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Autistic traits are associated with enhanced working memory capacity for abstract visual stimuli

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ABSTRACT

We tested whether the association between autistic traits and enhanced performance in visual-perceptual tasks extends to visual working memory capacity. We predicted that any positive effect of autistic traits on visual working memory performance would be greatest during domain-specific tasks, in which visual resources must be relied upon. We used a visual 'matrix' task, involving recall of black-and-white chequered patterns which increased in size, to establish participants' capacity (span). We assessed 144 young adults' ($M = 22.0$ years, $SD = 2.5$) performance on abstract, 'low semantic' versus 'high semantic' task versions. The latter offered multimodal coding due to the availability of long-term memory resources that could supplement visual working memory. Participants also completed measures of autistic traits and trait anxiety. Autistic traits, especially Attention to Detail, Attention Switching, and Communication, positively predicted visual working memory capacity, specifically in the low semantic task, which relies on visual working memory resources. Autistic traits are therefore associated with enhanced processing and recall of visual information. The benefit is removed, however, when multimodal coding may be incorporated, emphasising the visual nature of the benefit. Strengths in focused attention to detail therefore appear to benefit domain-specific visual working memory task performance.

1. Introduction

Working memory is a limited capacity cognitive system for the processing and temporary storage of information over periods of seconds (e.g. Baddeley et al., 2021; Cowan et al., 2021), and may be thought of as a mental workspace (Logie, 2011). Generally, the interactive use of working memory and/or long-term memory resources (i.e. semantics, or stored knowledge) can help to maximise working memory capacity. This is because verbalisable, more meaningful visual information may be better retained than abstract material that relies more specifically on visual processing and storage (Brown et al., 2006; Brown & Wesley, 2013). Autistic traits are related to perception and cognition and are positively associated with lower-level aspects of visual information processing (Fugard et al., 2011; Grinter et al., 2009; Stewart et al., 2009). The relationship between autistic traits and visual working memory capacity is less well understood, particularly regarding the interface of visual working memory and long-term memory resources (Hamilton, Mammarella, et al., 2018). The positive relationship observed for visual processing may indeed be sustained at the working memory level (Hamilton, Mammarella, et al., 2018; Richmond et al., 2013), but the potential nuances of this relationship need to be clarified, particularly in young adults. The present research aimed to assess whether a relationship exists between autistic traits and visual working memory capacity, and whether this is dependent on the abstractness of the stimuli.

1.1. Visual working memory

Working memory comprises a combination of functions, including attention and short-term (moment-to-moment) information processing and storage (Baddeley et al., 2019; Baddeley et al., 2021; Cowan, 2017; Cowan et al., 2021). Multiple component models conceive of a number of specialised working memory mechanisms: the central executive for attention-related functions such as focusing and shifting attention, inhibiting information, and active development and use of strategies; the phonological loop for verbal-based information processing and storage; the visuospatial sketchpad for processing and storage of visual and spatial material; and the episodic buffer for storing multimodal representations derived from the latter specialised working memory components and/or long-term memory (Baddeley, 2007, 2012; Darling et al.,

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2017; Logie, 2011).

The storage capacity of working memory is generally limited to approximately 3–5 'chunks' of information (Cowan, 2010), but this may be increased by drawing upon multiple resources. For example, capacity for letter or word sequences is improved when they are chunked into sets of shorter sequences, and via semantic relatedness amongst items (Cowan et al., 2012; Thalmann et al., 2019). Digit sequences are also better recalled when they are displayed via a standard keypad layout, benefiting from spatial knowledge at encoding (Darling et al., 2017). Likewise, when stimuli may be encoded via both verbal and visual codes, memory performance improves (i.e. dual coding; Paivio, 1971, 1991; see also Bower et al., 1975; Ensor, Bancroft, et al., 2019; Ensor, Surprenant, et al., 2019). For example, more 'concrete' words, which are more amenable to corresponding mental images, are better recalled than abstract words (Paivio & Csapo, 1969).

Regarding visual working memory performance, greater availability of verbalisable, more meaningful content, is associated with increased capacity (Postle et al., 2005; Postle & Hamidi, 2007). For instance, capacity to recall abstract visual stimuli such as Chinese characters or black-and-white matrix (chequered) patterns is boosted when they can be associated with meaningful words, symbols, everyday objects and animals, and so on (Brown et al., 2006; Riby & Orme, 2013; Verhaeghen et al., 2006). The extent to which this is due to verbalisation and/or semantic activation is unclear (Postle et al., 2005). However, Brown and Wesley (2013) found that the benefit of 'semantic availability' in working memory for visual matrix patterns was abolished when central executive resources were taxed using a secondary random spatial tapping task (and not repetitive tapping). This suggests that an active, attentional mechanism is involved.

