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Visual Orienting and Visual Search in Autism Spectrum Disorder: Characteristics and Neural Mechanisms

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Abstract

The orienting network constitutes a crucial component of the attention network, primarily encompassing two major tasks: visual orienting and visual search. For these two attention tasks, neurotypical individuals exhibit substantial overlap in neural mechanisms; however, individuals with autism spectrum disorder display contrasting behavioral evidence. From the perspective of non-social information attention, research has generally found that, in visual orienting, individuals with autism spectrum disorder do not exhibit deficits in attention shifting but experience difficulties in attention disengagement, although this conclusion remains controversial. In visual search, individuals with autism spectrum disorder demonstrate a visual search advantage, yet the stage at which this advantage emerges and its underlying mechanisms require further investigation. Future research should further examine the asymmetry between left and right visual fields in visual orienting tasks in autism spectrum disorder, the intrinsic mechanisms underlying the visual search advantage, and the interrelationship between these two attention tasks.

Full Text

Preamble

Characteristics and Neural Mechanisms of Visual Orienting and Visual Search in Autism Spectrum Disorder

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Abstract

The orienting network constitutes a crucial component of the attention system, encompassing two primary tasks: visual orienting and visual search. While typically developing individuals exhibit substantial neural overlap between these attentional tasks, individuals with autism spectrum disorder (ASD) demonstrate contrasting behavioral patterns. From the perspective of non-social information processing, research generally indicates that individuals with ASD show intact attentional shifting but impaired attentional disengagement in visual orienting tasks, though this conclusion remains controversial. In visual search tasks, individuals with ASD exhibit superior search performance, yet the specific stage at which this advantage emerges and its underlying mechanisms require further investigation. Future research should examine hemispheric asymmetry in visual orienting tasks among individuals with ASD, elucidate the intrinsic mechanisms underlying the visual search advantage, and explore the interrelationship between these two attentional tasks.

Keywords: autism spectrum disorder; non-social information; visual orienting; visual search; neural mechanisms

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Autism spectrum disorder (ASD) is a severe pervasive developmental disorder. Clinically, individuals with ASD typically exhibit three core symptom domains: social communication deficits (e.g., difficulties or reduced motivation in social interaction), language impairments (e.g., delayed or regressive language development, difficulty communicating verbally), and repetitive stereotyped behaviors (e.g., frequent atypical movements or resistance to change) [?, ?]. However, empirical research demonstrates that beyond these clinical manifestations, individuals with ASD also show significant differences from typically developing (TD) individuals in cognitive functions related to attention to non-social information [?, ?, ?, ?, ?, ?, ?].

Researchers investigating attentional characteristics in ASD typically categorize stimuli into two types: social information stimuli, such as eye gaze [?, ?, ?, ?, ?], facial emotions [?, ?], and social interactions [?, ?, ?, ?, ?, ?]; and non-social information stimuli, such as geometric shapes [?, ?, ?, ?, ?], letters [?, ?, ?, ?, ?], and numbers [?, ?, ?, ?]. While social communication difficulties in ASD are readily apparent and have led researchers to predominantly use social information stimuli (e.g., faces) to study attentional issues [?, ?, ?, ?, ?, ?], studies employing non-social information stimuli have revealed significant differences between ASD and TD individuals in attention-related tasks. For instance, individuals with ASD show impaired disengagement from dynamic geometric patterns [?, ?] and demonstrate superior visual search performance for colored letters [?, ?], indicating atypical attention to non-social stimuli.

Some researchers have found that high-level social information processing occurs later in development and may be influenced by earlier non-social information processing [?, ?, ?, ?, ?, ?, ?]. Other studies suggest that attentional biases to-

ward non-social information in ASD may reduce interest in social information, consequently leading to atypical attention to social stimuli [?, ?]. Therefore, examining attention to non-social information in ASD is essential. However, over the past two decades, research using non-social information stimuli has been relatively limited, with unresolved questions remaining. For example, do individuals with ASD exhibit deficits in visual orienting tasks when processing non-social information [?, ?, ?, ?, ?]? Do individuals with ASD truly demonstrate advantages in visual search tasks [?, ?], and if so, what are the underlying reasons [?, ?, ?, ?, ?]? These questions have become focal points for researchers in recent years. [?, ?] utilized functional near-infrared spectroscopy (fNIRS) to study 29 five-month-old infants and found that, compared to low-risk infants, high-risk infants for ASD showed increased HbO₂ concentration in the right posterior superior temporal sulcus-temporoparietal junction (pSTS-TPJ) region when viewing dynamic videos without social information. This suggests that atypical attention to non-social information exists in ASD from early infancy, highlighting the importance of investigating low-level cognitive processes in ASD alongside high-level social cognitive processing [?, ?, ?, ?, ?, ?].

