A review of behavioral evidence for hemispheric asymmetry of visuospatial attention in autism

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Abstract

Most individuals show a small bias towards visual stimuli presented in their left visual field (LVF) that reflects right-hemispheric specialization of visuospatial functions. Moreover, this bias is altered by some neurodevelopmental disorders, suggesting they may be linked to changes in hemispheric asymmetry. To examine whether autism potentially alters hemispheric asymmetry, we conducted a systematic search of scientific databases to review existing literature on the link between autism and alterations in visuospatial bias. This search identified 13 publications that had explored this issue using a wide range of experimental designs and stimuli. Evidence of reduced LVF bias associated with autism was most consistent for studies examining attentional bias or preference measured using tasks such as line bisection. Findings for studies examining attentional performance (e.g., reaction time) were more equivocal. Further investigation is called for, and we make several recommendations for how this avenue of research can be extended.

Lay Summary

Most people show a very small bias or preference for objects or information presented in the left side of their visual field compared to the right side. However, several studies have reported that autism is associated with an absence of visual field biases. In this paper, we review the studies that have examined this issue and find tentative evidence for a reduction in left visual field bias, which suggests that the brain may be less asymmetrically organized in autistic individuals.

KEYWORDS
attention, autism, hemispheric asymmetry/lateralization, spatial bias, visual bias

INTRODUCTION

Pseudoneglect

The real-time, inner workings of the brain are often veiled to observers, which is why situations where brain and behavior are inextricably linked receive a great deal of attention. One such example is that of visuospatial neglect (Bowers & Heilman, 1980), where individuals with unilateral hemispheric lesions do not show conscious awareness of stimulus details presented in the visual field contralateral to the hemispheric damage (Costa et al., 1969; Gainotti et al., 1972). Additional insight is gleaned from the observation that visuospatial impairments are greatest when lesions are primarily located on the right hemisphere (RH) compared to the left hemisphere (LH), suggesting that visuospatial functions are largely lateralised to the RH (Bowen et al., 1999; Corbetta & Shulman, 2011; Husain, 2005; K. Li & Malhotra, 2015). Consequently, certain visuospatial deficits, like neglect, can be used as markers to direct early neurological assessments and increase diagnostic efficiency.

Another, less extreme, phenomenon attributable to lateralisation is known as 'pseudoneglect', which refers to the tendency for neurotypical individuals to preferentially attend to or exaggerate the features of visual stimuli presented in the left visual field (LVF) or hemifield compared to visual features presented in the right visual field

(RVF) (Bowers & Heilman, 1980). This asymmetry in attention is not noticeable in day-to-day functioning, and typically requires specific behavioral tasks to be reliably observable. For example, on a line bisection task, in which participants attempt to mark the centre of a horizontal line, most individuals err slightly left of the true centre (Jewell & McCourt, 2000), indicating a perceived exaggeration of length of the line in the LVF. The phenomenon has been extensively observed, and a meta-analysis of 73 (sub-)studies found small, but robust, leftward biases across the healthy population (Jewell & McCourt, 2000). Supporting the view that RH specialization for visuospatial attention underlies attentional asymmetries, neuroimaging studies indicate that regions in the right ventral attention network, such as the temporo-parietal junction, are specifically associated with variations in visuospatial biases (Benwell et al., 2014; de Schotten et al., 2011).

In short, pseudoneglect and visuospatial neglect share distinct, yet similar, underlying mechanisms. Critically, while small attentional asymmetries favoring the LVF (i.e., pseudoneglect) appear to be the result of 'typical' asymmetries in brain organization, an absence or reversal of this pattern might be a marker of atypical organization or significant trauma, raising the possibility of other neurological and behavioral differences. Consequently, variations in attentional asymmetry might hold important meaning for better understanding brain functioning in both clinical and non-clinical populations.

Pseudoneglect variation in neurodevelopmental disorders

In addition to the aforementioned effects of physical trauma, several neurodevelopmental disorders are also associated with both atypical hemispheric activation and altered levels of pseudoneglect (for a review, see Ribolsi et al., 2015). For example, both dyslexia and schizophrenia have been associated with either dysfunction in the RH regions, such as the right parietal cortex, or a general reduction in hemispheric asymmetry (Kershner, 2020; Ribolsi et al., 2014; Stein, 1994), and individuals with either condition also report reduced, or absent, pseudoneglect compared to healthy controls (Michel et al., 2007, 2011; Sireteanu et al., 2005). Similarly, atypical hemispheric asymmetry is a feature of attention-deficit/hyperactivity disorder (ADHD) (Postema et al., 2021), and diagnosed children are also observed to show reduced pseudoneglect compared to healthy controls (Chen & Niemeier, 2017). Consequently, in conjunction with other tools, pseudoneglect could be used as a rough indicator of atypical brain organization. In addition to potential diagnostic utility, researchers often need to be aware of potential confounds in experimental data. Individual differences that alter attentional asymmetries would be a factor that many researchers studying lateralisation of attention might want to control for.

Pseudoneglect and autism spectrum disorder

Whilst there have been significant attempts to examine and review the relationship between altered attentional asymmetries in other neurodevelopment disorders, it is unclear if autism, which is primarily characterized by social impairments and restricted and repetitive behaviors and interests (American Psychiatric Association, 2013), might also be associated with similar attentional differences. Several lines of research support this possibility, such as studies showing structural and functional alterations in hemispheric asymmetry in autism (Q. Li et al., 2023). From a theoretical standpoint, there are also several aspects of cognition in autism that suggest atypical or reduced lateralisation that might result in reduced pseudoneglect.

Global processing (the integration of individual visual stimuli into a meaningful 'whole') and local processing (the processing of the finer details of a visual scene) are linked to the right and left hemispheres of the brain respectively (for a review see Ivry & Robertson, 1998; see also: Evans et al., 2000; Flevaris et al., 2010; Han et al., 2002; Hübner & Studer, 2009; Iglesias-Fuster et al., 2014; Lux et al., 2004; Malinowski et al., 2002; Volberg & Hübner, 2004; Weissman & Woldorff, 2005; Yamaguchi et al., 2000). Whilst global processing appears to be the preferred processing style for most individuals, autistic individuals have been noted for having difficulty in global processing or showing a preference for local processing (Happé & Booth, 2008; Mottron & Burack, 2001). Such differences in processing preferences could be attributable to reduced lateralisation of spatial functions to the right (i.e., global) hemisphere in autism.

