Actually, recent theories of visual search indicated that all search tasks require some amount of attentional allocation (Cave, 1999; Wolfe, 1994). Consequently, the distinction between parallel and serial search functions is no longer accurate but rather the distinction in between search that is efficient and not limited by attentional resources (e.g. pop out) or inefficient and sensitive to attentional resources.

Given these models of object recognition in adults, several questions arise in relation to infants' object perception: Do infants have the same vocabulary of fundamental features as do adults? Do infants perceive individual features in the same manner as do adults? In other words, are individual features of objects detected by a preattentive system in infancy also? The studies described below address these issue.

3.3 Pop out in early infancy

Studying visual pop out is important for understanding the determinants and consequences of visual attention during infancy (Dannemiller, 2005). Actually, in the natural environment many salient elemets are visible simultaneously. Thus, the attentional processes that signal local discrepancies in the image are important because such discrepancies are probably correlated with behaviorally relevant parts of the image. That is, some actions are more appropriately directed toward regions that differ in some way from their surrounds than to regions that are uniform on some dimension. This could be especially important developmentally for several reasons. First, early in development, before sufficient visual experience has occurred, it is unlikely that there is much top-down guidance of visual attention. In this case, bottom-up salience is likely to be more important in directing visual attention, and discrepancy-detecting processes would contribute to this bottom-up guidance.

Second, the impact of visual experience on the development of visual pathways is likely to depend on the distribution of the infants' looking behavior. Selectively looking at regions that are discrepant in some way from their surrounds rather than at uniform regions should promote the development of those pathways (Singer, 1982).

A number of studies using different stimuli and paradigms have demonstrated pop out in 3-month-old infants (Bhatt, 1997). Developmental researches have investigate the pop out effect during infancy using different procedures, e.g. the mobile conjugate reinforcement procedure (Adler, Gerhardstein, & Rovee-Collier, 1998; Adler, Inslicht, Rovee-Collier, & Gerhardstein, 1998; Bhatt, Rovee-Collier, & Weiner, 1994; Rovee-Collier, Bhatt, & Chazin, 1996; Rovee-Collier,Hankins, & Bhatt, 1992), novelty preference paradigms (Colombo, Ryther, Frick, & Gifford, 1995; Quinn & Bhatt, 1998), and the measure of eye movement latencies in visual search tasks (Adler & Orprecio, 2006).

3.3.1 The mobile conjugate reinforcement procedure

In the mobile conjugate reinforcement procedure (Rovee & Rovee, 1969), infants are trained to kick to move a mobile (Figure 3).

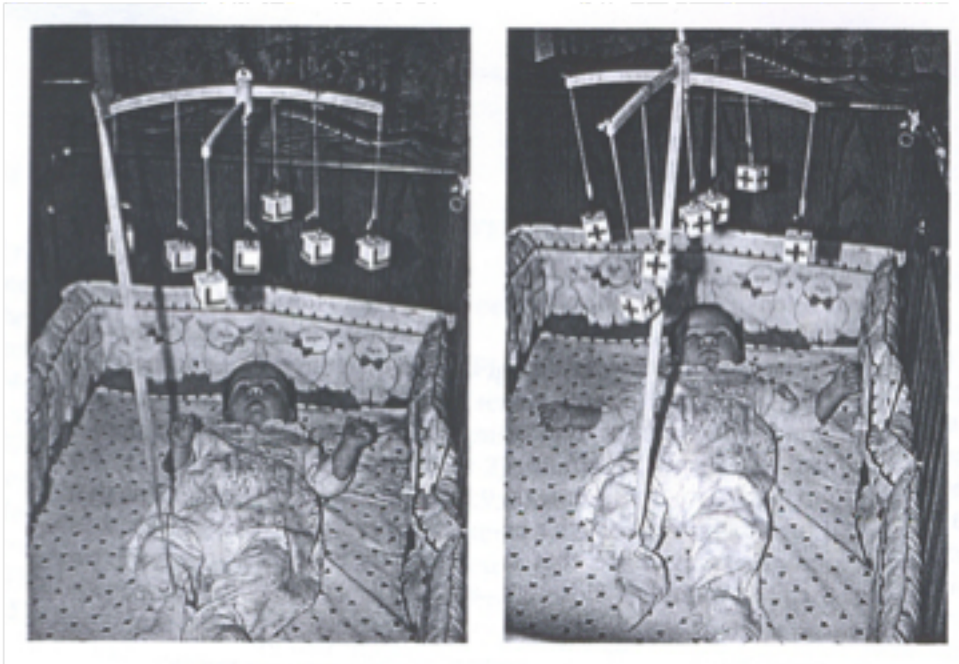

Figure 3: The experimental arrangement during training and testing with a 3-month-old infant (Rovee-Collier et al., 1992).

During training a ribbon is tied to the infants' ankle and is connected to the overhead mobile suspension hook. Infants are trained for two 15 minutes sessions (one session on each of two consecutive days). The first 3 minutes of the first session is the baseline phase, when the ribbon is connected to the empty hook, and we measure the infants' baseline or operant level of responding. If infants are tested 24 hours later, they show no memory deficit and continue to kick if they are tested with the same mobile that was used during training. If, however, they are tested with a novel mobile, they do no respond, indicating that they discriminated the change. Thus, this task is analogous to the Yes/No task frequently used in studies of adult perception and memory. Infants indicate Yes by responding at a rate greater than baseline levels during the test, and indicate No by failing to respond above baseline levels during the test.

Using the mobile paradigm, in a first series of experiments, Rovee-Collier et al. (1992) trained 3- and 6-month-old infants to kick to move an overhead mobile displaying seven instances of one element (e.g., +) and then tested them 24 hours later with a mobile composed of a single instance of the familiar training element amidst six novel elements (e.g., Ls), or vice versa (Figure 4).

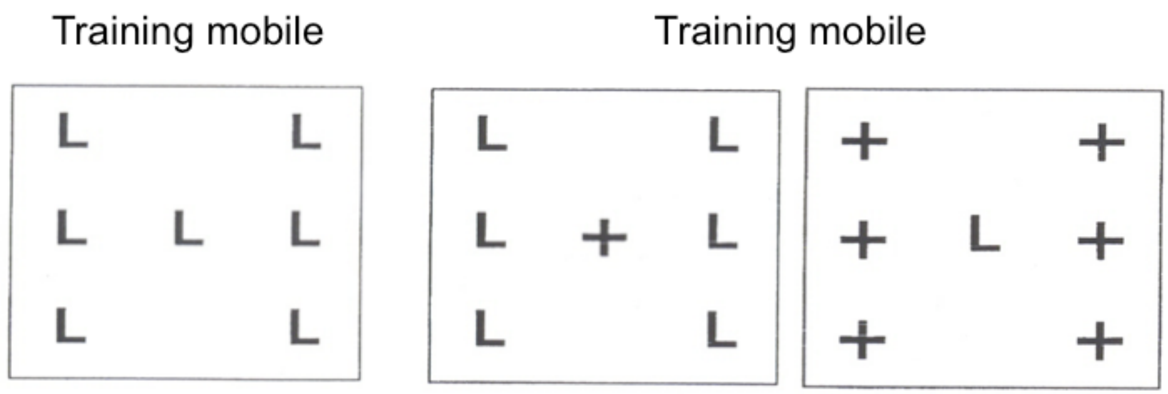

Figure 4: A schematic representation of the training and test conditions used in the visual pop-out studies. Infants were trained with seven-block mobiles displaying characters Ls (or +s). Independent groups were then tested with a single training block amidst six novel blocks or a single novel block amidst six training blocks (Rovee-Collier et al., 1992).

Julesz (1981) has hypothesized that + pop out from amidst Ls because the +s contain an additional perceptual feature – the line crossing – that is not part of the Ls. When the unique element in the test display was the previous training element, infants behaved as if the entire test mobile were composed of that element and responded to it robustly, despite the disproportionately greater number of novel elements that were used as distractors. When the unique element in the test display was novel, however, infants behaved as if the entire test mobile were composed of novel elements. In this case, infants failed to recognize the test mobile despite the disproportionately greater number of familiar training elements that were used as distractors. The recognition performance of groups suggested that the unique element in the test display, whatever it was, had popped out and captured their attention. As a result, 3- and 6-month-old infants' long-term memory performance was determined solely by the target element. The same differential allocation of attention to target and distractors also characterized visual pop-out effects in studies with adults (Treisman, 1988).

Using the mobile conjugate reinforcement procedure, several studies have provided evidence that pop out in infancy is affected by variables that are known to have systematic effects on pop out in adulthood, such as the set size (Rovee-Collier et al., 1996), the similarity between target and distractors (Bhatt et al., 1994), and the number and distribution of the discrepant elements (Rovee-Collier et al., 1992). The fact that a variety of variables have similar effects on pop out in 3- and 6-month-old infants as they have on pop out in adults suggests that pop out in early infancy is engendered by the same mechanisms as those operating in adults.

3.3.2 Novelty preference paradigms

Converging evidence of pop out in infancy using different procedure generalized the results obtained using the mobile conjugate reinforcement paradigm. Such evidence was first obtained by Quinn & Bhatt (1998) using a paired-comparison familiarity/novelty procedure and stimuli that more closely corresponded with those used with adults. The authors investigated possible pop out of line crossing and orientation information.

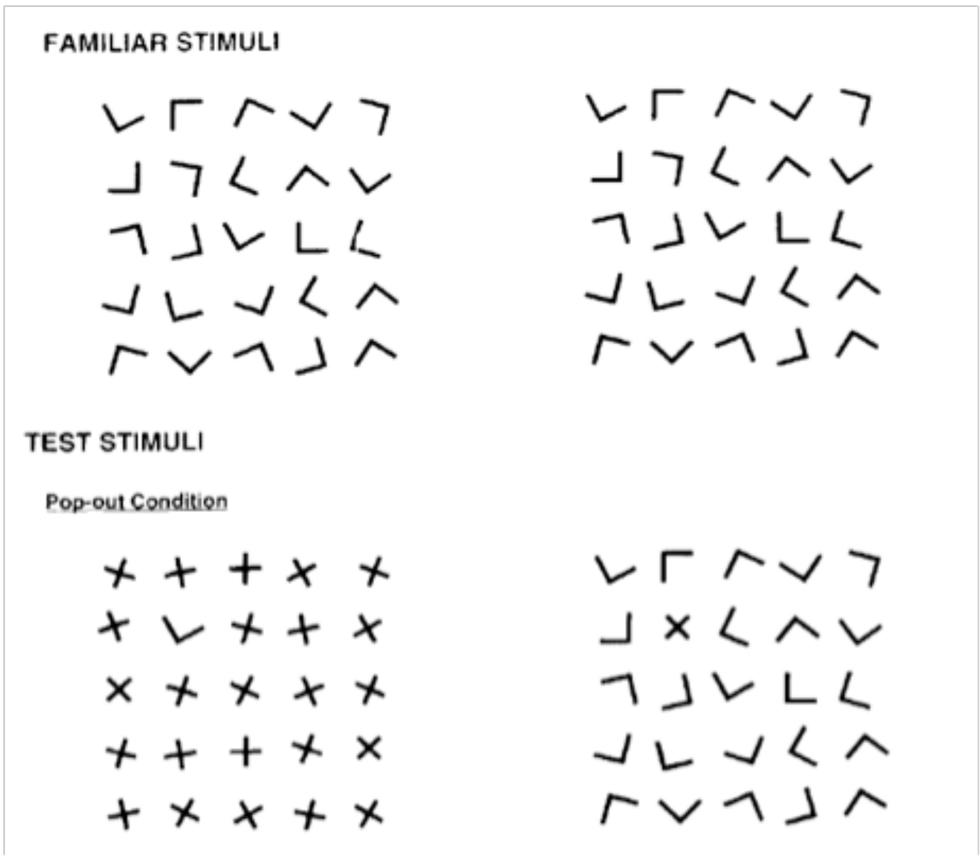

Figure 5: Familiar and test stimuli used in Quinn & Bhatt (1998) to investigated possible pop out of line crossing.

In the line crossing condition, 3- and 4-month-old infants were familiarized with homogenous 5 X 5 arrays of either Ls, or +s over four 15 seconds trials. They were then tested with two concurrently presented 5 X 5 test stimulus arrays, one of which contained a single novel character amid 24 familiar distractors, and the other contained a single familiar character amid 24 novel distractors (Figure 5). Infants were tested on two 10 seconds trials, with the position of the test patterns interchanged. If infants exhibit perceptual pop out, the individual L should be readily detected amid +s and vice versa, holding the infants' attention (operationally defined as where the infant look). In other words, as in the mobile studies, the expectation was that infants would treat an array with a discrepant element as being composed solely of the discrepant element. When this discrepant element is familiar, infants should treat the whole array as if it were familiar even though 24 out of the 25 elements in the array are novel.

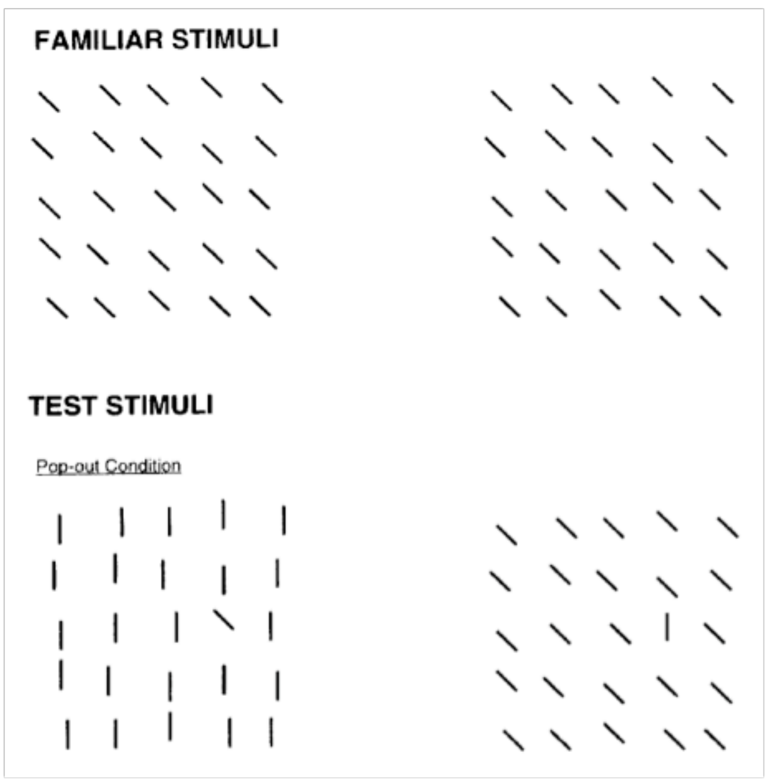

Figure 6: Familiar and test stimuli used in Quinn & Bhatt (1998) investigated possible pop out of orientation.

In contrast, if the discrepant element is novel, then infants should treat the whole array as if it were novel, even though 24 out of 25 elements in the array are familiar. Results showed that infants preferred the pattern with the single novel element. The same result was obtained in the orientation condition (Figure 6). These findings provided evidence of pop out based on line crossing and orientation information in 3- and 4-month-old infants.

Further support for the presence of the pop out phenomenon in infancy, using novelty preference paradigms, comes from a study reported by Colombo, Ryther, Frick, & Gifford (1995). Three- and four-month-old infants were exposed to two arrays to the left and the right of midline, one containing a homogenous array of objects (O) and another containing a single discrepant object (a Q target amidst the Os) (Figure 7). The visual preference was recorded by measuring the looking time to each array. Result showed that infants looked longer at the array that contained a discrepant object, than to the homogeneous array.