[?, ?] systematically summarized that attention comprises three networks: the alerting network, orienting network, and executive control network. The primary debate regarding the alerting network in ASD concerns inconsistent arousal levels to specific stimuli [?, ?, ?, ?, ?], such as over- or under-responsiveness to perceptual stimuli—a behavioral manifestation now included in ASD diagnostic criteria [?, ?]. Regarding the executive control network, [?, ?] have reviewed the characteristics, influencing factors, and neural mechanisms of inhibitory control in ASD. However, the orienting network in ASD, particularly the characteristics and neural mechanisms of visual orienting and visual search, remains controversial. Visual orienting primarily investigates spatial location-based orienting, whereas visual search examines target-based orienting. Brain imaging studies indicate substantial neural overlap between these two attentional tasks in TD individuals, with visual orienting associated with frontal and parietal regions [?, ?, ?, ?, ?, ?, ?] and visual search involving frontal, parietal, and temporal regions [?, ?, ?]. Intriguingly, individuals with ASD show opposite behavioral patterns: impaired visual orienting but superior visual search performance. Investigating the characteristics and neural mechanisms of visual orienting and visual search in ASD thus holds theoretical significance—why do two attentional tasks with substantial neural overlap in TD individuals produce divergent behavioral manifestations in ASD? This review focuses on the orienting network of attention, examining research on attentional characteristics and neural mechanisms related to non-social information processing in individuals with ASD through the lenses of visual orienting and visual search.

2 Visual Orienting

[?, ?] proposed that visual orienting involves three components: engaging attention to a stimulus, shifting attention, and disengaging attention—the process of disengaging from an attended stimulus, shifting attention from the previous stimulus, and subsequently engaging with a new stimulus. Current research findings remain controversial regarding whether visual orienting abilities are impaired in individuals with ASD.

2.1 Evidence for Impaired Visual Orienting in ASD

Most researchers support the view that individuals with ASD exhibit impaired visual orienting abilities [?, ?, ?, ?, ?, ?, ?, ?]. For example, [?, ?] investigated differences in attentional shifting and disengagement between high-risk infants for ASD (with siblings diagnosed with ASD) and TD infants (without family history of ASD). Participants were assessed at 6 and 12 months of age and later divided into three groups at 36 months: 16 high-risk infants diagnosed with ASD, 67 high-risk infants without ASD, and 53 TD infants. Using a gap-overlap paradigm, the experiment comprised two attentional tasks: a shift task and a disengagement task. In the shift task, a stimulus was first presented at the center of the screen; once the experimenter confirmed the participant was looking at the center, the stimulus disappeared and a new stimulus appeared randomly on either side of the visual field. The trial advanced when the participant shifted attention to the new stimulus or after 8 seconds. The disengagement task followed a similar procedure, except the original stimulus remained visible. Results showed that 12-month-old high-risk infants for ASD exhibited longer latencies in the attentional disengagement task compared to 6-month-old high-risk infants, demonstrating significant attentional disengagement difficulties. Notably, compared to TD infants, high-risk infants for ASD showed significantly longer disengagement latencies only when new stimuli appeared in the left visual field; no significant differences were observed for right visual field presentations. The researchers suggested that this left-right visual field asymmetry in attentional disengagement might result from right hemisphere dysfunction in ASD. Since the right hemisphere is associated with spatial attention to the left visual field, impaired right hemisphere function in ASD would manifest as longer disengagement latencies for left visual field stimuli. However, a challenge in this research is that maintaining optimal testing conditions for infants only a few months old is difficult [?, ?]. Increasingly, researchers are using infants under 36 months to identify early differences between high- and low-risk infants for earlier intervention. Therefore, controlling testing conditions for infant participants to obtain more reliable results represents a key challenge for future research.