A similar pattern is associated with language and verbal ability. For non-autistic individuals, tasks requiring verbal ability commonly activate more areas located in the LH compared to the RH (Flöel et al., 2005; Whitehouse et al., 2009; Whitehouse & Bishop, 2009), whilst autistic individuals display a more bilateral pattern of activation (Hollier et al., 2014). Comparable findings have been reported within the general population, with individuals who have higher levels of self-reported autistic traits also showing reduced language lateralisation (Jouravlev et al., 2020). Though speculative, given the evidence for atypical hemispheric lateralisation in other aspects of cognition in autism, it would not be surprising to also observe reductions in pseudoneglect in autistic individuals.

That is not to say that no work has been done in this area. In fact, numerous studies have used diverse methods to examine attentional bias as a function of autism or autistic traits, observing response biases to simple perceptual tasks (e.g. greyscales, landmark; English et al., 2015; Stettler, 2016), and comparing task performance when stimuli are presented in the left and right hemifields (Keehn & Joseph, 2016; O'Keefe et al., 2013). However, the extent to which pseudoneglect is altered due to autism is unclear, as various study designs used to address this issue have yielded heterogenous outcomes. Critically, despite a quarter-century of work (Wainwright & Bryson, 1996), there has yet to be a

comprehensive review of this heterogenous literature, and thus no synthesis of the existing research. This is unfortunate, as it is possible that there are as-yet unidentified patterns in attentional asymmetry associated with autism present across the studies that have examined this issue.

In short, previous research examining differences in language functioning and global–local processing ability in autism suggest that alterations in hemispheric specialization (specifically, reduced organizational asymmetry) might be a common contributing factor. Consequently, it is possible that potential variations in pseudoneglect may be a heretofore unrecognized autistic characteristic that is also linked to altered hemispheric specialization. If this is the case, closer study of altered pseudoneglect in autism may yield insights into other autistic features associated with altered hemispheric specialization (and potentially reveal autistic features linked to hemispheric specialization that were are not yet aware of). Finally, if the converse is found, and pseudoneglect does *not* appear to be associated with autism, this would create a new distinction between autism and ADHD that might aid the diagnostic specificity of these comorbid conditions.

The current review

A review of studies examining altered attentional asymmetry in autism is needed to draw together existing work and provide a state-of-the-science overview. We hope to provide a common starting point for future research in this area, and document the different paradigms used to date such that, in moving forward, more consistent methodologies will be used to investigate perceptual asymmetry in autism and its association with cognitive abilities. In the current review, we chose to conduct a broad review of the autism literature that encapsulated any methodological design that used an appropriate behavioral measure of pseudoneglect or attentional asymmetry to capture the widest breadth of relevant studies. However, we decided against reviewing studies that examined attentional biases towards face stimuli given they are associated with significant lateralized stimulus-specific processes of their own, often favoring the RH (Bourne, 2010; Meng et al., 2012; Rhodes, 1985), and thus the attentional processes used for tasks using face stimuli would not be readily comparable to the processes investigated in studies using simpler non-face stimuli. As it was expected that this broad approach would result in the identification of a collection of studies with heterogenous stimuli and methodologies, we planned from the outset to initially group and assess studies using similar methodologies and stimuli.

METHODS

Search strategy

The study was pre-registered on PROSPERO (CRD42020148693). In keeping with a broad review, no

single experimental design was specified and any study that provided some index of the prominence of visual attention directed to the left and right visual fields (e.g., through a line-bisection, greyscales, or landmark task) was considered. Studies comparing clinically identified autistic and non-autistic individuals, and studies examining non-autistic individuals who vary in autistic traits, were both considered. Our search also included peer-reviewed 'gray literature' such as post-graduate student theses, in addition to empirical articles published in peer-reviewed journals.

A search of the PubMed, PsycINFO and Web of Science databases was conducted on 22nd March, 2023. Wildcards were used to broaden search terms – for example, 'autis*' would return both 'autism' and 'autistic'. The terms used to search the databases were ('autis*' OR 'Asperger*') AND ('left' OR 'right' OR 'leftward' OR 'rightward') AND ('bias*' OR 'lateral*' OR 'pseudoneglect' OR 'hemifield' OR 'hemispace' OR 'visual field' OR 'asymmetry'). The abstracts of the studies returned in the search results were downloaded for later screening (see below). Finally, in addition to the initial search, we also examined the references and citations of the articles that passed full-text review.

Abstract screening

Duplicates were identified and removed using Endnote X8 and the remaining abstracts were uploaded to Rayyan (Ouzzani et al., 2016) for screening. To be included for full-text review, abstracts had to pass several criteria, including: (1) an English-language abstract was available, (2) the publication described participants who either had an autism-spectrum disorder diagnosis (including Asperger syndrome), were identified as 'high-risk' for future diagnosis, or were examined on the basis of autistic trait levels as measured by an established measure (e.g., Autism-Spectrum Quotient), (3) the publication described original data (i.e., not a review article), and (4) the publication described methodology that allowed for a behavioral comparison of visual attention to the left and right visual fields.

Abstracts that did not meet any one of these criteria were excluded and not assessed against subsequent criteria. Criterion four was intentionally broad as a wide variety of experimental designs are suitable for examining visual attention biases. Additionally, the measure of attentional bias did not necessarily have to be the focal outcome of a study for the study to be included. Screening was primarily conducted by MCWE. A random sample of 20% of the abstracts were also screened by MTM. In case of a disagreement, the authors discussed the article until a joint decision could be made.

Full-text screening and task categorization

Studies with abstracts that met all screening criteria were downloaded in full and reviewed for further

consideration. Studies were assessed against the abstract screening criteria again, though, the experimental method was more closely scrutinized to assess the suitability of the data for consideration in the review. An overview of full-text exclusion reasons can be found in Figure 1.