Overall, the studies just described and others (for a review, see Bhatt, 1997) seem to indicate that infants as young as 3 months exhibit the phenomenon of pop out. This would further suggest that the mechanisms for selectively allocating early visual processing resources are functioning in early infancy.

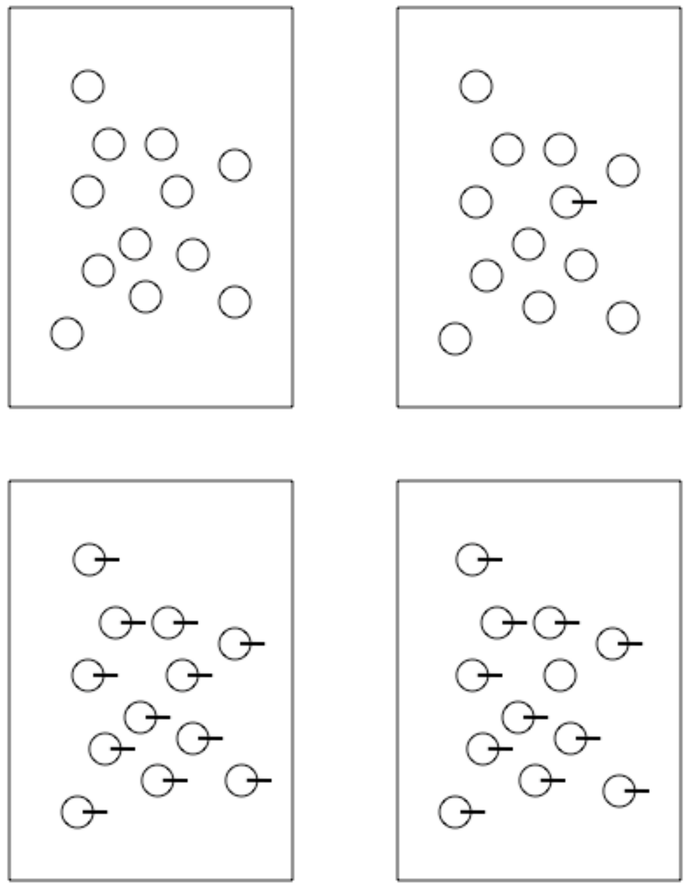

Figure 7: Visual search displays used in Colombo, Ryther, Frick, and Gifford (1995).

3.3.3 Infants' pop out studies: some methodological limits

Although studies that used the mobile conjugate reinforcement paradigm and the novelty preference paradigm seem to indicate that a pop out effect is exhibited in infants as young as 3 months, there are a couple of issue that have yet to be resolved by the infant pop out studies that would provide definitive evidence for pop out and efficient processing in infancy.

First, in adults pop out typically occurs on the order of milliseconds (e.g. Treisman & Gelade, 1980). In the infant studies described, however, paradigms are used in which results are measured in minutes or seconds at the vey least.

In the mobile-conjugate reinforcement paradigm, for example, assessment of pop out is done during a test phase that lasts 3 minutes (Adler et la., 1998; Rovee-Collier et al., 1992) – sufficient time for infants' behavior to be due to the allocation of attentive resources in an inefficient search rather that to pop out and efficient search. Infants' pop out studies that used the amount looking time as a dependent variable have a similar limitation as does the mobile paradigm. For example, in the Colombo et al. (1995) study which used preferential looking to an array that contained a pop out target among distractors versus an array that contained homogeneous stimuli, pop out was measured by requiring the infants to accumulate a total of 5 seconds of looking – a factor of 10 greater than is typically found in adult pop out studies – and more than enough time for later attentive and cognitive mechanisms to be responsible for infants' performance. Similarly, in studies using the novelty-preference methodology, tests for pop out might occur on trials that last 15 seconds. Interestingly, if infants has exhibited pop out and their attention had been automatically guided by the pop out target in these looking studies, then it should have been evident in their first looks. Yet, none of these studies report any data concerning infants' first looks. Thus, it can be argued that the novelty-preference studies, measuring looking time rather to a stimulus, rather than latency to orient to that stimulus, stressed the attention holding rather that the attention getting function of early visual processing (Bhatt, 1997; Cohen, 1972; Nakayama & Mackeben, 1989).

A consequence of the timing issue for measuring pop out in infants and the us of methods such as preferential-looking, novelty-preference and mobile-conjugate reinforcement is that the functioning of other cognitive mechanisms besides attention cannot be discounted from playing a role in observed effects. For example, infants' behavior, including evidence of pop out, is determined by recognition and discrimination processes. Consequently, memory (and forgetting) might play a role in determining infants' performance on search tasks using these paradigms.

A second issue that has yet to be addressed in the infant studies is that a key demonstration of pop out is that detection exhibit a flat search function. This means that the amount of time necessary to respond to the pop out target remains relatively the same even as the number of distractor items increases. No infants study has yet examined the effect of the number of distractors or set size on pop out. One study (Rovee-Collier et al., 1996) has examined the effect of the number of distractors on infants' recognition and discrimination of the pop out target, but because it too used the mobile paradigm in which there is no response time measure and the amount of time allocated to assess performance is so large (as described earlier), it is impossible to know whether infants in this study detected the pop out target.

These issues have been overcome by Adler & Orprecio (2006) by measuring 3-month-old infants' eye movement latencies, which are assessed in milliseconds, to further investigate whether infants exhibit pop out due to the output of a parallel processing mechanism.

3.3.4 Infants' eye movement latencies in visual search tasks

To overcome the two main limitations of the mobile paradigm and the novelty-preference paradigms in investigating visual pop out in infants, that is protracted test phase and failure to test for set size effect, Adler & Orprecio (2006) assessed the pop out effect in infancy by measuring the latency of 3-month-old infants' saccadic eye movements in a visual search task.

Many studies have indicated a tight linkage between adults' eye movement and attentional processing in visual search tasks. For example, findings from these studies demonstrated that the number of distinct eye movements are positively correlated with search times (Zelinsky, 1996), or that the latency and accuracy of the initial saccade to a visual search target is a function of the spatial certainty of the target (Findlay, 1997) and the number of distractors in the visual array (McSorley & Findlay, 2003; Motter & Belky, 1998). These findings indicate that an assessment of eye movements can be used as an accurate measure of visual search, pop out and mechanisms of attentional processing. Three goals guided the study: measure infants' eye movements in a perceptual task typically used with adults, i.e. a visual search task; assess the effect of increasing set sizes on infants' eye movement latencies; make a direct comparison to pop out in adults presenting the same stimuli and utilizing the same procedure in both ages.

Infants and adults were presented to arrays in which a target is either present or absent and that consisted of different numbers of distractors for set sizes of 1, 3, 5 or 8 items. The target was a + sign and the distractors were Ls (Figure 8).

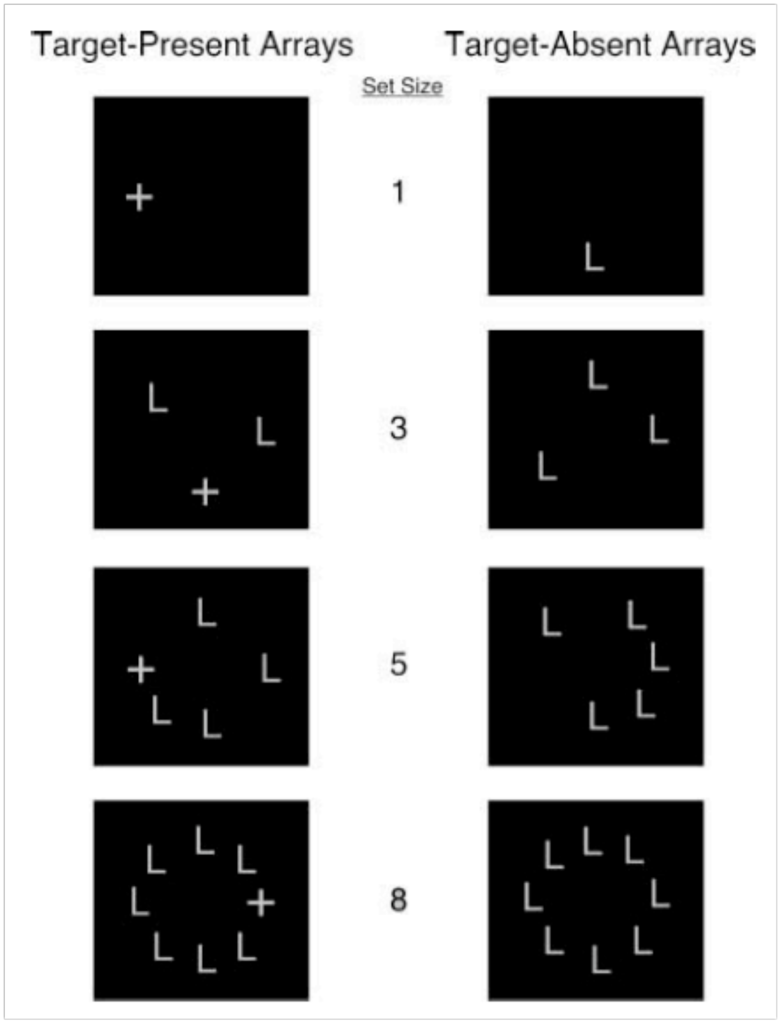

Figure 8: Examples of the visual search arrays used in Adler & Orprecio's (2006) study. The stimuli in the array shown to infants were actually red in color.

Results showed that the latency of infants' saccadic eye movements to stimulus arrays in which a unique + target was present among Ls were unaffected by the number of distractors, indicating that the + target popped out and the search was efficient. In contrast, saccade latencies to stimulus arrays in which the + target was absent increased with an increase in the number of distrctors, indicating that search was inefficient and requiring that significant attentional resources be allocated to the distractors. Moreover, infants' pattern of saccade latencies was found to be identical to adults' pattern. This findings provided evidence that, when saccade latencies were registered in a visual search task, infants from 3 months of age exhibit a pop out effect analogous to that found in adults.

3.4 Conclusions

The present chapter has reported some studies concerning adults' and infants' ability to selectively allocate visual attention to a target embedded in a display of competing stimuli.

When the target is defined by an unique features, adults' visual attention is automatically triggered by the target. As a consequence, the reaction time to find the target is not affect by the number of distractors, a phenomenon known as pop out. Using methods such as preferential-looking, novelty-preference, and mobile-conjugate reinforcement, many developmental researches have demonstrated that a visual pop out effect is present since 3 months of age (Bhatt, 1997). These paradigms have some limitations when compared to the assessment of visual pop out in adults. Actually, the pop out effect in adults is assessed by the measure of manual reaction times or saccades' latency, which occur in milliseconds. Conversely, in the mobile reinforcement paradigm and in the novelty preference paradigms, results on the pop out effect are measured in minutes or seconds. Thus, the functioning of other cognitive mechanisms, such as memory and forgetting, might affect infants' ability to exhibit pop out. Recently, Adler & Orprecio (2006) overcome these methodological limitations measuring pop out in early infancy by recording infants' saccades latency in a visual search task. The use of an eye tracker system allowed to directly compare infants' and adults' mechanisms to selectively allocating early visual processing resources. Adler & Orprecio (2006) provided evidence that, when saccade latencies were registered in a visual search task, infants from 3 months of age exhibit a pop our effect comparable to that found in adults

Overall, these studies demonstrated that, to select a visual object in complex scenes containing many other objects, infants can rely on the detection of the individual features of the object automatically, in a way that is analogous to that shown by adults.

The studies described in the present chapter, as well as evidences reported in Chapter 1 and 2, provided evidence that very early during the development infants are able to perform perceptual binding of separate surfaces to perceive partly occluded objects and illusory objects, and to selectively deploy the visual attention to detect local discrepancies in the image to detect single features of objects. Both perceptual binding and selective attention have been shown to be fundamental processes in achieving a veridical object perception.

In Chapter 4 the possible connections between attentional and perceptual processes in supporting object perception will describe, taking into account recent adults' and infants' studies that have tried to directly explore whether the perceptual binding of different fragments of an object is independent of selective attention or, on the contrary, whether perceptual binding requires spatial attention to be performed.

Chapter 4

The role of attention in adults' and infants' object perception

Figural binding and selective attention are two important processes that help us to perceive the outside world. Binding is necessary to link the different features of a single object. Selective attention serves to focus onto small subset of incoming information. Young infants rely on both perceptual binding (see Chapter 1 and 2) and selective attention (see Chapter 3) to detect the meaningful units in the flow of perceptual information and integrate these units into a coherent object. Although these results demonstrate that infants are able to use attentional and perceptual processes to differentiate the visual world into objects and to select objects as possible inputs for visual and cognitive processing, the relation and interaction between perceptual binding and selective attention in driving infants' objects perception remain unclear.

The recent adults' literature on the so-called 'object-based' view of attention represents a fertile new cross-talk between these two traditionally separate research fields, the one concerning visual segmentation and perceptual binding, and the other concerning selective attention (Driver, Davis, Russell, Turatto, & Freeman, 2001). This link has been widely investigated in adults by means of the visual search of illusory Kanizsa figures among competing stimuli.

In the first part of the present chapter a brief presentation of the object-based view of attention will be reported, as well as those studies that have directly investigated how selective attention and perceptual binding operate during the visual search of illusory figures. The last part of the chapter will report infants' studies that have tried to investigate the role of selective attention in supporting perceptual binding and object unity.

4.1 Objec- based view of attention

The object-based view of attention postulates that segmentation and binding processes can precede attention, so that the visual field can be preattentively parsed into coherent components that can be perceived as independent objects against a background. In other words, the object-based view of attention suggests that units of selective attention are discrete visual objects, instead of object features (Treisman & Gelade, 1980) or spatial regions (Posner, 1980), and that the limits imposed by attention may then concern the number of objects which can be simultaneously attended (e.g., Duncan, 1984; Kahneman & Henik, 1981).

Because objects occupy spatial locations, to support the objet-based view, objects have to be decoupled from locations. Duncan (1984) achieved that by briefly presenting normal participants with two superimposed visual objects, an outline box and a diagonal line, which occupied the same spatial location (Figure 1).

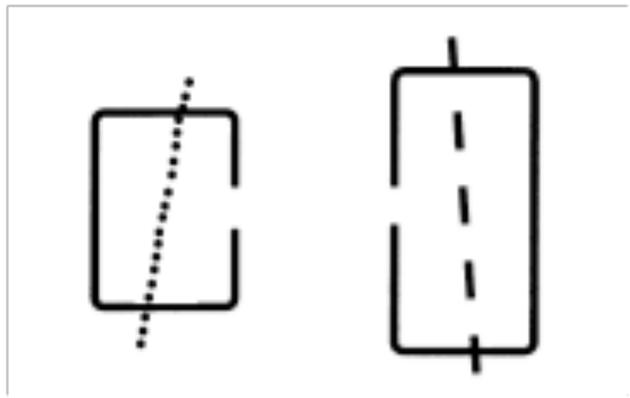

Figure 1: Examples of the displays used by Duncan (1984), adapted from his figure 1. Left: small box with gap on the right, dotted line with tilt clockwise. Right: large box with gap on left, dashed line with tilt counterclockwise.