An individual's strategic approach is related to their visual working memory capacity (see Gonthier, 2021, for a review). Young adults who report spontaneously having 'combined' verbal and visual strategies during task performance exhibit increased visual working memory capacity (Brown & Wesley, 2013; Nicholls & English, 2020). However, there are also individual differences in the extent to which availability of multimodal coding can boost performance. For example, while young adults consistently benefit from availability of semantics in a visual matrix task (i.e. 'high semantic'/more meaningful vs 'low semantic'/less meaningful stimuli), older adults do not (Hamilton, Brown, et al., 2018; Nicholls & English, 2020). This may depend on availability of resources and individual ability to implement particular strategies (Nyberg et al., 2003). One line of research has varied the semantic availability in visual matrix patterns, which are generally considered relatively abstract stimuli overall. However, high semantic patterns are more likely than low semantic patterns to resemble symbols, letters, objects, animals, etc. In young adults, high semantic availability benefits those with a lower overall capacity, and who generally report only concentrating on refreshing the visual image, rather than spontaneously incorporating verbal-based strategies (Brown & Wesley, 2013; Orme et al., 2017). This is probably because automatic (as opposed to strategic) activation of semantics (Logie, 2011; Mazard et al., 2005; Postle et al., 2005) is more likely to occur during encoding of high vs low semantic patterns. Once activated, semantics can be used actively and integrated with the visual codes to benefit recall. Furthermore, as strategy 'combiners' (i.e. those who spontaneously report using both visual and verbal strategies) perform relatively well when using both low and high semantic patterns, they may 'seek out' meaning in a more strategic, active fashion, boosting performance, even for low semantic patterns, and improving capacity overall. Semantic availability therefore consistently benefits young adults' visual working memory capacity. Importantly, this may draw upon central executive resources at encoding, for those actively using non-visual strategies, and at maintenance and/or recall for all participants to integrate and use activated semantics, regardless of whether the semantics were activated strategically or automatically via the properties of the stimuli.

1.2. Autistic traits and visual cognition

While the role of multimodal resources in visual working memory has received some general attention in the literature, it is important to investigate the potential role of variance in visual processing abilities, and autistic traits are one potential source of variance (Hamilton, Mammarella, et al., 2018). Autistic trait measures assess social and communication skills, attention-switching, imagination, and attention to detail (e.g. Autism-Spectrum Quotient (AQ), Baron-Cohen et al., 2001). Those who score high on autistic traits tend to exhibit focused attention/reduced attention switching, greater attention to detail, and an emphasis on concrete rather than imaginative thinking. There are differences in social skills, preferences, and communication such that, for high AQ scorers, group interactions, social chitchat, and meeting new people is typically challenging. Autistic individuals and those measuring high on autistic traits have demonstrated a tendency for more efficient visual processing in tasks such as embedded figures and modified block design (e.g. Grinter et al., 2009; Muth et al., 2014; Stewart et al., 2009), which have similar properties to the visual matrix tasks often used to assess visual working memory. This enhanced performance may be due to differences in integrating information, bottom-up processing, and an absence of interference (Foxton et al., 2003; Grinter et al., 2009; Kasai & Murohashi, 2013; Stewart & Ota, 2008).

Autistic traits were also associated with using a visuospatial rather than a verbal-analytic strategy when processing visual problems from the Raven's Advanced Progressive Matrices (Fugard et al., 2011). The Raven's Matrices can be solved using different strategies (e.g. Carpenter et al., 1990; DeShon et al., 1995) which have been broadly sorted into two categories, visuospatial and verbal-analytic. Items can be solved using strategies from one or both categories. Fugard et al. (2011) found that participants scoring high on the AQ (Baron-Cohen et al., 2001) were more accurate on items which required visuospatial strategies alone, relative to verbal-analytic items, and also than items requiring both verbal-analytic and visuospatial strategies, or items that could be solved by either strategy. Potential limitations in aspects of executive resources have been shown both in autistic people and those with a high autistic traits score, which could provide an explanation for some of the differences found in visuospatial processing (Christ et al., 2010; Demetriou et al., 2018; Ferraro et al., 2018; Hill, 2004; Wong et al., 2006).