Demographic data, sample sizes and the main outcomes of the studies that passed full-text review were extracted. Study outcomes were typically differences in the left and right visual field for attentional preference, attentional performance (i.e., accuracy or reaction time), or eye-
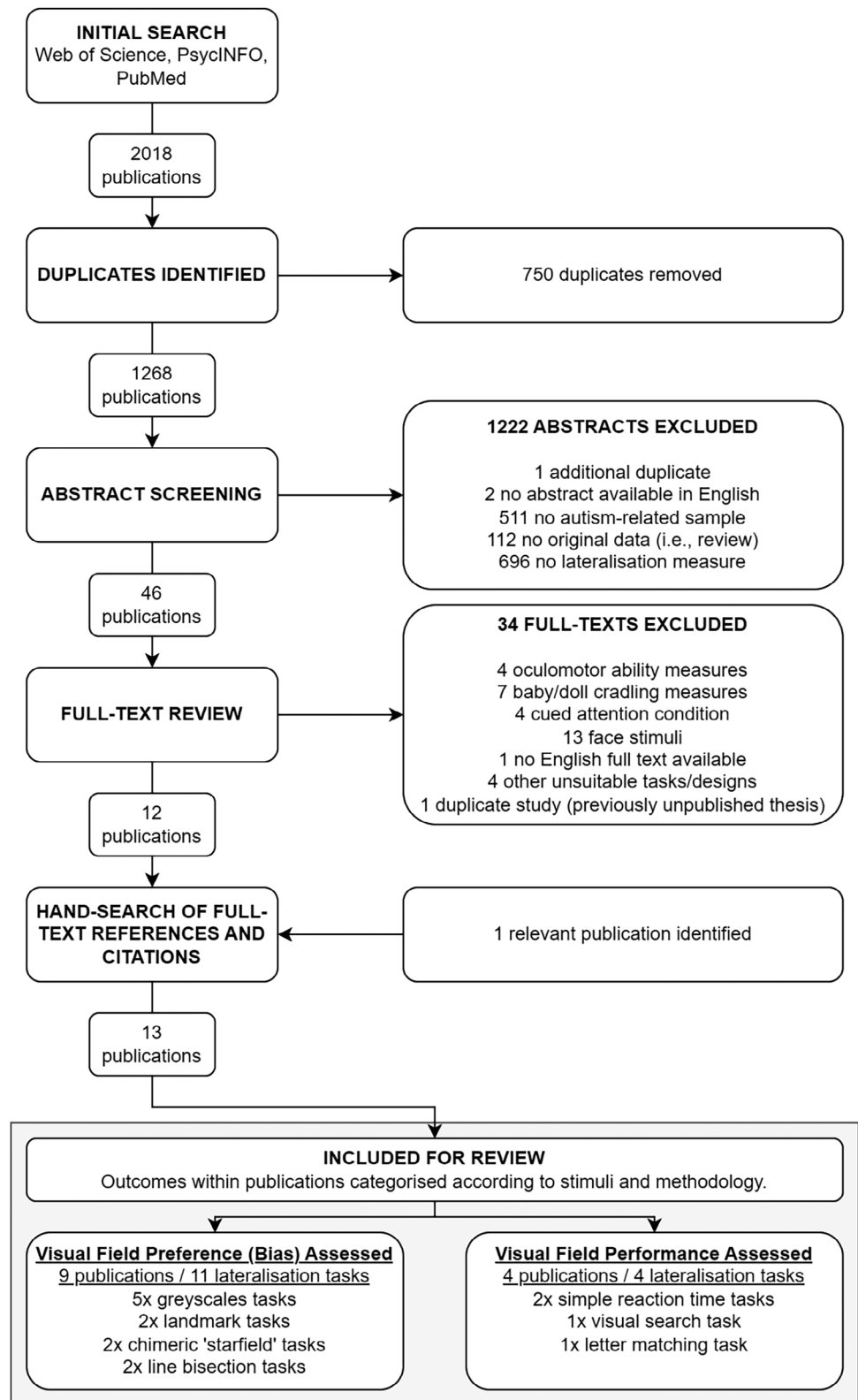
FIGURE 1 Overview of the results of the search strategy used, exclusion reasons for abstracts and full-texts, and categorization of study outcomes.

tracking measures (e.g., location of first fixations). Where multiple comparisons and outcomes (e.g., multiple experiments or experimental groups) were included in a single study, each comparison and outcome were extracted and examined independently where possible. Study outcomes were then categorized and grouped based on common methodologies.

RESULTS

The results of each of the steps in the systematic search are summarized in Figure 1. A total of 2018 abstracts were captured in the search which was reduced following de-duplication to 1268 abstracts for screening. Of the 20% of abstracts also screened by MTM, there was a decision disagreement on four abstracts. These abstracts were discussed between the authors and were all resolved in favor of the original decision made by MCWE. Next, 46 publications were considered at the full-text review stage. Twelve of these publications were accepted for the review and one additional publication was discovered though manual searches of the citations of accepted publications, resulting in a final total of 13 publications.

Of the accepted publications to review, several included two or more studies or tasks which examined visuospatial differences of interest. Additionally, the studies fell into one of two broad categories that were deemed different enough to warrant separate review; (1) those that examined attentional *bias* or *preference* to the left or right visual field, and produced a single index of said bias, and (2) those that examined attentional *performance* in the left and right visual fields, and typically produced separate outcome measures for each visual field. Accordingly, we review these two study categories in separate sections before discussing category similarities and differences.

Finally, there was some variation in how subject comparison groups were established, especially among studies that examined attention in unselected samples who differed in autistic traits. Given the modest number of studies to review, and prior examples of clinical and non-clinical autism studies showing comparable findings in other areas of visual attention such as global–local processing (for review, see Cribb et al., 2016), we decided not to further divide the reviewed studies. Among the studies that compared non-clinical subjects who differed in levels of autistic traits, several recruited an unselected participant sample and subsequently assigned group membership following a median split into high and low trait scores (English et al., 2015, 2018; O'Keefe et al., 2013). One study varied slightly in that they recruited participants who scored in the upper or lower third of a previously screened subject pool to enable greater separation in trait scores of the comparison groups (English et al., 2017). Two other trait-based studies elected to recruit an unselected sample and examine trait-based differences using correlational analyses, foregoing splitting their sample into high-low comparison groups (Stettler, 2016; Vladeanu et al., 2012).