Participants had to make judgments about one or two attributes the size of the box, the location of a gap in the box, the orientation of the line, and the texture of the line. They were able to make judgments concerning the same object (i.e., the orientation and texture for the line, or the size and gap size for the box) simultaneously without loss of accuracy, compared to when only a single feature was relevant. In contrast, they showed a cost (i.e., loss of accuracy) in making to judgments rather than one for features from different objects (e.g., the orientation of the line and the size of the box). Duncan's (1984) interpretation was that attention selects one object a time when objects occupy the same location in space.

Other similar studies have looked at the automatic spread of attention in response to the same type of cueing used by Posner et al. (1980) to demonstrate spatial effect. For example, Egly, Driver, ad Rafal (1994) used a display like that shown in Figure 2A to examine the possible contribution of object-based orienting of attention.

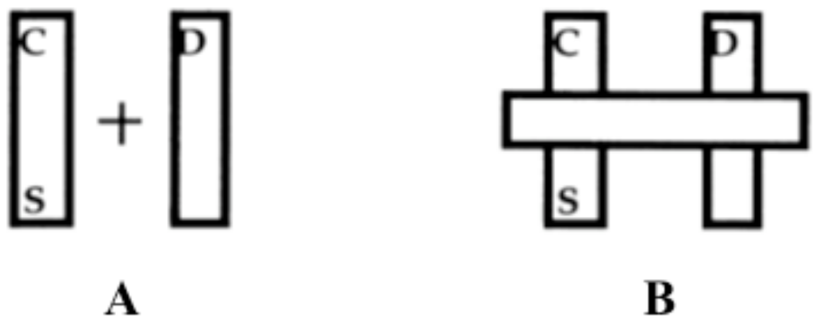

Figure 2: (A) Stimuli used in Egly, Driver, and Rafal (1994); (B) stimuli used in Moore, Yantis, and Vaughan (1998). In each display, 'C' indicates the cued location, 'S' indicates a same-object target location, and 'D' indicates a different-object target location.

Attention was directed to one end of one of the rectangles, by brightening. This cue was predictive of the location of the target, so would be expected to attract attention to that region. Thus, on most trials the target occurred at the location validity predicted by the cue (C). on a minority of invalid trials the target could appear in a location other than that cued. These invalid trials could be of two types: the target could appear either at the opposite end of the cued rectangle ('S' for 'same object), or at the end of the other rectangle ('D', for 'different object'). Both the invalid target positions were an equal distance from the location of the cue, so no spatial account of cuing would predict any difference between these two conditions. When targets appeared at an uncued location that was located on the same object as the cue (S), a modest increase in reaction time to detect the target was seen compared to validity cued trials. However, when targets appeared at the uncued location on a different object

(D) a much larger reaction time cost was seen. Since the spatial distance between the cued location and the two critical locations is identical, these results on a 'same-object advantage' are consistent with the notion that attention tends to spread to include the entire object, and not simply to region of space occupied by an object. This paradigm has also been used to demonstrate that the units of selection are complex enough to take occlusion into account, since the 'same-object advantage' have been replicated with displays in which the two bars are amodally completed behind an occluder (Figure 2B) and so are physically separate in the display (Moore, Yantis, & Vaughan, 1998). The studies discussed in this section do not disprove the hypothesis that attention operates in a spatial medium, but they do show that this medium is not continent-free. Instead, the locations that are enhanced or inhibited depend strongly on how the display is segmented (Drive & Baylis, 1998).

Overall, the object-based view of attention postulates that, in adults, perceptual binding is independent of selective attention, and that the visual field is automatically parsed into objects against a background.

4.2 Attentional processes in adults' visual search of illusory figures

One way in which figural binding and selective attention has been investigated is by assessing the attentional and perceptual processes necessary to perceive an illusory Kanizsa figure. As pointed out in Chapter 1, Kanizsa figures are considered to represent a prototypical case of the visual system binding together separate elements in the image, i.e. the inducing elements, to produce a single illusory object.

The majority of studies on illusory figures perception have been founded upon phenomenal measures (such as rating the perceived strength of a subjective figure; Warm, Dember, Padich, Beckne, & Jones, 1987), relying on subjective reports of what was perceived, given unlimited viewing of a single illusory figure display. Although phenomenology has considerably expanded our knowledge of illusory figure processing, phenomenal measures present some limits. For example, unspeed phenomenological judgments are clearly unsuitable for addressing how exactly figural binding and selective attention operate during the processing of an illusory figure. This is a critical point in the assessment of the processes involved in the perception of a Kanizsa figure, since it has been suggested that figural binding which is necessary for perception of the Kanizsa figure is closely related to processes of selective spatial attention (Driver et al., 2001).

Conversely to phenomenological measures, visual search tasks overcome these limits specifying whether the binding of the pacmen of the illusory figure is independent on selective attention or, on the contrary, whether binding requires spatial attention. As described in Chapter 2, in visual search tasks, the observer must typically determine as quickly as possible the presence of a prespecified target among a varied number of homogeneous distractors (Treisman, 1986; Treisman & Gelade, 1980). The efficiency of the search can be assessed by varying the number of distractors (the set size) and measuring reaction time (RT). When the observer detect the target automatically, the reaction time (RT) to find the target is unaffected by the number of distractors in the display (pop out effect). Conversely, when the observer uses focal attention and a serial scanning of the visual display to identify the target, the RT increases as a function of the number of distractors.

Two models regarding the temporal order of figural binding and attention have been conceptualized: the binding-first model and the attention-first model (Senkowski, Rottger, Grimm, Foxe, & Herrmann, 2005). The binding-first model proposes that visual binding of the inducing elements of the Kanizsa figure does not depend on visual focal attention. In this case, the Kanizsa figure automatically triggers visual attention when presented in a display of competing stimuli, i.e. pacmen that do not give rise to illusory contours. In contrast, the attentional-first model proposes that figural binding requires focal attention, that is, attentive mechanisms allocates processing resources to each pacman in turn to perform the perceptual binding and, consequently, detect the illusory figure. Thus, the binding of the inducing elements to detect the Kanizsa figure amidst competing stimuli require does not occur automatically.

A number of studies investigated whether illusory figures can trigger visual attention (Davis & Driver, 1994; Grabowecky & Treisman 1989; Gurnsey, Poirier, & Gascon, 1996; Herrmann, Mecklinger, 2000; Senkowski et al., 2005).

In a first research (Grabowecky & Treisman, 1989) carried out to investigate whether or not an illusory Kanizsa triangle popped out among distractors, the target stimuli were three inward-facing pacmen that induced the perception of an illusory triangle, whereas the distractors involved the same three pacmen arranged in such a way as not to induce illusory contours. The results showed that RT increase with set size and, consequently, that the search of the Kanizsa triangle was serial and requires focal attention, suggesting that the illusory figure did not pop out. This conclusion has not been supported by further studies, since contradictory results have been obtained with adults. For instance, in contrast to the Grabowecky & Treisman's study (1989) some researches succeeded in providing evidence for a pop out effect of a Kanizsa figure (Driver & Davis, 1994; Herrmann & Mecklinger, 2000; Senkowski et al., 2005).

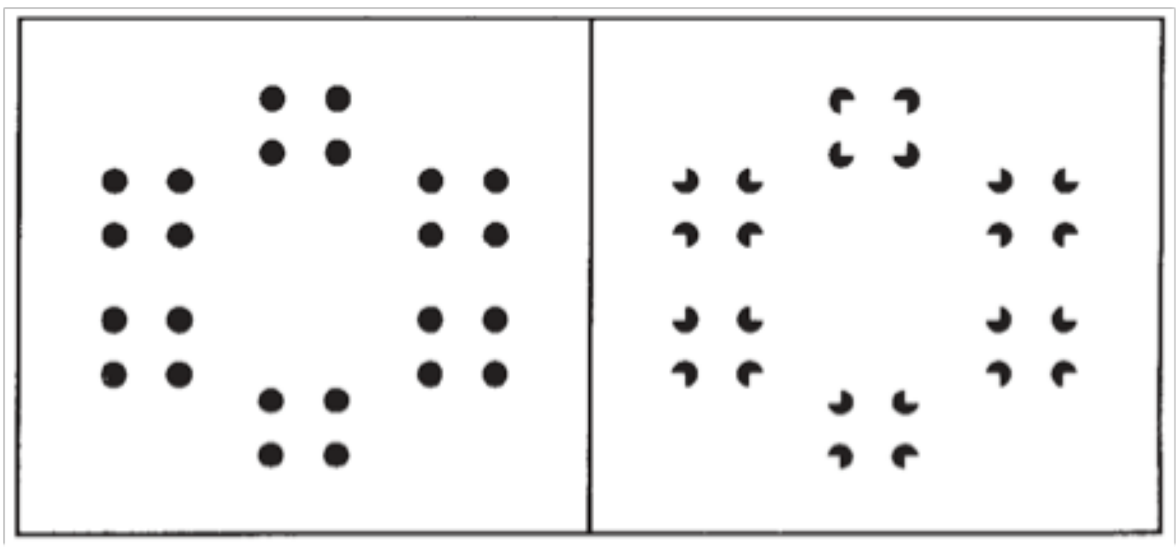

Figure 3: Visual search displays used in Davis & Driver's (1994) study.

Driver & Davis (1994) succeeded in demonstrating that a Kanizsa illusory figures can be detected without focal attention in a visual search task. The authors first presented uninformative clusters of circles. After some time, a quarter of each circle was erased (Figure 3). Participants had to report whether of not a Kanizsa square was created. It was shown that the detection of the Kanizsa figure was not dependent on the number of clusters. This indicates that subjects did not have to search within each cluster for the Kanizsa square, but that it popped out in the display, suggesting that the illusory object was detected automatically.

This outcome has been criticized arguing that Davis & Driver (1994) have supplied sufficient information in their search displays to support an automatic search of the Kanizsa target independently of whether illusory contours were present or not (Gurnsey et al., 1996). The critical point was that Davis & Driver (1994) used a display in which the luminance gradients inside the Kanizsa target was higher as compared to the luminance gradients inside the distractors. Thus, the visual search was driven by the basic perceptual feature of the Kanizsa figure, instead of being guided by the perception of a coherent illusory object. Using a display in which this factor was controlled Gurnsey et al. (1996) did not find evidence for a pop out effect for the illusory figure, suggesting that spatial attention may be necessary for illusory contour processing. In order to control the critical point mentioned by Gurnsey et al. (1996), Senkowski et al., (2005) used displays which included blank areas at various positions, as well as inducing elements that had the same spatial configuration as the Kanizsa target, but did not constitute an illusory figure (Figure 4). The authors again found a pop out effect for the Kanizsa figure, concluding that Kanizsa illusory objects automatically captured spatial attention when used a visual cue.

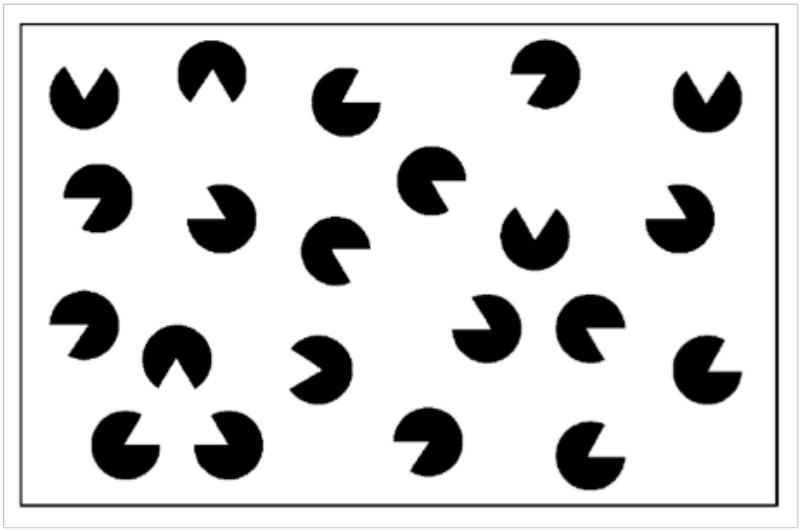

Figure 4: Example for visual search display used in Senkowsli et al. (2005).

Obtained results demonstrated that, under some conditions, object-based attention effects can be observed in Kanizsa illusory figures, which have a methodological advantage over real objects in experimental settings because in experiments in which physically present objects are used (e.g., Duncan, 1984) objectness is hard to manipulate without physically addition or omission of elements. Conversely, Kanizsa figures can be easily configured so that no illusory object is perceived, by simple rotation of the inducing elements. More intriguingly, these findings provided evidence that the visual search of a Kanizsa figure amidst competing stimuli is a reliable tool to investigate how segmentation processes constrain attentional processes, and vice versa.

4.3 Selective attention in infants' perception of partly occluded and illusory objects

Differently to adults' literature, to our knowledge just few developmental studies have investigated how selective attention and perceptual binding operate to support a veridical object perception in young infants using partly occluded objects (Amso & Johnson, 2006; Johnson & Johnson, 2000; Johnson, Slemmer, & Amso, 2004) and illusory objects (Wada, Shirai, Otsuka, Midorikawa, Kanazawa, Dana, & Yamaguchi, 2008).

Johnson & Johnson (2000) recorded scanning patterns in 2- and 3.5-month-old infants engaged in free viewing of partly occluded rod displays. Using an eye tracker system, infants' eye movements were recorded during the presentation of stimuli depicting two rod parts above and below an occluding box. The more proficient infants become at information pickup in support of visual binding, the more likely it is that they will be able to detect and utilize that information in perceptual tasks. Results showed that older infants scanned more extensively both the upper and the lower rod parts, whereas young infants scanned les often in the vicinity of the bottom rod part, indicating that the period in infancy during which unit formation undergoes rapid improvement is accompanied by important advances in scanning efficiency (Figure 6).

This result is supported by a subsequent research in which Johnson et al. (2004) investigated the perceptual completion of a partly occluded object combining habituation and eye-tracking methods. The goal of the study was to determine how young infants picked up visual information as they were engaged in an object perception task. Three-month-old infants were tested in a traditional object unity paradigm: infants were habituated to a rod and box displays and subsequently tested with a broken and complete rods test displays.