Similarly, [?, ?] demonstrated attentional disengagement deficits in ASD. Their study included children with ASD (mean age 5 years), TD children (mean age 3 years), and children with Down syndrome (mean age 5 years). Results showed that children with ASD exhibited longer reaction times in the disengagement task compared to both Down syndrome and TD children. More severely, in

20% of disengagement trials, children with ASD failed to disengage attention from the original stimulus. However, trial transitions relying solely on video recordings and experimenter judgment may introduce subjective bias, potentially affecting results. Combining functional near-infrared spectroscopy with eye-tracking technology would likely yield more objective measures of reaction times and spatial localization.

While the aforementioned studies showed abnormalities in ASD individuals during disengagement tasks but not in shift tasks, [?, ?] found that saccadic latencies were longer in individuals with ASD compared to TD individuals in both attentional shift and disengagement tasks. However, when gap effects (saccadic latency in shift tasks minus baseline) and overlap effects (saccadic latency in disengagement tasks minus baseline) were calculated, no significant differences emerged between ASD and TD groups.

Although behavioral and eye-tracking studies indicate abnormalities in attentional disengagement in ASD [?, ?, ?, ?], the specific event-related potential (ERP) components directly related to attentional disengagement remain unclear. Early research found larger positive components over the parietal cortex before new stimulus presentation in disengagement tasks compared to shift tasks [?, ?, ?, ?]. Consequently, researchers hypothesized that larger pre-saccadic positivity over the parietal cortex might reflect attentional disengagement processes. Using ERP technology, [?, ?] examined differences in ERP amplitudes between adults with ASD, individuals with mental retardation, and TD adults during visual orienting tasks. The study used pre-saccadic positivity over the parietal cortex before new stimulus presentation as an index, with larger amplitudes or longer latencies indicating abnormal attentional disengagement. Results supported the hypothesis: adults with ASD showed larger pre-saccadic positivity amplitudes in disengagement tasks compared to both mentally retarded and TD adults, and this effect was specific to stimuli presented in the left visual field. Since mentally retarded individuals showed similar pre-saccadic positivity to TD adults, the possibility that attentional disengagement deficits in ASD result from intellectual disability could be excluded. In summary, current research on visual orienting in ASD primarily uses behavioral measures of reaction time and accuracy; ERP studies remain scarce, possibly because ERP components related to attentional disengagement have not been definitively identified and because implementing ERP technology with ASD participants presents practical challenges. Furthermore, attentional disengagement deficits in ASD appear to exhibit left-right visual field asymmetry—difficulties emerge for left visual field stimuli while right visual field performance remains intact. Future research should investigate ERP components and neural mechanisms associated with attentional disengagement, clarify whether pre-saccadic positivity over the parietal cortex relates to attentional disengagement ability, and provide further evidence for left-right visual field asymmetry in attentional disengagement.

2.2 Evidence for Intact Visual Orienting in ASD

Despite behavioral, eye-tracking, and ERP evidence suggesting abnormalities in attentional shifting and disengagement in ASD [?, ?, ?, ?, ?], numerous studies report intact visual orienting abilities in ASD [?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?].

Using the same gap-overlap paradigm, [?, ?] investigated attentional shifting and disengagement differences between 44 children with ASD and 40 TD children. Unlike classic procedures, this study did not require participants to maintain specific eye positions; they could view stimuli freely while keeping their eyes on the screen. Eye-tracking data revealed no significant differences in saccadic reaction times between ASD and TD children in either task. Another study added a step task to the traditional shift and disengagement tasks; unlike gap tasks, step tasks involved no temporal interval between central stimulus offset and peripheral stimulus onset [?, ?]. Results showed that adults with ASD exhibited lower saccadic accuracy and slower peak velocity compared to TD adults, with greater variability in latency, accuracy, and mean velocity. However, no significant group differences emerged in saccadic latency, suggesting intact visual orienting abilities in ASD. [?, ?] obtained similar results in a study of 65 individuals with ASD and 43 TD individuals. Accumulating evidence indicates intact attentional shifting and disengagement in ASD. Although all studies used non-social information stimuli, specific materials varied, including geometric shapes, fruits, and vehicles. A meta-analysis of retrieved literature revealed that 67% of studies using geometric shapes and symbols supported attentional disengagement deficits in ASD, whereas only 34% of studies using familiar objects supported this conclusion. Researchers have proposed that stimulus characteristics may be important factors influencing attentional shifting and disengagement [?, ?]. While direct evidence for the influence of stimulus familiarity on visual orienting in ASD remains limited, stimulus familiarity may contribute to discrepant findings. From an attentional resource perspective, familiar objects consume fewer attentional resources in ASD individuals, enabling faster attentional shifts to other stimuli and resulting in normal disengagement. Conversely, unfamiliar objects consume more attentional resources, leading to longer disengagement latencies and apparent deficits. From a stimulus preference perspective, individuals with ASD may show heightened preference for and engagement with highly familiar stimuli, resulting in disengagement difficulties, while showing normal disengagement for less familiar stimuli. These contradictory interpretations highlight the need for future research to systematically examine how stimulus familiarity affects visual orienting in ASD. Additionally, researchers disagree on eye-tracking data analysis methods: some directly compare saccadic latencies between ASD and TD groups, while others calculate gap and overlap effects by subtracting baseline latencies before conducting difference tests. We argue that researchers should clearly specify their analytical approaches to facilitate better comparisons across studies.