Studies that examined differences in attentional bias or preference

Nine publications were identified that measured attentional *biases* to stimuli (see Table 1 for an overview) where the primary outcome measure of interest was the proportion of trials in which certain stimulus features appeared more pronounced in the left versus right visual field (i.e., a laterality index). Our review identified four different tasks that relied upon comparisons of laterality indices, each of which is discussed separately below. We extracted: (1) whether each group separately demonstrated an attentional bias in studies with comparison groups, and (2) whether attentional bias differed between comparison groups or correlated with a measure of autistic traits. While all studies reported on comparison group differences, two did not report on individual group measures of attentional bias (Drmic, 2007; Rinehart et al., 2002), and thus it is unclear if the tested samples showed attentional biases at all for those studies.

Description of tasks measuring attentional bias or preference

Five studies used the greyscales task (Nicholls et al., 1999) to obtain a measure of attentional bias (see Table 1). This task requires participants to select the darker of two centrally positioned horizontal bars, aligned on the horizontal plane but separated vertically and with opposite black-to-white gradients. A preference for selecting the bars with more black pixels on the left-side is considered indicative of an over-exaggeration of stimulus features presented in the left visual field. The difference between the two bars can be adjusted, with some studies choosing to use equiluminant bars (both bars having the same ratio of black and white pixels), whilst others choose to use non-equiluminant bars (one bar having more black pixels than the other). The main difference between the two stimulus types is that for equiluminant bars, no measure of accuracy can be obtained as neither bar is a 'correct' or 'incorrect' choice, while for non-equiluminant bars a measure of accuracy can be obtained, allowing researchers to detect and potentially exclude participants who show chance-level performance, thereby improving overall data quality.

Two studies used chimeric 'star-field' stimuli to obtain a measure of attentional bias (see Table 1). The star-field stimuli consisted of an image of small white squares (i.e., 'stars') set against a black background (i.e., 'space'). Images were edited to present more stars on one side of the stimulus (e.g., more stars on the left side), and then copied and mirrored to create a second

TABLE 1 Details and outcomes of studies using measures of attentional 'preference' or bias. Cells with dashes indicate the same group/condition as above. Age is the group mean except where only the range was reported. Group differences are coded with reference to effect of autism/autistic traits on left visual field bias

Study	Greyscale Stimuli	'Autism' group Sample	n (fem.)	Age (yrs)	Control group Sample	n (fem.)	Age (yrs)	Results 'Autism' bias	Control bias	Group difference
Greyscales Task										
Rinehart et al. (2002)	Equiluminant	ASD	12 (1)	9	Non-ASD[a]	-	-	Unavail.	Unavail.	None
	-	AD	12 (3)	12	Non-ASD[a]	-	-	Unavail.	Unavail.	None
Drmic (2007)	Equiluminant	ASD	29 (7)	32	Non-ASD	29 (7)	32	Unavail.	Unavail.	ASD↓
	Non-equiluminant	-	-	-	-	-	-	Unavail.	Unavail.	ASD↓
English et al. (2015)	Non-equiluminant	High AQ	142 (98)	20	Low AQ	135 (109)	23	LVF	LVF	High AQ↓
English et al. (2017)	Non-equiluminant	High AQ	52 (34)	20	Low AQ	52 (47)	21	None	LVF	High AQ↓
English et al. (2018)[b]	Non-equiluminant	High AQ	16 (6)	21	Low AQ	18 (10)	21	LVF	LVF	None
Chimeric 'Starfield' Task										
Ashwin et al. (2005) – Exp. 1		AD	16 (0)	27	Non-ASD	16 (0)	28	LVF	None	AD↑
Vladeanu et al. (2012)		BAPQ[c]	64 (32)	22	N/A			Bias not associated with BAPQ		
Landmark Task										
Stettler (2016)		AQ[c]	202 (122)	18–40	N/A			Bias not associated with AQ		
English et al. (2017)		High AQ	52 (34)	20	Low AQ	52 (47)	21	LVF	LVF	High AQ↓
Line Bisection Task										
Liu et al. (2022) – Exp. 1		ASD	31 (2)	10	Non-ASD	40 (2)	10	LVF	LVF	Same

Abbreviations: AQ, Autism-spectrum Quotient (Baron-Cohen et al., 2001); ASD, Autism Spectrum Disorder; AD, Asperger's Disorder; BAPQ, Broad Autism Phenotype Questionnaire (Hurley et al., 2007); LVF, left visual field.
[a]Control group matched on sex, age, and IQ. Exact statistics not reported.
[b]Sham transcranial direct current stimulation condition only.
[c]Continuous measure across single general population sample (i.e., correlation analysis). N and age refer to total sample.

stimulus with more stars on the other side (e.g., more stars on the right side). The mirrored images were then presented centrally on the horizontal plane but separated vertically and participants were asked to report which image contained "more" stars. Like the greyscales task, a preference for images with more stars on the left side of the display was considered indicative of an exaggeration of stimulus features presented in the LVF.

Two studies used the landmark task to obtain a measure of attentional bias (see Table 1). In this task, participants are presented with horizontal lines (or bars) that have already been bisected near the horizontal centre and must respond as to whether the bisection is closer (or further) to the left or right end of the line. Responses that endorse the line being closer to the right end imply that the right half is perceived as shorter than the left half, and this is indicative of an exaggeration of the left-side of space (Milner et al., 1992). Consequently, a pattern of responding showing mostly 'rightward' responses is considered indicative of LVF bias.