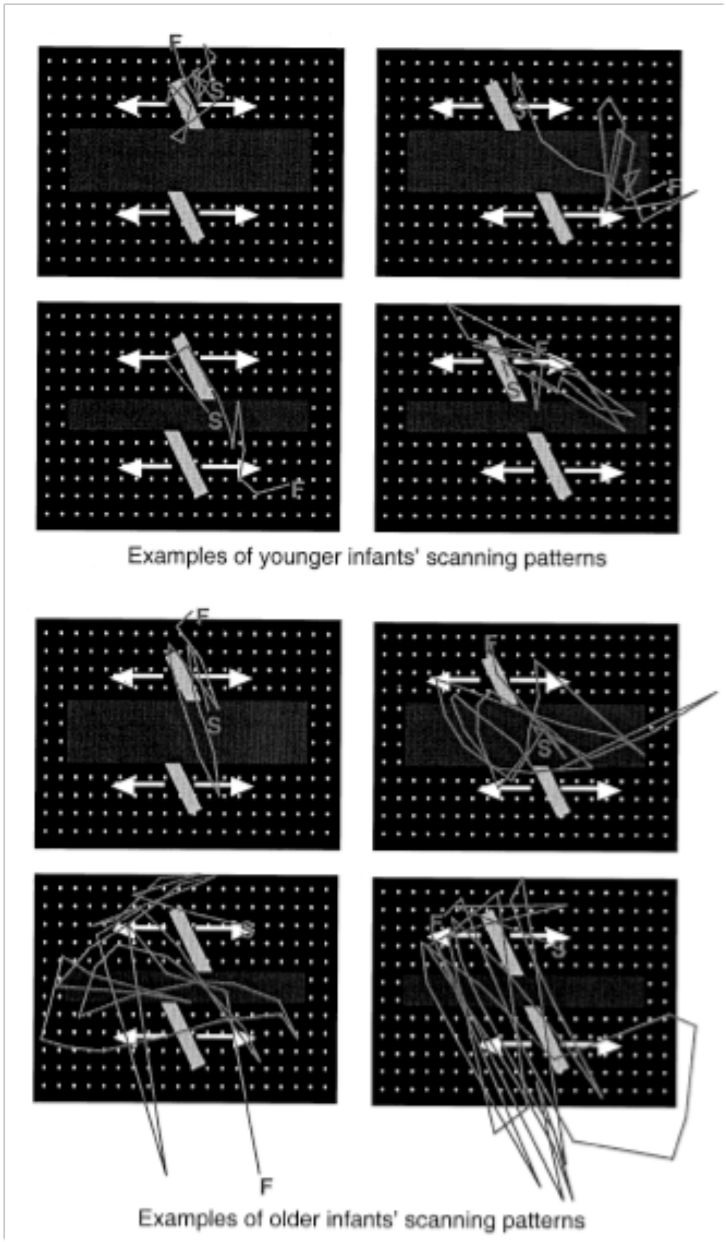

Figure 6: Displays used in Johnson and Johnson' (2000) study, and examples of superimposed scan paths from the two age groups observed. S = start scan path, F = finish scan path.

Since 2-month-old infants appear to be unable to perceive unity in a rod and box display when a wide occluder were presented, but 4-month-olds can (Johnson & Aslin, 1995), results were expected to provide a mixed result. In line with this prediction, a subset of infants achieving perceptual completion, while others failing to do so. Although all infants scanned actively across the stimulus, those infants whose posthabituation looking times implied unity percepts (i.e., infants who preferred the broken rod, termed perceivers) fixated the rod more frequently and scanned more often across the rod's path as it translated back and forth, relative to the infants whose test display preference did not imply perception of the partly occluded rod as unified (termed nonperceivers) (Figure 7).

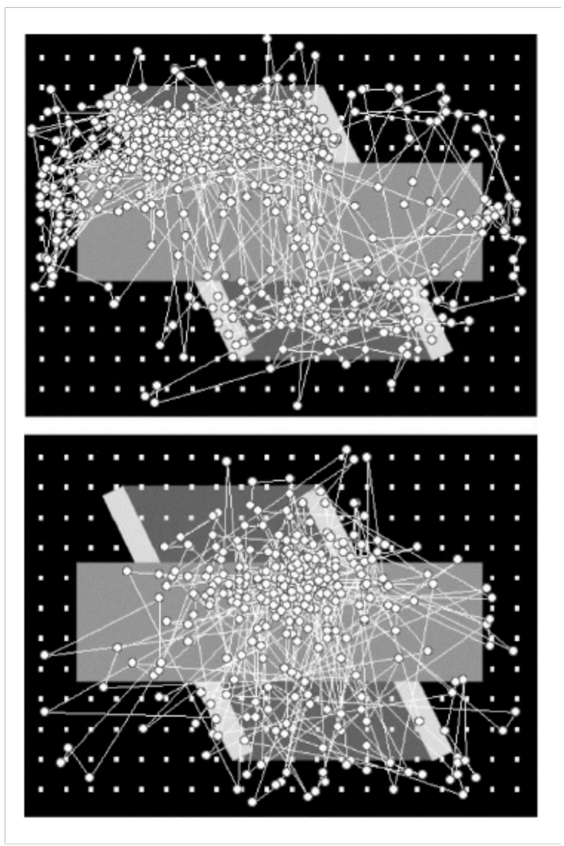

Figure 7: Examples of two infants' scanning pattern during habituation in Johnson, Slemmer, and Amso (2004). Each is shown with the full lateral extent of rod motion (between the left and right positions). Top: A perceiver. Bottom: A non perceiver. Note that both infants scanned actively across the display, but the perceiver spent more time inspecting the rod parts and their motion.

Johnson et al. (2004) speculated that the scanning patterns exhibited by the perceivers served to maximize the information uptake about the features of the habituation stimulus that were relevant for perceptual completion, features such as alignment of the visible rod parts and their motion. Identification and attention toward these features might have supported unity perception, perhaps more than so than would be possible via a focus on display features that were less relevant to unity (e.g., the occluding box or the background). This outcome suggests that infants who are inclined to perceive unity were also likely to attentively select to the right visual information to pursue object completion.

Although these findings suggest that emerging object perception is closely tied to the ability to selectively pickup the visual information available in the environment, the analysis of the scanning patterns during the presentation of a rod and box display did not disentangle the question of how selective attention may be relate to perceptual binding in infancy. As already report, this issue has been investigated in adults using the visual search of a target among competing stimuli, a procedure that allowed to determine how selective attention affect objects' perception and vice versa.

Amso & Johnson (2006) tried to find a possible link between selective attention and perceptual binding by means of an independent visual search task to investigate group differences between infants who provide evidence of unity perception and efficient visual exploratory behavior during the habituation phase of the object unity paradigm and those who do not. Using an eye tracker, 3-month-old infants were tested in a visual search task. Infants were presented with a display consisted of static homogeneous vertical bars with a single target bar, tilted from the vertical, at one of three possible orientations. Infants were also habituated to a rod and box display, followed by broken and complete rod test displays, as eye movements were recorded with an eye tracker (Figure 8).

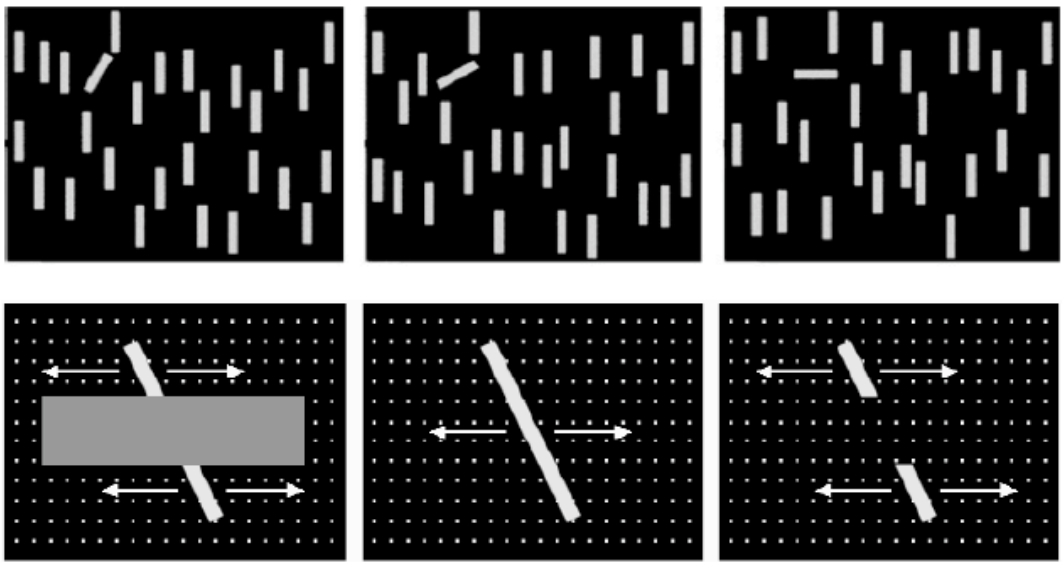

Figure 8: Stimuli used in Amso & Johnson (2006). Top: Displays used to assess visual search in infants. Bottom: Displays used to assess perceptual completion in infants.

Three-month-old infants who provided evidence of perceiving the unity of disjoint surfaces also provided evidence of efficient visual selective attention in a search task. These infants, relative to infants who provided no evidence of unity perception, selected orientation-defined target reliably more often. Amso & Johnson (2008) interpreted this results arguing that selective visual attention may be related to online information-gathering behavior, which, in turn, is related to objects' perceptual completion.

Wada et al. (2008) further investigated the role of attention in perceptual binding has been investigating testing the effect of a concurrent and unique sound on the visual detection of a Kanizsa figure in 5-, 6- and 7-month-old infants (Figure 9). Results showed that sounds enhanced the detection of illusory contours, in 7-month-old infants, but not in 5- and 6-month-old infants. The authors argued that this result may reflect the development of attention in infancy, since the constrain sound acted as an alerting signal, arousing infants' attention so that a brief presentation of the stimuli (200 ms) was sufficient to evoke a looking preference for the illusory contour at 7 months of age.

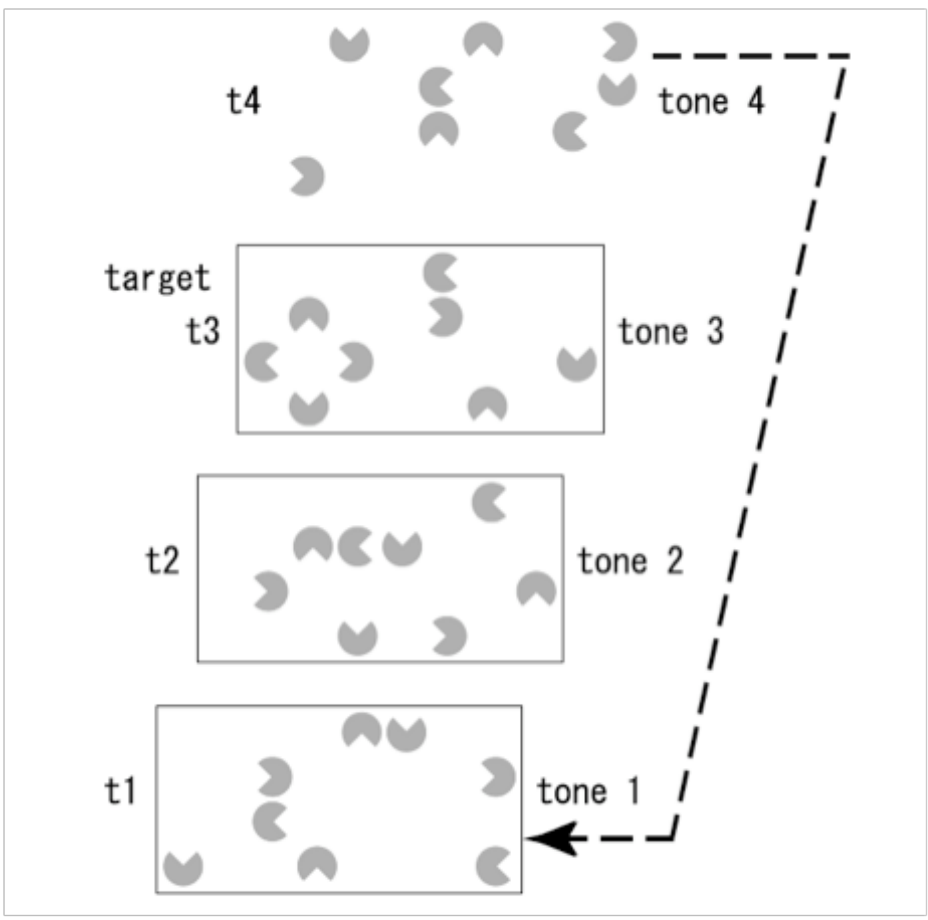

Figure 9: Schematic illustration of a stimulus sequence in Wada et al. (2008).

4.4 Conclusions

Overall, the data described in the present chapter provided evidence that in young infants attention mechanisms play a fundamental role in the selection of visual information to perceive coherent, unified objects. Nevertheless, it is worth noting that, differently form adults' studies, infants' studies gave only indirect evidences regarding the role of selective attention and perceptual binding in supporting objects' completion. In fact, in contrast to adults' researches in which attentional and perceptual processes in achieving object perception have been directly compared (e.g., Driver et .al., 2001), the procedures used in infants' literature, such as the measure of scanning strategies during object completion (Johnson & Johnson, 2000; Johnson et al., 2004), the comparison between infants' performance in independent visual search and perceptual completion tasks (Amso & Johnson, 2006), and the multisensory integration between sounds and illusory figures (Wada et al., in press), leave unresolved the question of how selective attention and perceptual binding interact to pursue object unity.

The study that will be described in the next chapter starts form this lack, and try to directly investigate whether young infants' ability to binding different fragments of an object is independent of selective attention or, on the contrary, whether perceptual binding requires attention to be performed.

Chapter 5

The role of selective attention in the perceptual binding of illusory figures in infants and adults

As reported in Chapter 4, perceptual binding and selective attention are two fundamental processes to pursue a veridical object perception in young infants. Although the way in which either perceptual binding or selective attention operate to process the incoming visual information in early infancy is well investigated, the relation between selective attention and perceptual binding in supporting infants' object perception remains unclear.

Conversely to developmental literature, the influence of selective attention on perceptual binding and vice versa has been widely assessed in adults. One of the way in which this issue has been studied was in assessing the visual search of an illusory figure among competing stimuli. This procedure has been shown to be a reliable measure in adults to investigate how perceptual binding and selective attention interact. To our knowledge, no developmental studies have investigated the role and relation of perceptual binding in support objects perception in early infancy.

5.1 Study 2

The present study was aimed at investigating the interaction between perceptual binding and selective attention in young infants, using paradigms that are more akin to those used with adults. The focus of the present experiments is not on particular cognitive achievements that are expressed at a particular age, but instead is on the fundamental developmental processes and mechanisms that interact to support infants' increasing facility to perceive the world in an adult like fashion.

To this end, 6-month-old infants' eye movements were assessed with an eye tracker system in order to investigate whether a Kanizsa figure can trigger visual attention in early infancy. Infants were tested with visual displays in which an illusory figure was presented with competing stimuli. The paradigm was adapted to disentangle the following questions: Can infants detect an illusory figure among distractors as adults do? Do infants and adults perform the same visual explorative behavior in the visual search of an illusory figure?

As already mentioned in Chapter 3, only a recent study was carried out to investigate whether infants exhibit a pop-out effect with a real figure by comparing infants and adults using a visual search task (Adler & Orprecio, 2006). This result supports the method of measuring eye movements as a comparable tool to examine visual search, pop-out and the underlying attentional mechanisms in early infancy and through development. To date infant's literature does not report any study in which an illusory target (i.e. a Kanizsa target), instead that a real target, has been utilized.

The ability to perceive a Kanizsa figure is well established in young infants. Six-month-old infants have been shown to perceive static Kanizsa figures under conditions in which infants were provided with a high support ratio (Otsuka et al., 2004). Given that 3-month-age infants exhibit the phenomenon of pop-out with real target (Adler & Orprecio, 2006), and the binding processes involved in the perception of the Kanizsa figure can be found in static displays at 6 months of age (Otsuka et al., 2004), it might be expected that a Kanizsa figure can automatically trigger infants' visual attention, as already demonstrated in adults (Senkonsky et al., 2005).