2.3 Neural Mechanisms of Visual Orienting in ASD

Functional magnetic resonance imaging (fMRI) studies indicate that the visual orienting system involves frontal and parietal regions [?, ?, ?]. The frontal eye field (FEF) is responsible for disengaging from attended stimuli [?, ?, ?, ?, ?, ?], patients with right posterior parietal cortex (PPC) damage exhibit longer saccadic latencies [?, ?, ?, ?, ?], and connectivity between left and right parietal regions plays a crucial role in visual orienting [?, ?, ?, ?, ?].

Early studies found that individuals with ASD showed abnormal activation in parietal [?, ?, ?, ?] and cerebellar regions [?, ?] during Posner spatial attention tasks. [?, ?] used the Posner spatial attention paradigm to compare 10 individuals with ASD (all with cerebellar abnormalities) to TD individuals. Six ASD individuals showed bilateral parietal abnormalities, primarily manifested as reduced posterior parietal volume (C+P+), while four showed normal parietal volume (C+P-). Results indicated that both C+P+ and C+P- groups exhibited slower reaction times during attentional shifting and engagement compared to TD individuals, with the C+P+ group showing significantly slower disengagement. The researchers concluded that visual orienting deficits in ASD result from parietal and cerebellar abnormalities.

Recent research provides different evidence. [?, ?] used the Attention Network Test to measure orienting networks in high-functioning autism (HFA) and TD individuals. The experiment presented cues for 100 ms, followed by a blank screen and then a target for 500 ms. Valid cues appeared at the same spatial location as the target, invalid cues appeared at opposite locations, and double cues (neutral) appeared on both sides. Participants judged the direction of target arrows. Attentional disengagement was assessed by subtracting reaction times in neutral cue conditions from invalid cue conditions, while attentional shifting and engagement were assessed by subtracting reaction times in valid cue conditions from neutral cue conditions. Behavioral results showed no significant differences between HFA and TD individuals in any task. Imaging results revealed significant activation in the pregenual anterior cingulate cortex bilaterally, right supramarginal gyrus, inferior parietal lobule, and angular gyrus during disengagement tasks, and in the fusiform gyrus, superior temporal gyrus, and anterior insular cortex during shift and engagement tasks, with no significant differences between HFA and TD groups. These findings contradict previous imaging studies on attentional orienting in ASD. The researchers suggested this discrepancy might arise because their ASD sample lacked cerebellar and parietal abnormalities, or because orienting deficits may only manifest with socially relevant stimuli [?, ?]. However, previous studies using non-social stimuli have found neural differences between ASD and TD individuals [?, ?]. Currently, fMRI research on visual orienting in ASD is limited and controversial, requiring additional evidence. Future studies should use fMRI to investigate the neural mechanisms of visual orienting in ASD and compare activation levels in left and right hemispheres to address whether left visual field disengagement deficits result from right hemisphere dysfunction.

2.4 Summary

The aforementioned studies demonstrate that visual orienting deficits in ASD manifest as longer reaction times for stimulus shifting [?, ?] and disengagement [?, ?, ?, ?], with some individuals failing to disengage attention from attended stimuli [?, ?]. Regarding task types, ASD individuals show differential impairments: attentional disengagement appears more severely impaired than attentional shifting [?, ?, ?, ?, ?, ?], with left-right visual field asymmetry in disengagement tasks warranting further investigation. Developmentally, visual orienting deficits emerge around 12 months of age and persist into adulthood [?, ?].