One study used the line bisection task to obtain a measure of attentional bias (see Table 1). Line bisection is one of the more common methods of assessing attentional asymmetries, and it was thus surprising that only one publication has administered this task in the context of autism research. The task involves participants being presented with horizontal lines (when assessing left–right asymmetries) and being tasked with identifying the horizontal centre or mid-point of each line. Traditional pen-and-paper administration has participants use a pen or pencil to mark the bisection on lines printed on paper, whilst computerized versions have participants use a keyboard or mouse to bisect lines presented on the display. Asymmetry in visual attention typically results in more bisections being marked on the side of the true centre that also corresponds to the preferred visual field. Task outcomes are typically participant's mean 'error' or variance from the true centre across multiple trials, or the proportion of trials with leftward errors. Lastly, certain experimental parameters have been shown to modulate biases on the task, with longer lines being associated with greater leftward deviation, and bisection using the left hand resulting in greater leftward deviations than those made using the right hand (Jewell & McCourt, 2000).

Outcomes of tasks measuring attentional bias or preference

When considering the overall picture found across studies using the greyscales, chimeric 'star-field', and landmark tasks, it appears that LVF biases in autism are either reduced or comparable to biases found in non-autistic individuals, with only one study (Ashwin et al., 2005) reporting a larger LVF bias in autism. It is noteworthy that several studies that did not report a reduced LVF bias associated with autism had relatively small sample

sizes (12–16 per comparison group; (Ashwin et al., 2005; English et al., 2018; Rinehart et al., 2002), with one interpretation being that measures of LVF bias may be particularly susceptible to random noise, which has a greater impact when samples are smaller (though the line bisection study had a moderately larger sample of 31–40 participants per comparison group, and also found no differences as a function of autism). Another noteworthy issue is the poor representation of female participants across many studies (several with 0–10% female participants), which further limits the generalisability of any patterns that may have been present across these studies. Interestingly, several studies identified a reduced LVF bias associated with higher levels of autistic traits, suggesting that this individual difference extends beyond clinical 'autism' and into the general population. Next, we will focus on the outcomes specific to each of the four behavioral tasks used to measure LVF bias.

Across the five studies using greyscale stimuli, we recorded seven separate results which were split between showing reduced LVF bias associated with autism (or autistic traits) and no group differences. In addition to the previously noted possible impact of sample size on study outcomes, age may also influence attentional biases on the greyscales task. For adult samples, a significant association between a reduced attentional bias and autism (or autistic traits) was reported for four of the five reports, whilst for the two child samples, there was no significant association between attentional bias and autism or Asperger syndrome.

Regarding the chimeric 'star-field' task, Ashwin et al. (2008) found evidence of *greater* LVF bias in an autistic sample compared to non-autistic controls, while Vladeneu et al. (2012) reported no relationship between autistic traits on the BAPQ and attentional biases on the task. It is possible that differences in attentional bias on this task are apparent only when making clinical versus control group comparisons, and that differences in trait levels do not provide enough separation on the autism spectrum to observe attentional differences. Additionally, it is possible the effect reported by Ashwin et al. (2008) is due to a sex difference given the absence of female participants in this study, and absence of group differences in several other studies with few female participants (Liu et al., 2022; Rinehart et al., 2002) provides converging data. Alternatively, studies with larger sample sizes might yield more consistent outcomes if LVF biases are modest or highly variable. Overall, it is premature to draw strong conclusions from these two studies alone and further work is necessary to understand the differing outcomes that were seen within these studies and differences relative to the study outcomes from other tasks.

Like the findings of the chimeric 'starfield' task, the two landmark task studies had different outcomes. English et al. (2017) found a small effect that was significant at the one-tailed level, with greater levels of LVF bias present in the low autistic-trait group compared to

the high autistic-trait group (comparable to biases on the greyscales task found in the same study). In contrast, the Stettler (2016) study did not find any performance differences as a function of autistic traits. The group comparison design of the English et al. (2017) study may have allowed for greater sensitivity to AQ-related effects than the continuous design used by Stettler (2016) (see Cribb et al., 2016). Like the 'star-field' task, there is not enough data to draw conclusions regarding autism and LVF bias using this task, a point compounded by the fact that only autistic traits, not clinical ASD, have been examined to-date.

Finally, the single study that reported attentional biases using the line bisection task found that both autistic and typically developing children displayed leftward biases of comparable magnitude. The authors also reported that the hand used for the task, and length of the line to be bisected, largely did not produce any differences between groups. Given the broad use of the line bisection task to examine differences in related conditions (e.g., ADHD, schizophrenia), it may be beneficial for additional observations to be made, especially for adult and female individuals who are largely unexamined by the single study reviewed. This may help with making further comparisons across these conditions to identify additional points of similarity or difference.

Studies that examined differences in attentional performance

Four publications were identified that measured attention performance to visual stimuli or stimulus characteristics where the primary outcome measure was accuracy and/or reaction time to specific stimuli presented in either the left or right visual fields (see Table 2 for an overview). For comparison, the studies in the preceding section focused on biases or preferences to either visual field, whilst the studies in this section are more concerned with objective performance measures.

Description of tasks measuring attentional performance

Two studies used a simple reaction task to obtain measures of performance in the left and right visual fields (see Table 2). This task typically required participants to attend to a computer screen with a central fixation cross, following which a visual target would appear in the left or right side of the screen. Participants had to press a response key as soon as possible following the onset of the target. Variations of the task may include additional stimuli, like distractors to be ignored and central targets (Wainwright & Bryson, 1996), or catch-trials without targets (Lodhia et al., 2017), but trials including these conditions are not the subject of the present review. Due to the simple nature of the task, accuracy tends to be high and so reaction time is the primary outcome measure with analyses focused on comparing performance to targets in the left and right visual fields.

One study used the Letter Name Identity Task (Banich & Belger, 1990) to assess attentional performance in the left and right visual fields (see Table 2). The task involves the presentation of two letters at the top of the display, one in each visual field, and a third letter at the bottom of the display in either the left or right visual field. Participants had to quickly decide if the bottom letter matched either of the top letters using two response keys (i.e., match, no match). Performance (accuracy and reaction time) was examined for trials where there was a match, which could occur when the matching letters were both in the LVF, both in the RVF, or across the visual fields, though this review will focus on the outcomes associated with the first two conditions. In separate blocks of trials, participants were required to match letters on simple physical characteristics (e.g., A = A), or on identity (e.g., A = a).