Associations have also been found between visual working memory performance and autistic traits in children (Hamilton, Mammarella, et al., 2018) and young adults (Richmond et al., 2013, though not for verbal working memory). In the latter study, the Attention to Detail subscale was positively associated with visual working memory capacity, whereas Social Skill was negatively associated with performance, showing opposing relationships across specific AQ subscales (Baron-Cohen et al., 2001). However, to our knowledge, only one study has investigated the relationship between autistic traits and visual working memory tasks in which the involvement of different cognitive resources is varied. Mammarella et al. (2014) investigated visual working memory performance in autistic and non-autistic children. They used Riby and Orme's (2013) stimuli which vary semantic availability, based on the modified Visual Patterns Test (Brown et al., 2006), the stimuli used in the current study. A significant overall positive effect of semantics was found only in the non-autistic children, suggesting that autistic children were not as able to take advantage of long-term memory resources to boost performance. However, autistic children performed better than non-autistic children on low complexity (i.e. the smallest), low semantic stimuli, presumably where specific visual details could be focused upon.

Strategic approach in visual working memory appears to be influenced by availability and efficacy of the various working memory resources (e.g. Brown & Wesley, 2013; Orme et al., 2017), including visual, verbal, and central executive processing resources. It is possible that autistic traits may be associated with enhanced use of visual processing resources to focus on visual details, which could result in enhanced visual working memory capacity. However, this is more likely to be the case in a low semantic visual working memory task, where the use of, and integration across, working memory mechanisms is more limited and activation of semantics could occur less automatically.

1.3. Anxiety and cognition

Research on autistic traits rarely takes into account factors such as anxiety, which may also influence visual processing (Eysenck, 1992). Rates of anxiety disorders tend to be high in autistic people, and autistic traits correlate highly with anxiety symptoms and trait anxiety (Freeth et al., 2013; Liew et al., 2015). Although highly correlated, opposing effects of autistic and anxiety traits have been found on social cognitive tasks (e.g. English et al., 2019; Dickter et al., 2018). Furthermore, both trait and state anxiety are known to affect aspects of working memory and visual processing. A meta-analysis of 177 samples ($N = 22{,}061$ individuals) showed that self-reported anxiety was related to poorer working memory capacity (Moran, 2016). Theoretically, trait and state anxiety interact to produce decrements in working memory performance by limiting top-down attention/executive control, and enhancing bottom-up/stimulus-driven attention to increase vigilance (e.g. Calvo et al., 1992; Eysenck et al., 2007; Eysenck & Derakshan, 2011). Trait anxiety therefore affects attention, particularly under situational stress, which elevates state anxiety and attention-demanding worry. The extent to which anxiety impacts visual working memory is less clear, and more research is needed (Moran, 2016). Interestingly, anxiety can positively influence perception, and is related to enhancement in perceptual attention and visual detection or search tasks (Berggren et al., 2015; Eysenck et al., 2007; see also Moriya, 2018). Yet, negative impacts of anxiety on visual working memory efficiency (correct response times) and effectiveness (accuracy) have also been observed (e.g. Spalding et al., 2021). This highlights the need to consider anxiety alongside autistic traits in the present research.

1.4. Summary and hypothesis

We tested whether autistic traits would influence visual working memory performance, and hypothesised a positive relationship due to more efficient visual processing. This relationship was predicted to be most evident in a low semantic task, which relies more exclusively on visual processing, as compared with a high semantic task, which can more readily incorporate wider cognitive resources, especially long-term memory (i.e. meaning/familiarity). Finally, given the relationship between anxiety and autistic traits, and the potential effects of anxiety on visual working memory more generally, we controlled for trait anxiety in our analyses.

2. Methods

2.1. Design

A correlational design, controlling for gender, years of education, and trait anxiety (e.g. Baron-Cohen et al., 2001; Mammarella et al., 2014; Nicholls & English, 2020) was used to identify the extent to which autistic traits might predict visual working memory capacity. This was measured across two task versions varying in semantic availability (low or high).

2.2. Participants

Prior to commencement of data collection, ethical approval was received. There were 144 participants; 75 identified as male, 68 as female, and 1 responded 'other/prefer not to say'. The mean age was 22.0 years ($SD = 2.5$; min = 18, max = 33) and the mean years of education was 16.4 ($SD = 1.7$). Participants were recruited via a University participation panel, local advertising, and word of mouth. A G*Power analysis (Faul et al., 2007) showed that, for a regression analysis with three covariates and one tested predictor, a sample size of 89 is required to detect a medium effect size ($f^2 = 0.15$; $\alpha = 0.05$; power = 0.95).