Four primary issues characterize research on visual orienting in ASD. First, some studies report visual orienting deficits only for left visual field stimuli, with intact performance for right visual field stimuli, yet most studies do not report left-right visual field differences. Future research should compare conditions with stimuli in left versus right visual fields to clarify the mechanisms underlying visual orienting deficits. Second, few studies have employed ERP or fMRI technology, leaving the neural mechanisms of visual orienting in ASD incompletely understood. Future research should identify ERP components related to visual orienting and consider using more practical fNIRS technology. Third, researchers disagree on eye-tracking analysis methods—whether to use raw saccadic latencies or latencies subtracted from baseline—requiring clarification. Fourth, stimulus type may modulate attentional shifting and disengagement [?, ?]. Future studies should examine how stimulus familiarity affects visual orienting in ASD. If visual orienting abilities vary with stimulus characteristics, controlling for these confounding variables becomes crucial.

3 Visual Search

Visual search is a complex cognitive process comprising three stages: parallel processing of basic stimulus features (e.g., color, orientation), planning and execution of attentional allocation, and focused processing of stimulus characteristics [?, ?, ?]. The visual search advantage in ASD was first reported by [?, ?], who found that adults with HFA showed significantly higher accuracy than TD adults when discriminating novel, highly similar stimuli. Subsequent research has confirmed superior visual search performance in ASD across various tasks and paradigms, including visual search paradigms [?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?], response competition tasks [?, ?, ?, ?, ?], and hidden pictures tasks [?, ?, ?, ?].

3.1 Evidence for Visual Search Superiority in ASD

Most researchers have confirmed visual search superiority in ASD using visual search paradigms [?, ?, ?, ?, ?], with this advantage observed in both children [?, ?] and adults with ASD [?, ?, ?, ?]. [?, ?] distinguished between static and dynamic search conditions: in static search, target and distractor positions remained constant, while in dynamic search, they changed every 500 ms. The

study also manipulated perceptual load with 15, 20, or 25 search items. Behavioral results showed faster reaction times in ASD individuals compared to TD individuals, particularly in dynamic search conditions. Eye-tracking data revealed shorter fixation durations in ASD individuals, further confirming their visual search advantage. Because children with ASD maintained high search efficiency in dynamic search tasks, memory effects could be ruled out as an explanation. The researchers proposed that the visual search advantage in ASD may not occur during the search process itself but rather before stimulus presentation, through enhanced attentional templates or attentional sets for target features, enabling faster target detection.

Other paradigms have also demonstrated visual search superiority in ASD. [?, ?] used a response competition task to examine visual search differences between ASD and TD individuals under high and low perceptual load. Participants ignored letters outside a circle while searching for target letters “X” or “N” inside the circle and responded via button press. Distractors were either neutral (e.g., letters “T” or “L”) or incongruent (e.g., letter “N” when target was “X”). Under high perceptual load, individuals with ASD successfully ignored task-irrelevant distractors, showing no significant differences in speed or accuracy compared to low load conditions, whereas TD individuals showed significant declines in both measures. The researchers suggested that ASD and TD individuals may have different perceptual capacities [?, ?], with ASD individuals possessing larger capacity that enables parallel processing of more features, facilitating target localization and producing visual search advantages. However, [?, ?] proposed that the visual search advantage in ASD is limited, disappearing under extremely high perceptual load conditions. Therefore, perceptual load may be a critical factor influencing visual search superiority in ASD [?, ?, ?, ?].

[?, ?] manipulated perceptual load in two ways while testing 13 adults with ASD and 14 TD adults. First, they manipulated target-distractor similarity: a simple module used tilted lines as targets and vertical lines as distractors, while a difficult module used vertical lines as targets and tilted lines as distractors. Second, they varied the number of stimuli (4, 16, or 25 items). Results showed that in the simple module, individuals with ASD exhibited faster reaction times than TD individuals across all set sizes, demonstrating visual search superiority, particularly when targets were absent. In the difficult module, although no significant group differences emerged, the pattern across set sizes resembled that of the simple module. The researchers argued that the difficult module, requiring search for vertical targets among tilted distractors, imposed higher perceptual load, preventing manifestation of visual search superiority in ASD. Previous findings showing visual search advantages in ASD under low perceptual load with large set sizes suggest larger perceptual capacity, yet the disappearance of this advantage when increasing load through target-distractor similarity manipulation provides indirect evidence that this capacity is limited. Therefore, examining the relationship between perceptual load and perceptual capacity is necessary to understand the characteristics of perceptual capacity in ASD and its relationship to visual search superiority.