Using an eye tracker system, three experiments were carried out. Infants were tested for a visual search of the Kanizsa figure amidst distractor pacmen, and their visual behavior during the presentation of the search display was directly compared to adults' visual behavior. Adults (Experiment 5 and 6) and infants (Experiment 7) were tested in two conditions, i.e. illusory and non illusory conditions. In the illusory condition, a Kanizsa triangle was embedded among distractor pacmen that did not generate illusory contours. In the non illusory condition, the illusory triangle was turned red to obtain a real triangle included in the same pacmen's display. The real triangle differed from the surrounding pacmen in terms of both shape and colour. The difference in these basic features between the real target and the distractors gives rise to a visual search in which the target popped out from the display (Neisser, 1967; Treisman & Gelade, 1980). Thus, the non illusory condition allowed us to obtain a control display in which the visual search of the target was highly efficient and does not require focal attention. If the illusory Kanizsa figure popped out from the search display as the real red triangle, the visual behaviour in the illusory condition should not differ from the visual behavior in the non illusory condition and the search of both the illusory and non illusory targets should not require selective spatial attention. On the contrary, if the search of the Kanizsa triangle is serial and require focal attention, only the red triangle should show a pop out effect. For both infants and adults direction and latency of the first saccade were registered.

Experiment 5

The purpose of Experiment 5 was to test adults' exploratory visual behavior during the visual search an illusory Kanizsa triangle amidst distractors pacmen. The visual search of the Kanizsa illusory triangle (illusory condition) was compared with the visual search of a red triangle embedded in the same pacmen's display (non illusory condition) (Figure 1).

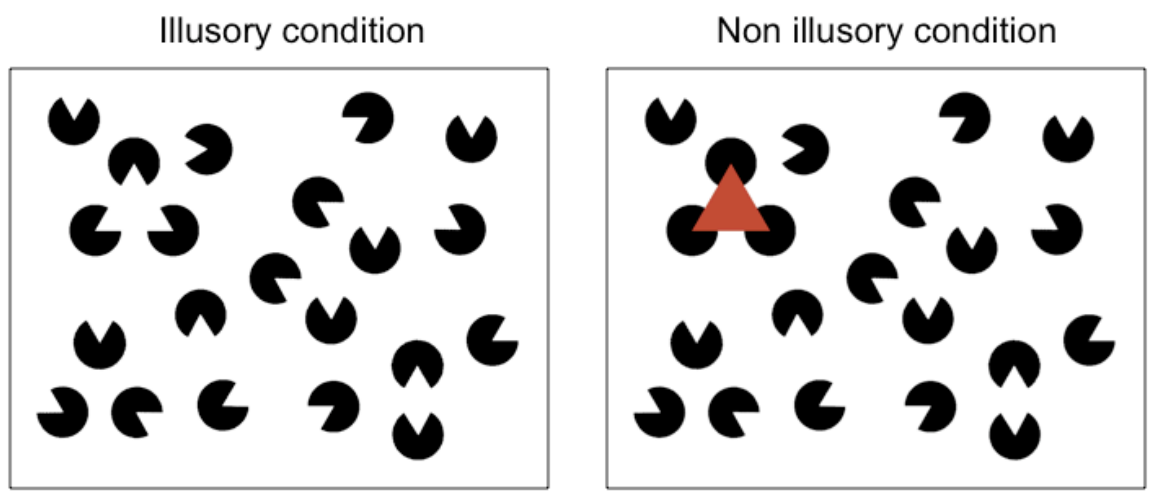

Figure 1: Visual search displays presented in Experiment 5.

In order to avoid the possibility that the detection of the Kanizsa illusory triangle could be due to its basic perceptual feature (Gurnsey et al., 1996), in both illusory and non illusory conditions some distractor pacmen in the search display were arranged to form three control stimuli that shared with the Kanizsa figure one of its perceptual features, i.e. triangular arrangement, luminance and closure. If the Kanizsa figure guided the deployment of visual attention as a unique illusory perceptual pattern and independently from its basic perceptual features, the number of the eye movements directed to the illusory target should be higher than those directed to each control stimulus. Similarly, it is expected that the distribution of the eye movements toward the target and the control stimuli should not differ for the illusory and the non illusory condition.

Method

Participants

Eighteen adults, selected between the undergraduate students of the University of Padova, participated in the experiment. Three participants were excluded from the sample because of uninterpretable eye movements due to poor calibration (2), or program errors during data collection (1). So, the final sample consisted of fifteen adults aged 19-28 years (mean age = 22.5 years). All of them had no previous experience in eye-movement studies and were naïve to the experimental conditions and hypotheses of this experiment. Participants gave their informed consent before participating in the study.

Stimuli

The stimuli were graphic images generated thorough the software Adobe Photoshop 6.0. The stimuli were constructed on the basis of those presented in Senkowski et al. (2005) study (see p. 104). Each stimulus display consisted of 21 black pacmen (3 cd/m^2) against a white background. The diameter of each pacman was 4 cm (2.9°). Participants were tested in two conditions. In the illusory condition, 3 pacmen gave rise to an illusory Kanizsa triangle. The base of the triangle measured 6.3 cm (9°) and the height 5.3 cm (7°). Some of the distractor pacmen formed three control stimuli that shared with the Kanizsa figure one of its perceptual features, i.e. triangular arrangement, luminance and closure. The control stimulus called ‘triangular arrangement’ was obtained by rotating the elements that constituted the Kanizsa triangle, so that to form a stimulus with the same triangular configuration as the illusory figure, but without any illusory contours. In the stimulus called ‘luminance’ 5 pacmen included a blank area whose luminance was comparable to the luminance inside the Kanizsa figure. Finally, in the stimulus called ‘closure’ 2 pacmen faced inward to form a closed configuration. In the non-illusory condition, the illusory triangle was filled red so that to obtain a real figure well defined against the background (Figure 2). The real target was embedded in the same pacmen’s display used for the illusory condition.

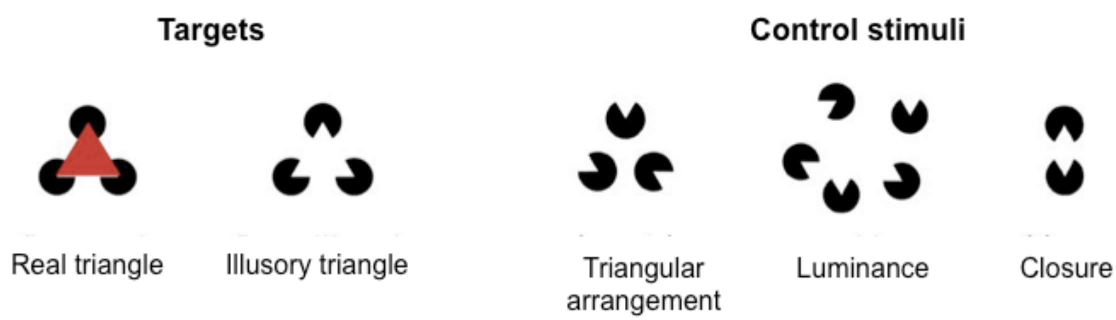

Figure 2: Targets and control stimuli embedded in the visual search display.

Apparatus and procedure

The apparatus and procedure were identical to those used in Experiment 4. The adult participants sat in a high-back chair so that their heads were resting against the back of the chair for stability and they were situated 60 cm from the stimulus monitor. Each visual search display had a duration of 3000 milliseconds (ms) during which either an illusory display or a non-illusory display was presented. Each participant was shown with 16 trials for both the illusory and the non-illusory condition, for a total of 32 trials which presentation sequence was randomly determined.

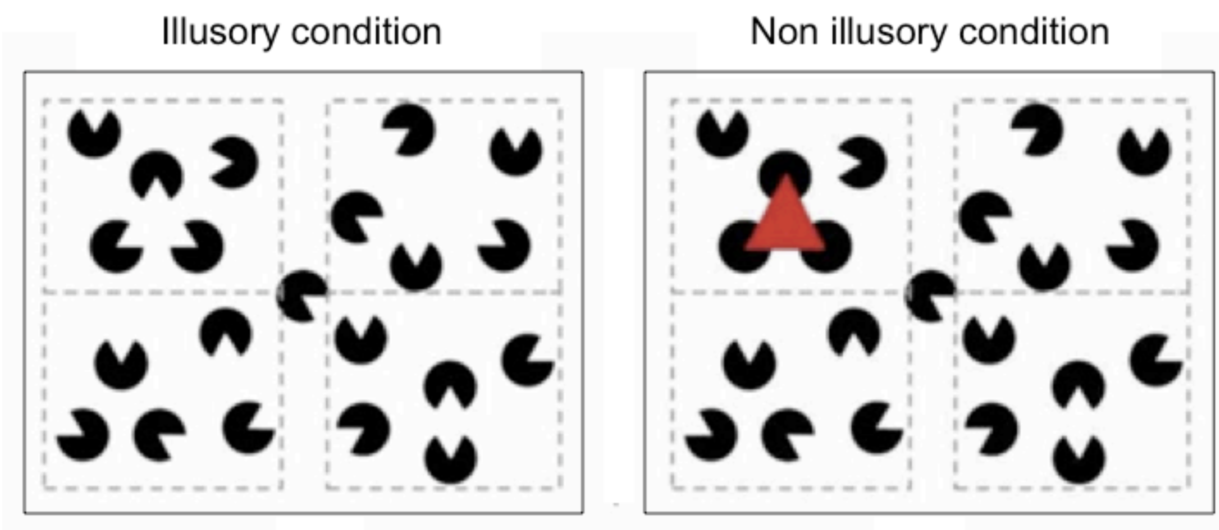

Figure 3: Sketched lines indicate the regions on interest (ROI) in which the displays presented in Experiment 5 were virtually divided for the computation of the eye movements' direction and latency.

Across all trials, either for the illusory and the non-illusory condition, the position of the target and the control stimuli (triangular arrangement, luminance and closure) was balanced within four regions of interest (ROI) previously selected by the experimenter and occurring in each of the four quadrant of the display (Figure 3). Each ROI measured 17 cm (12.2°) in weight and 15 cm (10.7°) in height.

Data analysis

The direction and the latency of the participant's first eye movement toward each ROI were measured. All analysis was performed through the software E-Prime 1.1.

Results

First saccade direction

To verify whether the illusory target, as the real one, captured visual attention, a distribution of the first saccades direction within the search display was calculated. For each participant, the number of the first saccades directed toward each ROI was divided by the total of the 32 trials performed, and subsequently converted into a percentage score.

In the illusory condition, the percentage of the first saccades directed toward the ROI that contained the illusory target and the control stimuli was distributed as follows: Kanizsa triangle = 62% (SD = 17%), triangular arrangement = 7% (SD = 8%), closure = 16% (SD = 8%), luminance = 15% (SD = 11%). These percentages were compared to the 25% chance value by means of one-sample *t* test. All the four percentages differed from the chance level, Kanizsa triangle: $t(14) = 8.61$, $p < 0.001$; triangular arrangement: $t(14) = 9.30$, $p < 0.001$, closure $t(14) = 4.31$, $p < 0.001$, luminance = $t(14) = 3.51$, $p = 0.003$. In the non illusory condition, the percentage of the first saccades directed toward the ROI that contained the real target and the control stimuli was distributed as follows: red triangle = 85% (SD = 15%), triangular arrangement = 4% (SD = 6%), closure = 4% (SD = 8%), luminance = 7% (SD = 8%). As in the illusory condition, the percentages were compared to the 25% chance value by means of one-sample t test. All the percentages differed from the chance level, red triangle: $t(14) = 15.12$, p < 0.001; triangular arrangement: $t(14) = 13.93$, $p < 0.001$, closure $t(14) = 9.98$, $p < 0.001$, luminance = $t(14) = 8.28$, $p = 0.003$.

Results showed that both in the illusory condition and in the non illusory condition the distribution of the first saccade toward the target and control stimuli was different from chance, revealing that a high percentage of the first saccades were performed toward the illusory and the non illusory target. Although the distribution of the first saccades was comparable in the two conditions, the red triangle was selected with a percentage of first saccades higher than the Kanizsa triangle (Kanizsa figure = 62% vs real figure = 85%), $t(14) = 5.11$, $p < 0.001$, paired samples. Most probably, this result can be due to the fact that the red triangle differed from the distractor pacmen more than the illusory triangle in terms of both shape and color (Treisman & Gelade, 1980). In contrast, the Kanizsa figure shared with the distractor pacmen at least one of the basic features (i.e. triangular arrangement, luminance, closure). This is an important difference between the two conditions, since visual selective attention literature of both adults (e.g. Duncan & Humphreys, 1989) and infants

(Dannemiller, 1998, 2000) show that alterations in the level of similarity between target and distractors affect search efficiency. More precisely, increasing the salience of the target improves target detection.

Saccades latency

The mean latency of the first saccades to select the targets in both the illusory and the non illusory condition was 418 ms (SD = 73.34 ms) for the Kanizsa triangle and 344 ms (SD = 70.18 ms) for the red triangle. It was not possible to analyze the saccade latencies to the control stimuli. As revealed from the previous analysis on the first saccade direction, both in the illusory and in the non illusory conditions only few saccades were directed to the control stimuli. Consequently, there were not enough data to perform the analysis. A paired sample *t* test was run to compare the latency of the first saccades directed to the Kanizsa figure (418 ms) vs those directed to the real figure (344 ms). As in the previous analysis, the difference was significant, $t(14) = 3.11$, $p = 0.008$.

Discussion

Experiment 5 was aimed at investigating whether a Kanizsa illusory triangle embedded in a display of distractor pacmen that did not form illusory contours (illusory condition) could guide the deployment of visual attention as a red triangle embedded in the same pacmen's display (non illusory condition). Since the red triangle differed from the distractors in both shape and color, the presentation of the non illusory target allowed us to obtain a control condition in which the target captured visual attention and popped out from the display

(Treisman & Gelade, 1980). In both the illusory and non illusory condition, some distractor pacmen gave rise to three control stimuli that shared with the illusory figure its basic perceptual features (triangular arrangement, closure and luminance) and ensured that the Kanizsa triangle was not selected for its basic perceptual features (Gurnsey et al., 1996). Results showed that in both the illusory and non illusory condition a high percentage of first saccades was directed to the targets, while only few saccades were directed to the control stimuli. Therefore, Experiment 1a demonstrated that the illusory target was selected independently from its basic perceptual features. More intriguingly, this outcome revealed that the Kanizsa triangle, as the real one, automatically guides attention, i.e. its selection did not require spatial attention.

Although the results of the present experiment pointed out that the Kanizsa figure captured visual attention, one may argue that the assessment of the efficiency of the search can not be investigated without the manipulation of the set size. Actually, as mentioned before, this is a classical procedure to determine whether the search requires selective spatial attention or can be made effortless in parallel (Treisman, 1998; Davis & Driver, 1994; Grabowecky et al., 1996; Senkowski et al., 2005). To test this possibility, a further experiment was performed in which the attentional processes underlying the selection of the Kanizsa figure was verified by varying the number of distractor pacmen.

Experiment 6

Experiment 6 was designed to investigate whether the reduction of the number of distractor pacmen affected the search of the Kanizsa figure. Starting from the outcomes of Experiment 5, our hypothesis is that the set size would have no effect on the selection of the Kanizsa triangle. If this is the case, the percentage of the first saccades directed toward the illusory figure and their latencies might not be affected by the number of distractors. Conversely, if the variation of the distractors affected the efficiency of the search, the amount of saccades directed to the illusory target and their latencies might change with the reduction of the set size.

Method

Participants

Sixteen adults, selected between the undergraduate students of the University of Padova, participated in the experiment. One participant was excluded from the sample because of uninterpretable eye movements resulting from poor calibration of the point gaze. So the final sample consisted of fifteen adults (mean age = 20.5 years; range = 19-26). All of them had no previous experience in eye-movement studies and were naïve to the experimental conditions and hypotheses of this experiment. Participants gave their informed consent before participating in the study.