2.3. Materials

2.3.1. Visual working memory task

The modified version of Della Sala et al.'s (1997; see also Della Sala et al., 1999) Visual Patterns Test (VPT) was used to assess visual working memory capacity ('span'). This comprised two task versions based on two sets of black and white matrix (chequered) stimuli. While all stimuli were relatively abstract matrix patterns, one stimulus set was more limited in the availability of meaningful verbal codes than the other (Brown et al., 2006; see Fig. 1). Aside from this difference, each task version used the same procedure, which was broadly the same as the original published test (Della Sala et al., 1997). The task was computerised and administered using E-Prime 2.0 (Psychology Software Tools, Inc.) in order to control presentation and timings.

2.3.2. Autistic traits

The Autism-Spectrum Quotient (Baron-Cohen et al., 2001) was used to measure autistic traits. The AQ is a 50 item self-report questionnaire which comprises five subscales: Social Skill (e.g. 'I find social situations easy'); Communication (e.g. 'I know how to tell if someone listening to me is getting bored'); Imagination (e.g. 'When I'm reading a story, I can easily imagine what the characters might look like'); Attention to Detail (e.g. 'I tend to notice details that others do not'); and Attention Switching (e.g. 'I frequently get so strongly absorbed in one thing that I lose sight of other things'). Half of the items are worded to elicit an 'agree' response and the other half, a 'disagree' response. Items were scored on a 4-point Likert scale ('definitely agree' – 'slightly agree' – 'slightly disagree' - 'definitely disagree') to increase the scale's sensitivity (e.g. Fugard et al., 2011). The AQ total scores ranged from 50 to 200, with a higher score indicating greater autistic traits.

2.3.3. Anxiety

The State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree et al., 2008) was used to gain measures of both the cognitive and somatic dimensions of trait anxiety. The STICSA includes one trait anxiety questionnaire (how often, in general, statements are true of participants; 1 = 'almost never' to 4 = 'almost always') and one for state anxiety (how participants feel right now, at this very moment, even if this is not how they usually feel; 1 = 'not at all' to 4 = 'very much so'). Within each scale, the 10 cognitive items include 'I can't get some thought out of my mind' (scores range from 10 to 40) and the 11 somatic items include 'my heart beats fast' (scores range from 11 to 44). Higher scores indicate higher anxiety. The STICSA has been shown to be highly reliable and to have excellent validity in both control and patient populations (Grös et al., 2007).

2.4. Procedure

After providing written informed consent, participants completed a brief demographic questionnaire followed by the STICSA (Ree et al., 2008) then the AQ (Baron-Cohen et al., 2001). The low and high semantic versions of the modified VPT (Brown et al., 2006) were then administered in a counterbalanced order across participants. A given trial was initiated by participants pressing the space bar and being presented with a fixation cross in the centre of the screen for 1500 ms. This was replaced by a pattern for 3 s (displayed on a white background). After a retention interval of 10 s during which participants were asked to continue viewing the blank (white) screen, the word 'recall' was presented. Participants were asked to recall the patterns using blank paper templates, by crossing out the cells that they believed to have been black. There was no time limit for recall (Brown et al., 2006; Della Sala et al., 1997). For each task version, following three practice trials, three patterns were administered at each of the levels

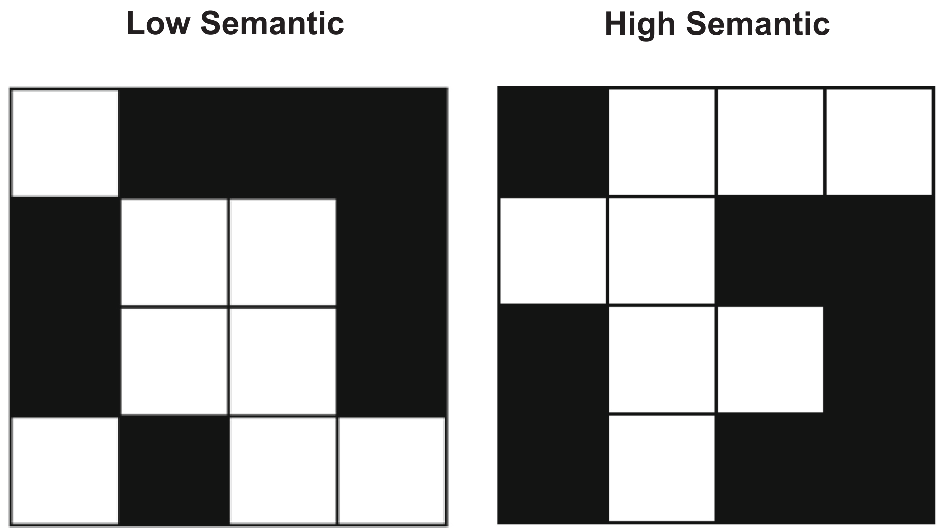

Fig. 1. Sample stimuli from the low and high semantic versions of the modified Visual Patterns Test (Brown et al., 2006). Participants are more likely to identify meaningful shapes within the black or white cells of the high semantic stimuli. In this example an 'i', 'back-to-front c', or an 'F' are some meaningful sub-patterns that previous participants could identify. Both stimuli are taken from level of complexity 8 (8 filled cells to recall).