Additionally, in hidden pictures tasks requiring search for 7 stars and 9 “X” shapes in real-world scenes, individuals with ASD showed significantly higher accuracy than non-ASD individuals, demonstrating visual search superiority [?, ?]. These empirical studies collectively indicate that individuals with ASD possess visual search advantages supported by multiple task paradigms.

Recent research has begun investigating the underlying mechanisms of visual search superiority in ASD. [?, ?] attempted to determine the stage at which this advantage occurs and its causes by adding audiovisual masking stimuli. Experiment 1 used a conjunction search task where participants searched for a white “X” among distractors that shared one feature with the target (white “T” or black “X”). The experiment included two conditions: one with masking stimuli presented immediately after the search array, and one without masking stimuli. Experiment 2 used a hard search task requiring participants to search for the number “2” among digits 1-9, examining whether ASD individuals maintained search superiority when distractors were heterogeneous and feature-based judgments were impossible. Both experiments manipulated perceptual load and eccentricity to investigate crowding effects on search efficiency. Results showed: (1) individuals with ASD exhibited significantly faster reaction times than TD individuals across all perceptual load conditions, regardless of masking stimuli presence, confirming visual search superiority; (2) the presence of masking stimuli, designed to interrupt serial processing, did not impair ASD performance, suggesting the advantage does not stem from serial processing during search; (3) in Experiment 2 with heterogeneous distractors, ASD individuals showed even faster reaction times and higher accuracy than in Experiment 1, unaffected by eccentricity, indicating that neither feature-based search nor crowding effects explain the search advantage, though these crowding findings contradict [?, ?]. In summary, studies using dynamic search or masking stimuli indicate that visual search superiority in ASD does not originate from search processes or serial processing of stimulus arrays. The researchers suggested that individuals with ASD have enhanced discriminability during early visual processing, enabling rapid parallel processing of multiple stimuli. Future research should combine high-temporal-resolution ERP technology to compare early visual ERP components between ASD and TD individuals during visual search tasks, providing direct evidence for the mechanisms underlying visual search superiority.

3.2 Evidence Against Visual Search Superiority in ASD

Despite most studies supporting visual search superiority in ASD, some researchers have raised objections. These objections fall into two categories: (1) intact visual search abilities in ASD, characterized by no significant reaction time differences between ASD and TD individuals [?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?]; and (2) impaired visual search abilities in ASD, characterized by slower reaction times compared to TD individuals [?, ?].

3.2.1 Evidence for Intact Visual Search Abilities Contrary to most findings of visual search superiority, [?, ?] found that individuals with ASD showed visual search abilities similar to TD individuals, with no superiority advantage. In their experiment, participants searched for an upright letter “T” among distractors rotated at three different angles. In homogeneous conditions, distractors had only one rotation angle, while in heterogeneous conditions, all three rotation angles were present. Results showed no significant reaction time differences between ASD and TD groups, consistent with [?, ?] and indicating intact visual search abilities in ASD.

Additionally, maze experiments investigating visual search characteristics in ASD have supported intact visual search abilities [?, ?]. The study included three maze tasks: route learning, reverse route, and designated direction, with difficulty manipulated by varying route length and number of turns. All three tasks showed no significant group differences in reaction time or error rate, suggesting intact visuospatial search abilities without superiority. However, given substantial differences between maze tasks and classic visual search paradigms, these findings should be interpreted cautiously.

3.2.2 Evidence for Impaired Visual Search Abilities More recently, researchers have found impaired visual search abilities in ASD. [?, ?] used a multiple conjunction search task to examine visual search time differences between children with ASD and TD children. Stimuli included black and white, hollow and solid circles. Participants searched for a unique stimulus among distractors that matched the target on one feature (e.g., when the target was a black solid circle, distractors were white solid circles and black hollow circles). Results showed that individuals with ASD had significantly slower reaction times than TD individuals, showing no visual search superiority. The researchers argued that previous findings of visual search superiority in ASD were based on top-down (rapid target-stimulus comparison) or bottom-up (enhanced target template/distractor inhibition) perceptual processes that do not apply to multiple conjunction search tasks. Notably, unlike other search tasks where targets remain constant, this task required participants to search for a unique stimulus that changed on each trial, preventing enhancement of target templates before search array presentation. Future research should examine the processing stages of visual search superiority in ASD by manipulating task types.