Stimuli

The overall characteristics of the stimuli were identical to those described for the stimuli presented in Experiment 5, with the exception of the number of distractor pacmen surrounding the targets. Actually, in both the illusory and non illusory condition, the number of distractors was reduced from 21 to 13. The control stimuli 'triangular arrangement', 'closure' and 'luminance' were maintained as in Experiment 5. As a consequence of the reduction of distractors number, the pacmen that gave rise to the stimulus called 'luminance' were reduced from 3 to 5, although the portion of blank area enclosed in the control stimulus was preserved (Figure 4).

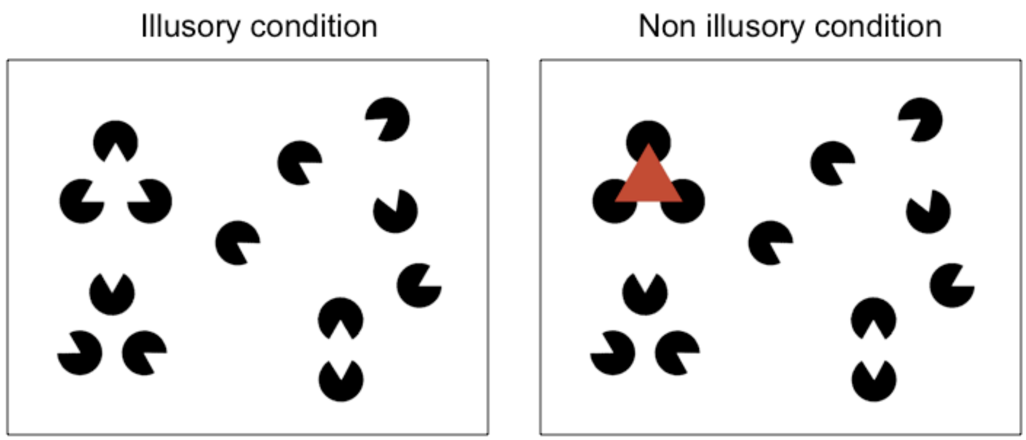

Figure 4: Visual search displays presented in Experiment 6.

Apparatus, procedure and data analysis

The apparatus, procedure and data analysis were identical to those applied in Experiment 5.

Results

First saccade direction

As in Experiment 5, for each participant, the number of the first saccades directed toward each ROI was divided by the total of the 32 trials performed, and subsequently converted into a percentage score.

In the illusory condition, the percentage of the first saccades directed toward the ROI that contained the illusory target and the control stimuli was distributed as follows: Kanizsa triangle = 59% (SD = 23%), triangular arrangement = 13% (SD = 10%), closure = 14% (SD = 13%), luminance = 14% (SD = 8%). These percentages were compared to the 25% chance value by means of one-sample *t* test. All the four percentages differed from the chance level, Kanizsa triangle: $t(14) = 5.79$, $p < 0.001$; triangular arrangement: $t(14) = 4.84$, $p < 0.001$, closure $t(14) = 3.27$, $p = 0.006$, luminance = $t(14) = 5.11$, $p < 0.001$. In the non illusory condition, the percentage of the first saccades was distributed as follows: red triangle = 78% (DS = 18%), triangular arrangement = 7% (DS = 9%), closure = 9% (DS = 9%), luminance = 6% DS = (7%). A one-sample t test was run to compare each percentage to the 25% chance value. As in the illusory condition, all the percentages differed from the chance level, red triangle: $t(14) = 11.44$, $p < 0.001$; triangular arrangement: $t(14) = 9.08$, $p < 0.001$, closure $t(14) = 6.87$, $p < 0.001$, luminance = $t(14) = 9.54$, $p < 0.001$.

As in the previous experiment, a paired samples t test revealed that the percentage of the first saccades directed to the Kanizsa figure (59%) was significantly different from the percentage directed to the real figure (78%), $t(14) = 3.01$, p = 0.009.

Saccades latency

The mean latency of the first saccades to select the illusory and the non illusory target was respectively 398 ms (SD = 58.53 ms) and 335 ms (SD = 40.67 ms). A paired sample t test showed that the difference in the saccades' latencies between the Kanizsa and the real triangle was significative $t(14) = 4.2$, $p < 0.001$.

Comparison between Experiment 5 and Experiment 6

Results of Experiment 6 paralleled those obtained in Experiment 5. In both the illusory and non illusory conditions a high percentage of the first saccades was directed to the target, while only few saccades were directed to the control stimuli. These data demonstrated that the illusory target, as the real one, was detected without the employment of selective spatial attention. To verify whether the reduction of the number of distractor pacmen between Experiment 5 (21 distractor pacmen) and Experiment 6 (13 distractor pacmen) had an effect on the visual search of the illusory and non illusory targets, the percentage and latencies of the first saccades directed to both targets were compared between the two experiments by means of *t* tests for independent samples. The comparisons were not significant neither for the red triangle (saccades direction: Exp. 5 = 62% vs Exp. 6 = 59%, $t(28) = 0,43$, $p = 0,67$; saccades latency: Exp. 5 = 418 ms vs Exp 6 = 398 ms, $t(28) = 0,8$, $p = 0,43$), nor for the Kanizsa triangle (saccades direction: Exp. 5 = 85% vs Exp. 6 = 78%, $t(28) = 1,19$, $p = 0,25$; saccades latency: Exp. 5 = 344 ms vs Exp. 6 = 335 ms, $t(28) = 0,42$, $p = 0,68$).

Discussion

Results indicated that the reduction of the number of distractor pacmen within the search display did not affect the selection of both the Kanizsa and the red triangle in terms of percentage and latencies of the first saccades, providing evidence that the selection of the Kanizsa figure did not require selective spatial attention. These data extended the results of Experiment 5 and confirmed that, even though the set size was manipulated, the Kanizsa figure automatically and selectively guided the deployment of visual attention without the necessity of a serial scanning of the visual display.

These data are in line with previous studies that investigated the attentional mechanisms underlying the processing of a Kanizsa figure (Driver & Davis, 1994; Herrmann & Mecklinger, 2000; Senkowski et al., 2005), and provide evidence for a pop-out effect of the Kanizsa figure. Two models have been proposed to explain the temporal order of figural binding and selective attention involved in the perception of Kanizsa figures (Senkowski et al., 2005). One model, called the 'binding-first' model, proposed that the binding process does not depend on visual attention and operates in parallel across the visual field (Albert, 1993). The second model, called 'attention-first' model, proposed that figural binding requires attention. The results of Experiment 1 support the binding-first model, demonstrating that a Kanizsa figure was detected with a parallel search during a visual search task, even when the basic perceptual features of the Kanizsa figure (triangular arrangement, luminance and closure) were controlled. Unlike previous studies, adults' search of the illusory figure was tested by assessing eye movements in a free looking condition, in which the observer was not explicitly required to find the illusory target. This procedure limited the top-down bias due to the observer's goals and intentions about the task (i.e. goal directed) and allowed us to investigate whether the distribution of attention was determined by the attributes of the stimulus (i.e. stimulus driven)

(Egeth & Yantis, 1997; Yantis, 1993). More intriguingly, the lack of explicit requests to find the target allowed us to test infants in exactly the same experimental condition and with the same procedure as adults and, consequently, to directly compare infants and adults. Thus, the use of a visual search task in a free looking condition reduces the difference between the traditional developmental measures (habituation or preferential looking) and the tasks usually adopted to testing adults, allowing to investigate the underlying processes involved in the perception of illusory figures across ages (Aslin & Fiser, 2005). Such a comparison is necessary for understanding the nature of the attentional and perceptual mechanisms involved in the perception of an illusory figure in infancy and to make more definitive statements about the way in which those mechanisms are akin to those operating in adults. Experiment 7 was designed to directly compare the visual search of a Kanizsa figure amidst distractors between infants and adults.

Experiment 7

Experiment 7 was aimed at investigating whether a Kanizsa figure can capture visual attention in 6-month-old infants. To this end, infants' visual behavior in the visual search of a Kanizsa illusory triangle amidst distractor pacmen was compared to that performed by adults in the previous experiments of the present study. Infants were tested in the same illusory and non illusory conditions that were presented to adults. Furthermore, the same variables, i.e. the direction and latency of the first saccade, were registered using an eye tracker system. The use of a visual search task allowed us to investigate infants' attentional mechanisms involved in the figural binding of a Kanizsa figure, bridging the gap between the traditional habituation or preferential looking paradigms used by developmental studies on illusory object perception (Johnson & Mason, 2002; Otsuka & Yamaguchi, 2003; Otsuka, Kanazawa, & Yamaguchi, 2004; Kavšek & Yonas, 2006) and the visual search paradigm used with adults (Davis & Driver, 1994; Grabowecky & Treisman 1989; Gurnsey et al., 1996; Senkowski et al., 2005). Since previous studies provided evidence that the ability to perceive illusory figures improved significantly between 5 and 7 months of age (Otsuka & Yamaguchi, 2003; Otsuka, Kanazawa, & Yamaguchi, 2004), the age of 6 months was chosen as a critical developmental point for the study of the relation between figural binding and attention.

Method

Participants

Sixteen 6-month-old infants (mean age = 180 days, range = 173-194) composed the final sample. Seven infants were observed but excluded from the sample because of uninterpretable eye movement data resulting from poor calibration of the point gaze (2 infants) or general fussiness (5 infants). All infants were born at full term, in good health, with no visual, neurological or other disorders. Infants were recruited from a database of new parents, and parents were contacted by letter and telephone. Infants were tested only if they were awake and in an alert state.

Stimuli and apparatus

Stimuli and apparatus and procedure were identical to those used in Experiment 5. A support ration of 66% was used to construct the Kanizsa illusory tragle. This support ration has been shown to support 6-month-old infants perception of a Kanizsa figure (see Experiment 4, p. 64). Each infant was placed in an infant seat at a distance of 60 cm from the computer screen.

Procedure

The procedure was the same as with adults, with the exception of a reduction in the number of trials. Infants were presented with 8 trials in the illusory condition and 8 trials for the non illusory condition, in a pseudorandom sequence, for a total of 16 trials.

Data analysis

Data analysis was the same to that performed in the previous experiments with adults. Anticipatory eye movement that occurred within the first 133 ms after the onset of the visual search display were excluded from the final data sample even if they happen to correctly fixate the illusory and non-illusory targets. This latency was chosen as the cut-of for anticipations because 6-month-old infants cannot typically make eye movements in reaction to the onset of a stimulus faster than 133 ms (Canfield, Smith, Brezsnyak & Snow, 1997).

Results

First saccade direction

In order to verify whether the illusory target, as the real one, captured visual attention, a distribution of the first saccades' direction within the search display was calculated. For each infant, the number of the first saccades directed toward each ROI was divided by the total of the 16 trials performed, and subsequently converted into a percentage score.

In the illusory condition, the percentage of the first saccades directed toward the ROI that contained the illusory target and the control stimuli was distributed as follows: Kanizsa triangle = 24% (SD = 26%), triangular arrangement = 29% (SD = 20%), closure = 23% (SD = 19%), luminance = 26% (SD =17%). These percentages were compared to the 25% chance value by means of one-sample *t* test. All the four percentage did not differed from the chance level, Kanizsa triangle: $t(15) = 0.21$, $p = 0.83$; triangular arrangement: t(15) = 0.89, p = 0.38, closure $t(15) = 0.54$, $p = 0.6$, luminance = $t(15) = 0.14$, $p = 0.89$. In the non illusory condition, the percentage of the first saccades directed toward the ROI that contained the real target and the control stimuli was distributed as follows: red triangle = 77% (SD = 21%), triangular arrangement = 7% (SD = 8%), closure = 6% (SD = 10%), luminance = 11% (SD = 11%). As in the illusory condition, the percentages were compared to the 25% chance value by means of one-sample t test. All the percentages differed from the chance level, red triangle: $t(15) = 10.04$, $p < 0.001$; triangular arrangement: $t(15) = 8.53$, $p < 0.001$, closure $t(15) = 8.07$, $p < 0.001$, luminance: $t(15) = 4.98$,

$p = 0.003$.

Saccades' latency

As in the previous studies with adults, only the first latency to reach the illusory and non illusory targets was considered. The mean latency of the first saccades to select the targets in both the illusory and the non illusory conditions was 631 ms (SD = 147.7 ms) for the Kanizsa triangle and 543 ms (SD = 80.77 ms) for the red triangle. A paired samples t test was run to compare the latency of the first saccades directed to the Kanizsa figure vs the real figure. The difference was significant, $t(15) = 2.92$, $p = 0.01$.

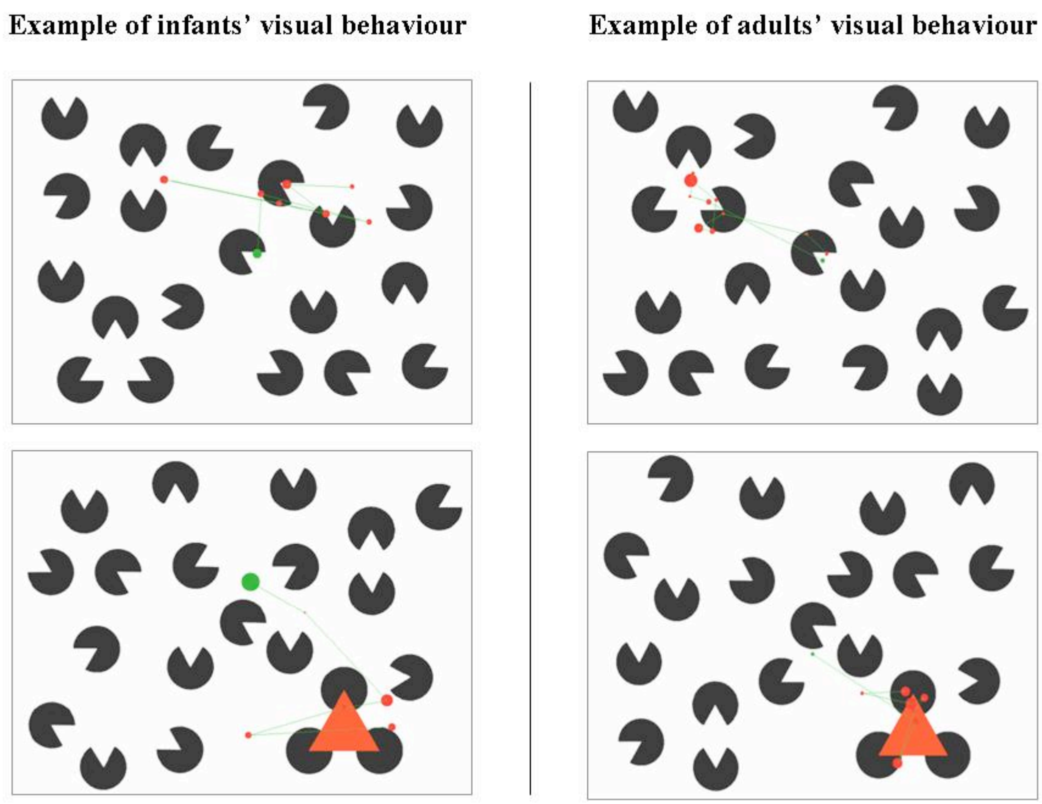

Figure 7: Outputs from the eye tracker: paradigmatic examples of infant's and adults' visual search behavior during the visual search of the illusory and non illusory target.