One study used a visual search task to obtain measures of performance in the left and right visual fields (see Table 2). Visual search tasks typically involve participants viewing an array of varying visual stimuli (e.g., simple geometric shapes or letters) consisting of a single target and multiple distractors to be ignored. In versions of the task that have a target present on each trial, participants usually indicate the location of the target once found, whilst in versions where a target is not always present, participants must decide if a target is present or absent. In most cases, reaction time for correct responses is the main outcome. In the study described by Keehn and Joseph (2016), the authors leveraged the varying position of the target across the array to determine if a visual field advantage was present, dividing 'target-present' trials into left and right presentations, and then comparing reaction times.

Outcomes of tasks measuring attentional performance

Looking at the studies that assessed attentional performance together, the overall picture suggests autism is not associated with attentional differences across the visual fields with respect to accuracy and reaction time responses. While control groups in about half of the studies showed measurable levels of LVF advantage, autism groups only displayed a LVF advantage in about a quarter of observations. Only one instance of a reduction in LVF advantage in autism was reported in a study that assessed eye-tracking outcomes during visual search though, arguably, this is a measure of attentional bias and not performance (Keehn & Joseph, 2016). In general, it is not possible to draw any strong conclusions given the relatively small number of studies (and unique samples of

TABLE 2 Descriptions and outcomes of studies identified from the systematic search that examined task performance in the left visual field (LVF) and right visual field separately. Group differences are coded with reference to effect of autism/autistic traits on LVF advantage

Study	Stimuli	Measure	'Autism' group			Control group			Results		
			Sample	N (fem.)	Mean Age (yrs)	Sample	N (fem.)	Mean Age (yrs)	'Autism' group adv.	Control group adv.	Group difference
Simple Reaction Time Task											
Wainwright and Bryson (1996) – Exp. 1	Laterally presented 'crosses'	Reaction time	ASD	10 (0)	23	Chronological Age Match	10 (0)	24	LVF	LVF	None [a]
	-	-	-	-	-	Mental Age Match	10 (0)	12	-	None	None [a]
Lodhia et al. (2017)	Laterally presented 'checkerboards'	Reaction time	ASD	15 [b]	26	Non-ASD	15 [b]	27	None	None	None
Letter Name Identity Task											
O'Keefe & Lindell (2013)	Matching physical characteristics (K=K) of laterally presented letters	Accuracy	High AQ	23 (17)	28 [c]	Low AQ	24 (10)	28 [c]	None	None	Unavail.
		Reaction time	-	-	-	-	-	-	None	None	Unavail.
	Matching identities (A = a) of laterally presented letters	Accuracy	-	-	-	-	-	-	LVF	None	Unavail.
		Reaction time	-	-	-	-	-	-	None	LVF	Unavail.
Visual search task with lateralised targets											
Keehn and Joseph (2016)	Laterally presented 'circle' target embedded in an array of rotated 'C's	Reaction time	ASD	22 (6)	14	Non-ASD	30 (4)	14	None	LVF	None
		First-fixation position [d]	-	-	-	-	-	-	None	LVF	ASD ↓

Abbreviations: AQ, Autism-spectrum Quotient (Baron-Cohen et al., 2001); ASD, Autism Spectrum Disorder; LVF, left visual field.
[a]Assessed as part of an ANOVA that included all three participant samples at once.
[b]Comparison groups matched on sex ratios, but numbers of each sex not reported.
[c]Mean age of entire sample across comparison groups.
[d]Technically attentional *bias* but reported here to keep each study within a single table.

participants) that have been conducted so far. However, with additional work it might be possible to verify the current trend that suggests autism is not associated with differences in attentional asymmetries. Next, we will focus on the outcomes specific to each of the three behavioral tasks used to measure attentional performance.

Regarding studies that examined simple reaction time performance for targets presented in the left or right visual field, it should be noted that only two autistic samples were examined, with the autistic children in Wainwright and Bryson (1996) compared to both chronological and mental age-matched control groups. While both the autistic and chronological age matched groups displayed a LVF advantage, the younger, mental age-matched children did not. Conflictingly, the similarly aged autism group in the study by Lodhia et al. (2017) showed no visual field bias, and neither did their control group. Moreover, neither study found differences in attentional symmetry between the comparison groups. One shortcoming of both studies is the relatively small comparison groups sizes (10–15), and either the absence of female participants (Wainwright & Bryson, 1996), or the absence of specifying participant sex ratios beyond being 'matched' (Lodhia et al., 2017). It is also possible that the task may be overly straightforward and any group differences too small to reliably observe.

Regarding the outcomes from the Letter Name Identity Task used by O'Keefe et al. (2013), it is unfortunate that the results from several separate tests of attentional asymmetry did not clearly converge. Additionally, the authors only reported within-group differences, and thus it is unclear if the two comparison groups differed in attentional asymmetry on any of the four conditions reported. Most group observations indicated an absence of any attentional asymmetry, with LVF advantages only observed in the more difficult identity matching condition, suggesting that a certain amount of cognitive load might be necessary to observe attention asymmetries.

Finally, the observations made using the visual search task used by Keehn and Joseph (2016) uniquely suggest a reduction in attentional asymmetries favoring the LVF in autism. The authors found that reaction times were faster for trials where the target was in the LVF compared to the RVF in their control group, but no such difference was present for the autistic group. However, confounding matters is that between-groups comparisons indicated no significant difference between the two groups. It is difficult to determine why this study produced a different outcome to the others in this section but given that this was also the sole study to recruit a majority female sample, sex differences might play a role. Once again, further work will be needed to establish the reliability of outcomes attributed to the visual search task.

Of note is that the authors recorded eye-tracking measures, specifically visual field first-fixations, during the visual task and reported a compatible pattern of results to those found using reaction time measures (but, unlike the reaction time measures, also significantly differing between the two groups). While eye-tracking outcomes are technically a measure of attentional *bias*, it is a technique that could be theoretically applied to most visual attention tasks, providing additional data to potentially converge with other outcomes, as occurred with this study. Consequently, eye-tracking is one possible way to produce study outcomes that might be interpreted with greater certainty, and also examine possible convergence between asymmetries in attentional bias *and* performance.