3.3 Neural Mechanisms of Visual Search in ASD

fMRI studies have identified activation in right superior parietal cortex, intraparietal sulcus, frontal operculum, putamen, frontal eye field, temporoparietal junction, and the junction of intraparietal and transverse occipital sulcus during visual search [?, ?, ?, ?, ?, ?, ?, ?].

fMRI research indicates differences between ASD and TD individuals in occipital and frontal regions during visual search [?, ?, ?]. [?, ?] examined neural mechanisms of visual search in 9 individuals with ASD and 13 TD individuals

using the same paradigm as [?, ?], with upright letter “T” as target and three rotation angles of “T” as distractors. TD individuals showed activation primarily in occipital and temporal regions, with high occipital activation extending to the inferior temporal gyrus. In contrast, individuals with ASD showed more diffuse and higher activation across frontal, parietal, and occipital regions, including bilateral occipital cortex extending dorsally to precuneus, superior parietal lobule, and right frontal cortex. The researchers suggested that enhanced search efficiency in ASD relates to stronger discriminability and top-down processing, reflected in higher activation in occipital and frontoparietal regions. A subsequent study using the same paradigm with ASD individuals having social communication deficits found stronger functional connectivity in occipital regions and both local and long-range connectivity in frontal regions [?, ?]. The researchers proposed that enhanced visual spatial processing of non-social information in ASD individuals with social communication deficits may be related to the development of these social impairments.

3.4 Summary

Visual search superiority in ASD, first proposed nearly 40 years ago, has received substantial empirical support [?, ?, ?, ?, ?, ?, ?, ?, ?]. Pupillometry data also show larger pupillary responses in individuals with ASD compared to TD individuals during visual search [?, ?, ?, ?, ?, ?, ?, ?, ?].

Most researchers support the view that individuals with ASD exhibit visual search superiority, possibly due to enhanced attentional templates or attentional sets for target features before stimulus presentation, enabling faster target detection. However, more empirical support is needed. Current research faces two main issues. First, the relationship between task difficulty, perceptual load, and visual search superiority remains unclear. Some studies show that visual search superiority disappears under high task difficulty, while others demonstrate enhanced superiority under high perceptual load. Task difficulty varies substantially across studies, from simple feature search tasks where targets pop out, to complex conjunction search tasks requiring simultaneous attention to color and shape features with heterogeneous distractors and varying set sizes. We argue that researchers should evaluate search abilities using tasks with similar difficulty levels to ensure comparability. Second, the cause of visual search superiority remains debated. From a perceptual perspective, researchers attribute this to larger perceptual capacity in ASD [?, ?, ?, ?], enabling parallel processing of more information under high perceptual load and resulting in faster reaction times and shorter fixation durations. Alternative explanations include weak central coherence theory [?, ?, ?, ?], which proposes that individuals with ASD have difficulty integrating fragmented information into wholes and thus rely more on local stimulus features [?, ?]. From an attentional perspective, superiority may relate to narrower attentional focus [?, ?, ?, ?, ?, ?, ?, ?, ?] or over-focus [?, ?, ?, ?, ?].

4 Future Directions

Extensive research reveals controversies regarding attention to non-social information in ASD, specifically in visual orienting and visual search. Visual orienting studies present inconsistent conclusions and unresolved questions: Do individuals with ASD truly have deficits in attentional shifting and disengagement? Does left-right visual field asymmetry in visual orienting exist, and does it appear in other attentional tasks? Visual search studies raise questions about the stage at which superiority emerges and its influencing factors: Does the advantage occur before stimulus presentation? Should it be attributed to larger perceptual capacity or weaker central coherence? What roles do perceptual load and task difficulty play? These issues highlight gaps in current research that warrant investigation in three key areas.