Comparison between 6-month-old infants and adults

The outcome of Experiment 2a showed that, in the non illusory condition, a high percentage of first saccades was performed toward the non illusory target, while only few saccades were directed to the three control stimuli: symmetry, closure and luminance. On the contrary, in the illusory condition, the percentage of first saccades did not differ for the chance level (Figure 7).

Independent samples *t* tests were run to compare infants' and adults' percentage and latencies of the first saccades toward the targets in both illusory and non illusory conditions. Analysis showed that, in the illusory condition, the percentage of first saccades did not differ between infants (77%) and adults (85%), $t(29) = 1.25$, $p = 0.22$, while in the illusory condition the difference (infants = 24% vs adults = 62%) was significant, $t(29) = 4.93$, $p < 0.001$. The comparison with adults' data indicated a similar performance in terms of distribution of the first saccades for infants and adults in the non illusory condition, but not in the illusory condition. For the saccades latencies, infants and adults differed both in the illusory condition (infants = 543 ms vs adults = 344 ms), $t(29) = 7.32$ 001, and in the non illusory condition (infants = 631 ms vs adults = 418 ms), $t(29) = 5.04$, $p < 0.001$. Results indicated that infants were slower than adults to reach both the illusory and non illusory target (Table 1).

Set size	Participants	Illusory target		Non illusory target	
		First sacc.	*Latency*	*First sacc.*	*Latency*
13 pacmen	*Adults*	**59%**	**398 ms**	**78%**	**335 ms**
21pacmen	*Adults*	**62%**	**418 ms**	**85%**	**344 ms**
	Infants	**24%**	**631 ms**	**77%**	**543 ms**

TABLE 1: Summary table with the results of adults' (Exp. 5 and 6) and 6-month-old infants' (Exp. 7) visual search of the illusory and real target.

This pattern of results was comparable to that obtained in the study of Adler & Orprecio (2006) with 3-month-old infants, in which infants' saccadic latencies to reach the real target among homogeneous distractors was consistently slower than in adults. The authors explained this discrepancy as an immaturity of the neural circuitry that mediates eye movements in early infancy (Shea, 1992). More precisely, infants' eye movements result slower than adult's eye movements due to the slowness of infant's visual information from eyes to the cortex (e.g., Hood & Atkinson, 1990) that determines a delay to make the saccade (Johnson, 1995).

Discussion

Evidence obtained with 6-month-old infants indicates that the Kanizsa triangle cannot guide visual attention. Actually, in the illusory condition, 6-month-old infants did not orient their first saccades toward the illusory figure, but they spread out their saccades within the visual display in a casual manner. On the other hand, in the non illusory condition, the red triangle showed a pop out effect, with a high percentage of first saccades performed toward the non illusory target. When compared with adults' data, these results showed that the red triangle captured visual attention in both infants and adults, in contrast the Kanizsa triangle popped out from the display guiding the deployment of visual attention only in adults.

To summarize, Experiment 5 and 6 showed that adults selected both the illusory and the real figure automatically, indicating that the illusory triangle triggered visual attention. In contrast to adults the results of Experiment 7 pointed out that 6-month-old infants showed a pop-out effect only for the real figure, but not for the illusory one. The deployment of attention to real figure provided a further evidence for the presence of a pop-out effect in infancy, in line with previous developmental studies (for a review see Bhatt, 1997). Crucially, in the present study, the registration of the first saccade orientation and latency and the direct comparison between infants' and adults' visual behavior demonstrated that the attentional mechanisms implied in pop-out effect for the real figure in infants are akin to those found in adults. This result is in line with the study of Adler & Orprecio (2006), in which the authors, using the assessment of eye movements, demonstrated that even 3-month-old infants exhibit the phenomenon of pop-out with real target and posses visual search mechanisms similar to adults. Unlike the real figure, the Kanizsa figure captured automatically visual attention only in adults, but not in 6-month-old infants. When infants were presented with the illusory display, they spread out their attention within the visual display in a casual manner.

Why infants did not show a pop-out effect for the Kanizsa figure as adults do?

Three different explanations might account for infants' inability to show a pop out effect for the Kanizsa figure in Experiment 7.

First, the absence of a pop out effect for the Kanizsa figure could be due to the complexity of the visual display. In fact, in Experiment 7 the illusory target was embedded in a display in which some of the distractor pacmen gave rise to three different control stimuli (i.e., triangular arrangement, luminance and closure). Consequently, infants' selection of the target could be difficult due to the complexity of the competing stimuli. In general, search is less efficient when nontargets are heterogeneous. This is thought to occur because heterogeneous nontargets form a less coherent group than homogeneous nontargets, and are thus harder to reject en mass (Duncan & Humphreys, 1989).

Second, infants' inability to select the illusory target could depend on the nature of the particular type of illusory contours, i.e. Kanizsa-type illusory contours, and not on the use of illusory contours per se. This explanation is in line with a recent adults' study in which Kanizsa illusory contours failed to capture attention, while other types of illusory contours, i.e. illusory contours produced by line endings, can efficiently guide the deployment of visual attention (Li, Wolfe, & Cave, 2008). The difference between Kanizsa-type and line endings illusory contours is also supported by neurophysiological studies suggesting that these two types of illusory contours might be detected by different neural structures (Von der Heydt, Peterhans, & Baumgartner, 1984; Grosof, Shapley, & Hawken, 1993).

Third, it is possible that, for infants, the target in the real condition is more salient than the one presented in the illusory condition. Indeed, the red triangle might be a highly distinctive information for young infants since it is different from the distractors in two perceptual features, i.e. form and color, and therefore infants might have used not only the real contour but also the color and form information as cues to select the target.

Using such visual search displays, two different experiments were carried out with adults (Experiment 8) and infants (Experiment 9) to overcome these issues.

The complexity of the search display has been reduced presenting an illusory horizontal bar (target) among homogenous vertical illusory bars (distractors), while the nature of the illusory contours on the deployment of visual attention has been investigated by a direct comparison between the visual search of the horizontal bar when it was defined by Kanizsa-type contours over line endings illusory contours. Finally, the discrepancy between the target in the real conditions and the illusory condition was reduced using a real target outlined by thin black lines, instead of color.

Experiment 8

The purpose of Experiment 8 was to test adults' visual search for a horizontal illusory bar among vertical illusory rectangles defined either by Kanizsa-type illusory contours or by line ends illusory contours. In two control conditions, real lines appeared at the locations that would otherwise have manifested illusory contours. Conversely to Experiment 7, in which the distractor pacmen gave rise to three heterogeneous control stimuli (closure, triangular arrangement, and luminance), in Experiment 8 and 9 the target and distractor stimuli were perceptually identical and differed only on the basis of only one characteristic, i.e. the orientation.

Method

Participants

The experiment was carried out at the UCLA Baby Lab, Department of Psychology, University of California, Los Angeles. Participants were 14 adults, selected between the undergraduate students and the staff of the University of California, Los Angeles. One participant was excluded from the sample because of uninterpretable eye movements resulting from poor calibration of the point gaze. So the final sample consisted of 13 adults (mean age = 36 years; range = 18-66). All of them had no previous experience in eye-movement studies and were naïve to the experimental conditions and hypotheses of this experiment. Participants gave their informed consent before participating in the study.

Stimuli and apparatus

Gaze was measured with a Tobii 1750 eye tracker (www.tobii.com). The system records the reflection of near infrared light in the pupil and cornea of both eyes at 50 Hz (accuracy = 0.5°, spatial resolution = 0.25°) as the participant watches an integrated 17 inches monitor. During calibration, a blue and white sphere expanded and contracted in synchrony with a sound.

Stimuli were graphic images generated thorough the software Adobe Photoshop 6.0. Participants were tested in four conditions, two illusory conditions and two real conditions (Figure 8). In the Kanizsa-type illusory condition, each display consisted of 11 Kanizsa-type illusory bars defined by two gray incomplete circular elements (32 cd/m^2) against a white background. The elements measured 3.5 cm (3.5°) in diameter, and each element was situated 1.7 cm (1.7°) from each adjacent element, so the illusory bar measured 5.1 cm (5.1°) in width, and 1.53 cm (1.53°) in height. Distractors and targets were arranged pseudorandomly in each trial. The display was divided into 10 imaginary columns (4 cm, 4° wide). Two bars were placed in each column in no overlapping positions. The target stimulus appeared in one of four possible locations around the display center. These designed locations could also hold distractors bars, depending on the pseudorandom arrangement per trial – that is, they did not necessarily remain empty if they did not hold the target. Targets were oriented 90° from vertical. In the line ends illusory condition, the illusory bars were induced by gray line segments (0.23 cm, 0.23° wide) on a white background. The luminance of the line segments was the same as the inducing elements in the Kanizsa-type contours, as the dimension and the position of distractors and targets within the display. The distance between inducing lines was 0.6 cm (0.6°). In two real control conditions, black real lines appeared at the locations that would otherwise have manifested illusory contours, both in the

Kanizsa-type, and in the line ends conditions.

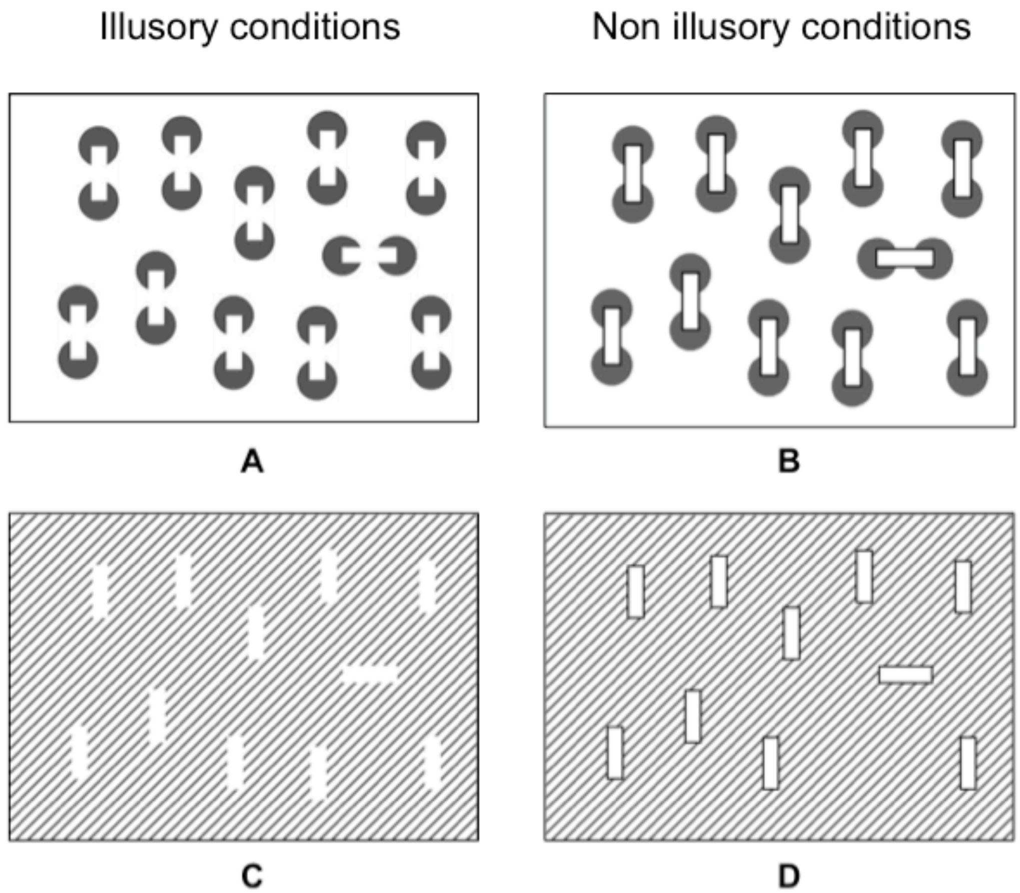

Figure 8: Samples of the visual search displays used in Experiment 8. (A) Kanizsa-type illusory condition. (B) Control displays for the Kanizsa-type illusory condition: target and distractors are outlined by black real contours. (C) Line-ends illusory condition. (D) Control displays for the line.ends illusory condition: target and distractors are outlined by black real contours.

Procedure

Each participant was seated in front of the Tobii eye tracker and monitor (eyes approximately 60 cm from the screen). Before the experimental session a calibration procedure was carried out. In preparation for the calibration the experimenter adjusted the eye tracker to make sure that the reflections of both eyes were centered in the cameras field of view. During calibration, a blue and white ball appeared on each of 9 calibration points in a random order. At the end of the calibration, a graph appeared that reported how successful the calibration was. Any unsuccessfully calibrated points were recalibrated.

An experiment controlled the presentation of the displays. Each participant was presented with 12 trials for each condition (Kanizsa-type illusory condition, line ends illusory condition, Kanizsa-type real condition, and line ends real condition), for a total of 48 trials. In between trials, one of 8 different attention-gettering movies was presented, displaying a small toy that moved and sound in the middle of the screen. As soon as the participant looked at the attention-getter, the experiment pressed a key and the trial commenced. The participant viewed the display until either the experiment determined that a saccade was made to the target stimulus, or 4 s had elapsed. The display was then replaced by the attention-getter to recenter the point of gaze, and the next trial began.

Data coding

Orienting to the targets was coded frame by frame from video to determine saccades accuracy and latency to direct the point of gaze toward the target stimulus. Once the display appeared, the time in milliseconds to begin an eye movement toward the target stimulus was recorded. The trial ended automatically after 4 s if the target was not selected. Accuracy was calculated as the proportion of correct trials form the total number of trials in which data are provided. Following Amso & Johnson (2006), the probably of selecting the target by chance was 25%, corresponding to one of four target locations.

Results

To verify whether the target captured visual attention search accuracy was calculated in each of the four conditions. Performance was above chance (25%) in all four conditions: Kanizsa-type illusory condition = 67%, $t(12) = 7.11$, $p < 0.001$; line ends illusory condition = 51%, $t(12) = 3.88$, $p = 0.002$; Kanizsa-type real condition = 65%, $t(12) = 8.69$, $p < 0.001$; and line ends real condition = 61%, $t(12) = 5.87$, $p < 0.001$.

The saccades latency to reach the target was not different thorough the four condition: Kanizsa-type illusory condition = 1310 ms; line ends illusory condition = 1370 ms, Kanizsa-type real condition = 1514 ms, and line ends real condition = 1607 ms.

Discussion

Results demonstrated that both in the illusory and in the real conditions, the proportion of horizontal targets selected as a function of trials is above chance. Moreover, the latency to reach the target did not differ between the four conditions.

In line with Experiments 5 and 6, data provided evidence that adults showed a pop out effect for the horizontal bar among vertical bars in both the Kanizsa and line ends illusory conditions, and that this effect was equal to that showed in the two real conditions. Differently to Experiments 5 and 6, in the present experiment no difference was found in saccades accuracy and latency between the illusory and real conditions, providing evidence that the difference between the illusory and the real condition found in Experiments 5 and 6 was due to the high salience of the red triangle. In other words, when the real target was defined by a thin outline, instead of red color, adults' performance in the visual search task did not differ between illusory and real conditions.

Nevertheless, it worth noting that a comparison between the present experiments and Experiments 5 and 6 d can only be qualitative, since a direct statistical comparison is not possible. In fact, differently from Experiments 5 and 6 in which the accuracy and latency of the first saccades were measured, in the present experiment accuracy and latency referred to proportion of trials in which adults found the target within the 4 s target presentation, independently on the number of saccades. This procedure was constrained by technical limitations of the eye tracker system used to collect the data.