DISCUSSION

Overview

Differences in perceptual and attentional ability between individuals with and without autism have been studied extensively over the years. While some perceptual aspects, like central coherence, have been explored in depth and have been subject to several reviews (Happé & Frith, 2006; Mottron & Burack, 2001), others have largely gone unexamined. One such area, and the focus of the current review, is alterations of attentional biases across the visual field in autism. These biases are particularly interesting because they are a potential indicator of atypical hemispheric specialization. Most neurotypical individuals display a small attentional bias towards stimulus features presented in the LVF, which is believed to be a consequence of specialization of spatial processing to the right hemisphere (Bowers & Heilman, 1980; Heilman, 1995; Hellige, 1993). Conversely, a review by Ribolsi et al. (2015) suggests that individuals with neurodevelopmental disorders, such as schizophrenia and ADHD, show evidence of a lack of, or rightward, attentional bias on a line bisection task. The aim of our literature review was to determine whether autism is also associated with alterations in attentional symmetries.

Review findings

Our review found 13 different publications that reported on links between attentional biases and autism or autistic traits. Taking the 'big picture' perspective of the studies examined in this review, there appears to be a difference in outcomes between studies that examine attentional *bias or preference* (i.e., subjective responses to lateralised stimulus features) and those that looked at attentional *performance* (i.e., reaction time and accuracy to lateralised target stimuli).

Specifically, regarding attentional *preference*, there is tentative evidence that autism is associated with a small reduction in the left visual field bias (i.e., pseudoneglect) typically observed in members of the general population. Five of the nine studies reviewed in this section reported

at least one statistical test in support of this outcome, whilst the converse (*greater* LVF bias associated with autism) was reported in just one study (Ashwin et al., 2005). Such a conclusion could be considered in line with the patterns previously reported by Ribolsi et al. (2015), who noted a general tendency for neurodevelopmental conditions (other than autism which was absent from Ribolsi and colleagues' review) to be associated with reduced leftward biases. This view would also be compatible with existing research suggesting that autism is associated with reduced lateralisation for other key functions, such as language and verbal ability (Hollier et al., 2014; Jouravlev et al., 2020).

However, it is difficult to argue that a similar pattern exists, even tentatively, across the studies that examined attentional *performance*. Ignoring the eye-tracking result that was found as part of the visual search study conducted by Keehn and Joseph (2016) (as this is technically attentional *bias*), none of the four studies reported evidence of alterations in attention towards either visual field as a function of autism. While Keehn and Joseph (2016) did find a LVF advantage for visual search reaction time in their control sample that was absent in their autistic sample, this group difference was not significant. A similar pattern was evident in the Letter Name Identity Task (O'Keefe et al., 2013), where participants with lower levels of autistic traits showed a LVF advantage that was absent in participants with higher levels of autistic traits. No evidence was shown for a statistical difference in performance between the groups.

Presuming that an actual difference exists in asymmetries in attentional *bias* and attentional *performance* as a function of autism, what possible explanation could account for this difference? Perhaps a clue can be taken from research into global and local processing differences in autism. Originally, it was suggested that autistic individuals' superior local processing ability was a trade-off for poorer global processing performance (Frith, 1989). More recent work indicates that local processing may simply be the preferred processing style for autistic individuals, with global processing ability remaining intact (Happé & Frith, 2006; Mottron et al., 2006). Specifically, some studies have shown that when instructed, or due to task demands, autistic individuals are as adept at using global processing strategies as non-autistic individuals (Plaisted et al., 1999). In relation to attentional asymmetries, a similar pattern occurs where, when participant responses are relatively subjective (e.g., which rectangle is darker?), individual differences in attentional biases are observable, but the presence of explicit task demands (e.g., respond quickly to targets) overrides any attentional preference to a particular visual field.

Another possibility relates to the nature of the stimuli used. In the studies examining attentional *bias*, participants typically had to attend to a stimulus or stimuli that spanned both visual fields (e.g., a centrally-presented line to bisect, a large visual search array), whilst most of the attentional *performance* type studies had stimulus presentations where a single target would appear in a specific visual field which could be quickly attended to due to the absence of other stimulus features presented in the other visual field. In other words, autistic differences in attentional asymmetry only arise when task demands require a relatively broad spread of attention.

However, we should highlight that these interpretations are drawn from a limited number of studies (especially regarding the attentional *performance* cluster of studies), where most comparison groups were relatively small (e.g., less than 20 participants per group) and often heavily dominated by males. While this, and other factors that we will discuss below, limit the ability to draw conclusive patterns from the studies reviewed and generalize the described data patterns, the review does highlight areas requiring further attention for future research.

Future directions

Participant sampling

A concern affecting many studies regards participant sampling. In addition to the issue of small sample sizes mentioned earlier, numerous studies showed significant under-representation of female participants. This is problematic given the growing understanding that autism may present differently between males and females (Hull et al., 2020), rather than simply being a neurodevelopmental disorder that primarily effects males. Four studies reviewed included participant groups with minimal (<25% of the sample) or no female participants which limits the generalisability of the respective study outcomes. To a lesser degree, several studies observing group differences as a function of autistic traits were imbalanced, with the 'low' autistic trait groups often having greater female representation than the 'high' autistic trait group.

The results of Jewell and McCourt (2000)'s meta-analysis of studies using the line bisection task to index attentional biases suggests that there are slightly stronger levels of leftward bias in males compared to females. This sex difference has been paralleled in other measures such as visual search, where male participants' target detection accuracy is strongest when targets are presented in the LVF, while female participants performance is more even across the visual fields (English et al., 2021). Such differences have been linked to suggestions that the brain is more asymmetrically organized in males than females (Heilman, 1995; Hellige, 1993; Ocklenburg & Güntürkün, 2017), and thus the potential exists for a greater reduction in leftward bias in autistic males compared to autistic females. Limited work has attempted to address this question. For example, English et al. (2015, 2017) reported no interaction between sex and autistic-trait group (Low vs High AQ) on biases observed using

the greyscales or landmark tasks. However, we did not identify any studies using clinical samples that examined this issue (although most clinical samples reviewed would have been underpowered). Consequently, it is important that the two sexes are equally represented in future work to be able to discriminate between LVF bias differences attributable to sex and autism.