4.1 Hemispheric Asymmetry in Visual Orienting

Studies have found left-right visual field asymmetry in attentional disengagement, with longer latencies for left visual field stimuli [?, ?]. Earlier ERP research by [?, ?] also showed larger pre-saccadic positivity over parietal cortex during attentional disengagement, primarily for left visual field stimuli. Few other studies have reported similar findings. We argue that eye-tracking technology offers advantages for real-time monitoring of eye movements in examining attentional shifting and disengagement. Future research should compare saccadic latencies for targets in left versus right visual fields to further validate hemispheric asymmetry in visual orienting.

[?, ?] suggested that left-right visual field asymmetry might result from right hemisphere dysfunction. If right hemisphere function is impaired in ASD, would similar asymmetries appear in other visual attention tasks, such as visual search? Future studies should include conditions with targets in left or right visual fields and analyze differential results. For example, when using visual search paradigms to examine search abilities, researchers could separately analyze trials with targets in left versus right visual fields. If right hemisphere dysfunction exists in ASD, visual search superiority might only appear for right visual field targets. Additionally, researchers could use the N2pc component to examine attentional allocation differences to various stimuli in visual search tasks. The N2pc component serves as an index of attentional allocation in ERP studies [?, ?, ?], with its latency reflecting the timing of attentional allocation to targets and its amplitude reflecting distractor filtering [?, ?] or target capture [?, ?, ?, ?, ?]. Using ERP to examine asymmetry in visual search superiority would predict later N2pc latency and smaller amplitude for left visual field targets, and earlier latency and larger amplitude for right visual field targets.

4.2 Mechanisms Underlying Visual Search Superiority

First, at what stage does visual search superiority emerge? Research indicates that individuals with ASD show visual search advantages when search targets

are constant, but not when targets vary across trials [?, ?]. This suggests that the advantage may occur before stimulus presentation through enhanced attentional templates or sets for target features. Future research should manipulate task types by including both target-known and target-unknown conditions to dissociate when visual search superiority appears. Additionally, ERP technology's high temporal resolution offers significant advantages for addressing this question. Researchers should combine ERP with visual search tasks to compare early spatial attention components (P1, N1) and attentional allocation-related N2pc components between ASD and TD individuals, providing direct evidence for the stage at which visual search superiority emerges.

Second, controversy persists over whether visual search superiority results from larger perceptual capacity or weak central coherence. We propose that resolving this debate requires using relatively heterogeneous distractor materials that prevent ASD individuals from relying on local features. For example, using double digits or letters as stimuli would eliminate weak central coherence as an explanation if visual search superiority persists. Researchers could then manipulate perceptual load by varying stimulus quantity and similarity to examine differences in perceptual capacity between ASD and TD individuals.

4.3 Interrelationship Between Visual Orienting and Visual Search

Behavioral studies show that individuals with ASD exhibit deficits in attentional disengagement but superiority in visual search. No unified explanation currently accounts for these opposing patterns. We attempted to identify neural mechanism differences, but imaging studies reveal substantial overlap between visual orienting and visual search in TD individuals, with frontal and parietal regions participating in both tasks [?, ?, ?, ?], making it difficult to find dissociating neural evidence. Meanwhile, neural mechanism research on these attentional tasks in ASD remains scarce. Current evidence suggests visual orienting deficits may relate to parietal and cerebellar abnormalities, while visual search superiority may involve local and long-range connectivity in occipital and frontal regions, though more imaging evidence is needed. Notably, visual orienting and visual search may not exclusively involve non-social information processing, and language deficits in ASD, such as comprehension of instructions, could affect results. Therefore, strict matching of ASD and control groups on age, intelligence (including verbal intelligence), and other factors is essential.

Increasingly, researchers are studying younger populations, including high-risk infants for ASD (with family history but no diagnosis) [?, ?, ?, ?, ?, ?], aiming to identify early attentional markers for diagnostic criteria. In examining the relationship between visual orienting and visual search, fNIRS and eye-tracking technologies play crucial roles. fNIRS is considered one of the most suitable neuroimaging techniques for studying cortical activity in infants [?, ?]. Eye-tracking offers unique spatiotemporal precision and well-defined neural circuits, with neuroimaging and histopathological studies indicating that saccades are controlled by cerebellar and brainstem regions [?, ?, ?, ?, ?, ?], allowing assessment of brain

functional integrity in ASD through saccadic measures. Combining fNIRS with eye-tracking to examine similarities and differences in neural mechanisms underlying these attentional tasks in high- and low-risk infants could significantly contribute to ASD diagnosis and intervention.

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