In Experiment 9, infants' ability to select the illusory and real targets will be directly compared to that found in adults in the present experiment, using the same stimuli and procedure, and measuring the same variables.

Experiment 9

Experiment 9 was aimed to test 6- to 11-month-old infants' visual search for a horizontal illusory bar among vertical illusory rectangles defined either by Kanizsa-type illusory contours or by line ends illusory contours. To this end, infants' visual search for the horizontal bar in an array of vertical bars was compared to that performed by adults in Experiment 8. Infants were tested in the same illusory and real conditions presented to adults.

Several developmental studies have investigated young infants detection of a discrepancy in orientation (Quinn & Bhatt, 1997; Atkinson & Braddick, 1992; Rieth & Sireteanu, 1994). The possibility that orientation might be produce a pop out effect in infants has been typically investigated embedding a small line (singleton) or a region of small lines (patch) that differ from a surrounding region that contains small line segments with uniform orientations. These studies provided evidence that from 3 months of age infants are able to detect a single line (Quinn & Bhatt, 1997) or a patch of line elements (Atkinson & Braddick, 1992; Rieth & Sireteanu, 1994) that were oriented differently from the surrounding lines.

Moreover, young infants have been shown to perceive illusory contours defined by line end by 3 months of age (Kavsek, 2002; Sireteanu & Reith, 1994). For example, Sireteanu & Reith (1994) provided evidence that infant as young as 3 months of age prefer a pattern containing an illusory contour defined by line ends over a pattern containing only parallel lines. More intriguingly, by 4-5 months of age infants dishabituate to a pattern of orientation of the illusory contour, and by 5-6 months of age, infants show a tendency to generalize the perception of the illusory contour to a real, solid line.

Overall, these studies demonstrate that both ability to exhibit a pop-out effect for stimulus orientation and the ability to perceive illusory line ends contours are present from 3 months of age.

Method

Participants

The experiment was carried out at the UCLA Baby Lab, Department of Psychology, University of California, Los Angeles. Twenty-two infants aged 6–11 months participated in this experiment (age, M = 8.72 days, SD = 2.15, range = 5.9–11.5). Four infants were observed but excluded from the sample because of general fussiness (1), sleepiness (1), or uninterpretable eye movement data resulting from poor calibration of the point of gaze (2). All infants were born at term with no developmental difficulties. Infants were recruited from a public database of new parents, and parents were contacted by letter and telephone.

Stimuli and apparatus

Stimuli and apparatus were the same as used in Experiment 8. A support ration of 66% was used to construct the Kanizsa illusory tragle. This support ration has been shown to support 6-month-old infants perception of a Kanizsa figure (see Experiment 4, p. 64). Infants were placed in an infant seat, at a distance of approximately 60 cm from the screen.

Procedure and data coding

Procedure and data coding were identical to those used in Experiment 8.

Results

Saccades accuracy

To verify whether the target captured visual attention in each of the four conditions, search accuracy was calculated. Performance was at the chance level of 25% in all four conditions: Kanizsa-type illusory condition = 27%, $t(21) = 0.81$, $p = 0.43$; line ends illusory condition = 21%, $t(21) = 0.89$, $p = 0.38$, Kanizsa-type real condition = 27%, $t(21) = 0.56$, $p = 0.58$; line ends real condition = = 25%, $t(21) = 0.07$, $p = 0.95$.

The saccades latency to reach the target was not different thorough the four condition: Kanizsa-type illusory condition = 1782 ms, line ends illusory condition = 1858 ms, Kanizsa-type real condition = 2056 ms, and line ends real condition = 1932 ms.

Discussion

Results showed that infants' accuracy to find the target was not above chance in all the four illusory and real conditions, and that the saccades' latency to reach the target did not differ between the real and illusory conditions. This finding provided evidence that the horizontal bar among homogeneous vertical bars did not trigger infants' visual attention: infants spread out their saccades in a casual manner within both the real and the illusory visual search displays.

Overall, in contrast with adults' data, infants did not showed a pop out effect, neither in the Kanizsa and line ends illusory conditions, nor in the two real conditions.

When compared to Experiment 7, these findings revealed that the reduction of the complexity of the distractor pacmen in which the illusory figure was embedded, and the use of line ends illusory contours, did not affect the selection of the illusory targets. As found in Experiment 7, infants did not exhibit a pop out effect in the illusory conditions. Surprisingly, in contrast to Experiment 7, infants did not show a pop out effect also in the two real conditions. This difference could be due to the different perceptual salience of the real target. In Experiment 7, the real target differed from the distractors in both form and color, while in Experiment 9 the real target was defined by a thin black line and differed from the surrounding homogenous distractors only by orientation. This result is in line with the adults' literature regardless the target-distractors similarity: There are performance differences between searches involving a target that is extremely salient relative to the background distractors, and searches in which an increase in target-distractors similarity heightens the difficulty of target detection (Duncan & Humphreys, 1989; Wolfe, 1998).

As already pointed out in the discussion of Experiment 8, a direct statistical comparison of infants' visual search behavior between Experiment 7 and 9 is not possible, because of the different procedure adopted to collect infants' eye movements.

5.2 Conclusions

The purpose of the present study was to investigate the relation between perceptual binding and selective spatial attention in supporting infants' integration of spatially separated elements to perceive an illusory object. Six-month-old infants and adults were tested with a visual search task of an illusory figure among distractor stimuli. This is a classical procedure used in adults' literature to investigate whether perceptual binding of different fragments of an object is independent of selective spatial attention or, on the contrary, whether perceptual binding requires selective attention to be performed (e.g., Davis & Driver, 1994; Senkowski et al., 2005). Illusory figures are clearly seen due to the visual binding of their inducing elements. If perceptual binding does not require selective attention, the illusory figure automatically pops out from the display. In contrast, if perceptual binding requires selective attention, the binding of the inducing elements does not occur automatically, but attention has to be allocated to each element in turn within the visual search display.

An eye tracker system was used to directly assess adults' and infants' eye movements during the visual search of an illusory target and a real target among competing stimuli. In the illusory condition, a Kanizsa triangle was embedded in a display of pacmen that did not give rise to illusory contours. In the non illusory condition, a red triangle, instead of an illusory one, was presented among competing pacmen. Adults showed a pop out effect for both the illusory and the real triangle (Experiments 5 and 6), whereas 6-month-old infants exhibited a pop out effect for the red triangle, but not for the illusory one (Experiment 7). A similar pattern of results was obtained when the complexity of the display was reduced using homogeneous distractors, and line ends illusory contours, which are detected easier than Kanizsa-type illusory contours by the visual system, were used to define target and distractors stimuli (Experiment 8 and 9). Adults and 6- to-11month-old infants were presented with a horizontal bar amidst homogenous vertical bars. Bars could be defined by Kanizsa-type illusory contours, line ends illusory contours, or by thin black outlines. Adults easily selected the target in both the illusory and the real conditions (Experiment 8), whereas infants explored the search display in a casual manner, providing evidence to be unable to find the target (Experiment 9).

Overall, findings from this study showed that illusory figures automatically trigger visual attention in adults, providing evidence that adults' perceptual binding of separate elements to perceive an illusory object does not require focal attention. In other words, the visual system automatically binds the inducing elements of an illusory figure in complex scenes. As a consequence, visual attention is directly oriented to the illusory target. This outcome is consistent with single-cell results in macaque (Grosof et al., 1993; von der Heydt et al., 1984), in which neural responses to illusory figures have been found in early stages of cortical visual processing (V1 and V2), suggesting that illusory figures can be coded without focal attention.

In contrast, infants did not exhibit a pop out effect for the illusory figure. This result shows that infants' binding of an illusory figure in complex displays does not occur automatically. Although an illusory figure triggers visual attention over a control stimulus in a visual preference task as shown in Experiment 4, when a visual search task more akin to those used in adults to investigate the role of spatial attention in an illusory figure's binding was used, infants did not perform binding processes in an adult lime manner.

General conclusions

One central issue in developmental cognitive science is to understand how infants detect the meaningful units in the flow of perceptual information and integrate these units into a coherent structure. Perceptual binding and selective spatial attention are two fundamental processes that help to perceive the outside world. Binding is necessary to link the different features of a single object. Selective attention serves to focus onto small subset of incoming information. The selection and binding of the various parts of an object in the correct combination pose little difficulty for adults, who readily report veridical object perception under most viewing conditions (Kellman & Shipley, 1991). It is still not clear however how exactly these two mechanisms operate and interact in early infancy.

The purpose of this thesis was to study the role of perceptual and attentional processes in supporting infants' perception of illusory objects in complex visual scenes. Two studies have been carried out.

In Study 1, using the habituation technique, a first set of experiments has investigated whether newborns were able to link together spatially separated fragments to perceive the unity of a moving rod partly occluded by a moving Kanizsa-type illusory box (Experiment 1, 2 and 3). Both modal (illusory box) and amodal (occluded rod) visual completions had to be simultaneously used to solve the perceptual task. Results showed that newborns perceived the partly occluded rod and the illusory box as complete objects, providing evidence that, at least when motion information was used, newborn infants were able to utilize simultaneously modal and amodal completions to perceive object unity in complex displays. In line with previous studies presented in literature (Johnson & Aslin, 1996; Kellman & Spelke, 1983; Otsuka & Yamaguchi, 2003; Valenza et al., 2006; Valenza & Bulf, 2007), these findings support also the hypothesis that dynamic displays facilitate the solution of many perceptual tasks because motion triggers infant's attention toward the visual information that must be integrated. In other words, the results of the first three experiments reported in my thesis suggest that, beside perceptual binding, even attention has a crucial role in perceiving veridical object during early infancy.

Using an eye tracker system, in a subsequent experiment (Experiment 4) saccades latency, which is a standard variable to measure orienting of attention in infancy (Cohen, 1972), was measured to determine whether a Kanizsa illusory figure triggers 6-month-old infants attention over a control stimulus. Results showed that infants detected the illusory figure faster than the illusory one, showing that the Kanizsa figure was able to orient infants' visual spatial attention. Overall, this outcome demonstrates that both perceptual binding (Experiments 1,2 and 3) and selective spatial attention (Experiment 4) support the perception of an illusory figure in early infancy.

In Study 2 it was investigated the relation between perceptual binding and selective spatial attention. Visual search of illusory figures is usually used in adults' literature to assess whether the binding of different fragments of an illusory object is independent of selective spatial attention or, on the contrary, whether perceptual binding requires spatial attention to be performed (e.g., Senkowski, 2005). Using an eye tracker system, adults' and 6-month-old infants' visual search behavior was compared in a visual search task.

Participants were presented with an illusory figure and a real figure embedded in a display of competing stimuli (Experiments 5-9). Results showed that both the illusory figures and the real figures automatically trigger visual spatial attention in adults (i.e. pop out effect), providing evidence that adults' perceptual binding of separate elements to perceive an illusory object does not require spatial attention. In contrast to adult's data, infants show a pop out effect only when a high salient real target has to be detected (Experiment 7). Conversely, when an illusory target (Experiments 7 and 9) was used, or when the real target-distractors similarity was increased (Experiment 9), infants spread out their attention within the display in a casual manner.

In other words, when adults are presented with an illusory figure among distractors, perceptual binding of the illusory figure occurs automatically. Conversely, although it has been shown that perceptual (Experiments 1-3) and attentional (Experiment 4) processes in supporting the binding of an illusory figure are functional very early during the development, infants are not able to automatically bind an illusory figure when it is presented in among competing stimuli.

Why infants do not automatically bind the inducing elements of the illusory figure, showing a pop out effect for the illusory target, as adults do? Why infants' ability to use both perceptual binding and spatial attention to parse the visual scene into objects is not sufficient to solve the visual search task?

A possible 'neural' explanation of this issue is that in the first months of life many perceptual abilities might be more closely linked to selective spatial attention than in adulthood, as a consequence of the neural immaturity of the brain area involved in binding processes. Several lines of evidence deriving from the studies that have utilized neuroimaging techniques, support this claim. Indeed, whereas many data converged to demonstrate that the neural apparatus (frontal eye fields) to support saccadic eye movements, attentional processing and pop out are available by 3 months of age (Johnson, 1990, 1995), the only study that have compared brain activation in supporting perceptual binding in infants and adults shows different brain activity between the two ages tested (Csibra et al., 2000). More specifically, 6- and 8- month-old infants were presented with a Kanizsa square and a control stimulus composed of precisely the same pacmen elements of the Kanizsa figure, but rearranged so as not to elicit perceptual grouping and consequently no perception of an illusory figure. In adults, binding involved in the perception of illusory objects induces a burst of 40-Hz oscillations at about 250 to 300 ms after stimulus onset (Muller et al., 1996; Tallon-Baudry, Bertrand, Delpuech, Pernier, 1996). Eight-month-old infants showed an enhancement of induced gamma-band activity in response to the Kanizsa square over the left frontal scalp in the 240- to 320-ms time window, corresponding in time course to results found in adults. The time-frequency analysis for the group of 6-month-old infants yielded quite different results from those observed in the older group. Although there were some fluctuations in amplitude in the gamma band over the left frontal cortex after presentation of the Kanizsa squares, these did not come in bursts like those observed in adults but were smeared over long time intervals. This finding suggests that the neural development around 6 to 8 months of age that allows infants to perceive static illusory objects involved a decrease in the variability of gamma-range bursts of oscillatory activity in the frontal cortex. Analyses of early, low-frequency, event-related potential (ERP) responses revealed that infants in both age groups discriminated between the Kanizsa figure and the control stimulus. However, only the 8-month-old group showed the pattern characteristic of adult ERPs. Csibra et al. (2000) study also indicates that the frontal cortex may play a crucial role in the development of perceptual binding, although results leave unresolved the question of whether the frontal activation is directly related to the binding process or reflects further attentional processing on the object 'bound' elsewhere in the infants brain. Overall, these data suggest that neural maturation through the first year of life strongly affect infants' ability to perform binding processes in an adult-like manner.

Another 'cognitive' explanation concerns infants' inability to efficiency extract visual information from the environment. This claim is supported by several studies that have investigated the link between infants' scanning strategies and the achievement of object perception support (Johnson & Johnson, 2000; Johnson et al., 2004), comparing infants' scanning patterns during the perception of a partly occluded rod and their ability to perceive the occluded rod as an unitary object. The results of these studies provided evidence that emerging object perception is closely tied to the ability to selectively pickup the visual information available in the environment. This conclusion was recently supported by a study carrie out by Amso & Johnson (2006). More precisely, the authors found that only infants who provided evidence of efficient visual selective attention in a search task also provided evidence of perceiving the unity of disjoint surfaces. This finding suggests that the ability to attend to the rod parts and ignore irrelevant yet salient display elements increases the like-hood of gathering the relevant information for the adult-like percept of unity object. With the emergence of selective attention, infants become active participants in their own development rather than passive recipients of information.

The emergence of the ability to selectively pickup visual information, as well as the neural development of binding processes, might support infants' increasing facility to perceive the world in an adult like fashion, leading to the ability in performing binding automatically, as found in adults' mature visual system.

It worth noting that the strength of this thesis is the attempt to test infants using the same stimuli, procedure and tasks usually used in adults, overcoming the methodological limitations of the classical visual habituation and visual preference techniques. This effort allowed to draw a better picture of infants' attentional and perceptual mechanisms, which are so crucial for efficient cognitive functioning, and how they differed from those adopted by adults.

Starting from the procedure used in the present work, further researches need to be carried out in order to individuate how selective attention mechanisms affect infant's ability to perform binding processes in an adult-like manner.

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