Methodological consistency

Substantial variation in study design and materials was noted across the reviewed studies, even within studies that were grouped together based on common methodology. Regarding the studies using greyscales stimuli, despite the stimuli being relatively standardized across studies, there was variation as to whether they were equiluminant (mirrored, and thus no 'correct' answer as to which was darker) or non-equiluminant and whether the stimuli were presented using a printed paper or computerized format which may have influenced outcomes in unknown ways. We would recommend that future researchers use non-equiluminant stimuli so that accuracy might also be assessed, enabling researchers to identify participants performing at chance level and therefore likely to be disengaged with the task. Outcomes using the greyscales task tended to be consistent, perhaps owing to the consistency of the stimuli used.

The two studies that examined biases on the landmark task used slightly different test stimuli with participants judging bisections in plain rectangles in the English et al. (2017) study and a patterned rectangle in the Stettler (2016) study. While the tasks are conceptually identical, the different stimuli used might also affect the biases elicited. Interestingly, despite prevalent use in other fields, the line bisection task was only found to have been used once to examine attentional biases in autism. The simple nature of the task and stimuli make this design easy to administer in a consistent manner, and so we would recommend greater use of this task in the future. To reduce the influence of statistical 'noise' attributable to differences in experimental methodology, it is recommended that future work attempt to maintain consistency with previous designs as much as feasible.

Most of the research-to-date has assumed that a single mechanism is responsible for individual variations in bias across the many tasks that measure it, and that biases obtained from a given task may inform expected biases on another. However, no study to our knowledge has investigated the extent to which differences in attentional bias as a function of autism obtained from different, but notionally comparable, tasks are similar (e.g., LVF bias obtained using landmark and greyscales tasks). Administering multiple lateralisation tasks within a single study with the intent to determine if lateralisation differences are maintained across different measures would assist in assessing the reliability of future outcomes.

Attentional asymmetries when viewing faces

While reviewing studies that examined attentional biases towards faces was beyond the scope of the current review. It is noteworthy that several studies have explored if attentional biases towards faces differ between autistic and non-autistic individuals. Interestingly, studies have reported patterns suggestive of reduced attentional bias towards the left side of face stimuli in autism with relative consistent findings being reported using eye-tracking outcomes such as overall fixation duration and initial fixation position (Dundas, Best, et al., 2012; Dundas, Gastgeb, et al., 2012; Guillon et al., 2014), and less consistent results found using chimeric face tasks (Ashwin et al., 2005; Rinehart et al., 2002; Taylor et al., 2012). However, it is important to note that due to face processing being lateralised, it is difficult to establish if any alterations in attentional biases linked to autism are the result of altered hemispheric lateralisation for face processing, visuospatial processing more generally, or some combination of both. Nonetheless, it would be interesting to determine to what extent that altered attentional asymmetries for face and non-face stimuli might overlap, and if a common mechanism is responsible. Finally, given the relatively consistent outcomes from eye-tracking studies using face stimuli, it would be interesting to see if outcomes were similarly consistent across eye-tracking studies using non-face stimuli.

Review limitations

While the aim of the present review was to cast a purposefully wide net to identify as many study designs as possible that have examined differences in attentional bias as a function of autism, the approach is not without drawbacks. The most pertinent issue we faced was trying to draw conclusions across a range of study designs. We attempted to offset this challenge by grouping studies into smaller clusters that were more conceptually comparable prior to examining individual study outcomes.

An associated problem that arises when clustering small numbers of studies together is the need to compromise on separating certain study characteristics. For example, given the small number of studies that administered each task included in the review, we elected to forgo detailed explorations of variations in certain experimental factors such as task timing or stimulus display durations. Additionally, we chose to pool together studies that examined neurotypical participants who differed in levels of subclinical autistic traits and studies that compared individuals with and without clinical diagnoses of autism. Whilst outcomes of studies that have compared autistic and non-autistic, and high and low autistic-trait, samples generally result in comparable outcomes (Landry & Chouinard, 2016), and examination of the findings reported in this review does not indicate any patterns of strong differences arising from the use of clinical

or non-clinical participants, it remains a factor that should be considered in future work. Furthermore, though it is reasonable to consider these two bodies of work together for a broad review like in the present investigation, this diversity in design is not conducive to conducting meta-analyses, which would provide a much clearer picture regarding any potential pattern of study outcomes.

Similarly, distinctions were not made based on demographic factors such as age and sex. For example, if autistic and non-autistic individuals differ in attentional biases, it is also possible that the magnitude of this difference changes across the lifespan, or on the basis of sex. Such alterations in attentional bias are not without precedent as a previous meta-analysis of line bisection performance in neurotypical individuals demonstrated a decrease in pseudoneglect with increasing age, as well slight elevation in pseudoneglect in males compared to females (Jewell & McCourt, 2000). Accordingly, additional studies that explicitly aim to examine the additional effects of age and sex, in addition to autism, are necessary to understand the extent to which individuals differ in their attentional biases.

Conclusion

To summarize, our review of the literature revealed that a number of studies have investigated the possibility of atypical attentional asymmetries as a function of autism diagnosis or autistic traits. Despite mixed methodologies and conflicting findings, we believe there is tentative evidence to suggest that the typical *bias* towards visual stimulus features presented in the left visual field may be reduced in autism. Conversely, for tasks that compare attentional *performance* to visual targets presented in the different visual fields, no alterations associated with autism appear to be present. However, further work is needed to verify the reliability of these outcomes. Specifically, we suggest that future work focus on conducting sufficiently powered studies to maximize the reliability of LVF bias outcomes and ensure equal representation of male and female participants. The examination of multiple measures of LVF bias will also help to determine if LVF bias differences are broad or narrow (i.e., task specific). It is our hope that this review will aid future researchers in this area by drawing together all the relevant studies into a single reference, and that this may create a solid foundation upon which to extend this body of work.

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