four to fifteen, with reference to the number of black cells to be retained. Each task continued until participants could no longer reliably recall the patterns (i.e. no patterns fully correct at a given level). The 'mean span' score for each VPT version was the mean size of the last three correctly recalled patterns, which is more sensitive than absolute span. After completing the first task version, a short break was offered to participants before progressing to the second one. Upon completion of the VPT, participants were debriefed.

3. Results

Descriptive statistics and correlations amongst the key variables are shown in Table 1. As expected, capacity was lower in the low vs high semantic visual working memory task, $t(142) = -5.18$, $p < .001$. Furthermore, the low and high semantic visual working memory tasks exhibited a moderate-large correlation ($r = 0.64$, $p < .001$), reflecting a strong relationship, but some independence between the two, as expected. The sample was quite young, so a correlation between age and the working memory tasks was not necessarily expected, and indeed was negligible. Participants varied in their years of education, which correlated significantly with age, and negatively with trait somatic anxiety. However, there was no relationship between years of education and the working memory tasks (all $p > .095$).

As predicted, there was a small correlation between AQ and the low semantic visual working memory task ($r = 0.20$, $p = .019$), but no correlation with the high semantic task ($r = 0.08$, $p = .32$; see Fig. 2). There were no significant correlations amongst the working memory capacity and anxiety measures (all $p > .51$). However, as expected, AQ showed small-moderate correlations with all trait anxiety measures.

A hierarchical linear regression was conducted to examine whether autistic traits was a predictor of low semantic visual working memory capacity, controlling for gender, trait anxiety, and years of education, based on the data presented in Table 1. Gender was included as a dummy variable (male or female). For the first block of the analysis, the control variables of gender, trait anxiety, and years of education were analysed. This model was not statistically significant, $F(3,139) = 1.98$, $MSE = 3.13$, $p = .12$. For the second block, AQ was added, revealing a statistically significant model, $F(4,138) = 3.48$, $MSE = 2.99$, $p = .010$, $R^2 = 0.092$, adjusted $R^2 = 0.065$ (see Table 2). The same model for high semantic task performance was not significant, $F(4,138) = 1.76$, $MSE = 4.21$, $p = .14$, adjusted $R^2 = 0.021$.

As a secondary objective, we explored the relationship between autistic traits and visual working memory task performance according to AQ subscale. There were no significant correlations between high semantic task performance and any of the AQ subscales (all $r < 0.13$, all $p > .146$). There were also no correlations between low semantic task performance and the Social Skill or Imagination subscales (all $r < 0.09$, $p > .32$). The relationship between low semantic task performance and Attention to Detail showed a higher correlation size, but was not significant ($r = 0.15$, $p = .081$). However, Attention Switching ($r = 0.19$, p

Table 1
Descriptive statistics and Pearson's correlations related to demographic data, visual working memory performance across low and high semantic tasks, autistic traits, and trait anxiety.

	M (*SD*)	Min-max	1	2	3	4	5	6	7	8
1. Age	21.99 (2.49)	18–33	–							
2. Gender	–	–	−0.12	–						
3. Years of education	16.39 (1.72)	11–22	0.36***	−0.06	–					
4. Low semantic	9.05 (1.79)	4.67–14.67	−0.01	−0.15	0.14	–				
5. High semantic	9.77 (2.07)	5.00–14.67	−0.10	−0.16	0.13	0.64***	–			
6. AQ	107.39 (13.83)	78.00–151.00	−0.14	−0.03	−0.14	0.20*	0.08	–		
7. Total trait anxiety	39.41 (9.20)	22.00–64.00	−0.17*	0.27**	−0.16	−0.03	−0.04	0.45***	–	
8. Trait cognitive anxiety	21.69 (6.05)	11.00–36.00	−0.12	0.22**	−0.10	−0.05	−0.06	0.44***	0.93***	–
9. Trait somatic anxiety	17.72 (4.28)	11.00–32.00	−0.20*	0.26**	−0.21*	−0.01	0.00	0.35***	0.84***	0.58***

Note. $N = 143$ (including all participants identifying as male (0) or female (1)).
[*] $p < .05$.
[**] $p < .01$.
[***] $p < .001$.

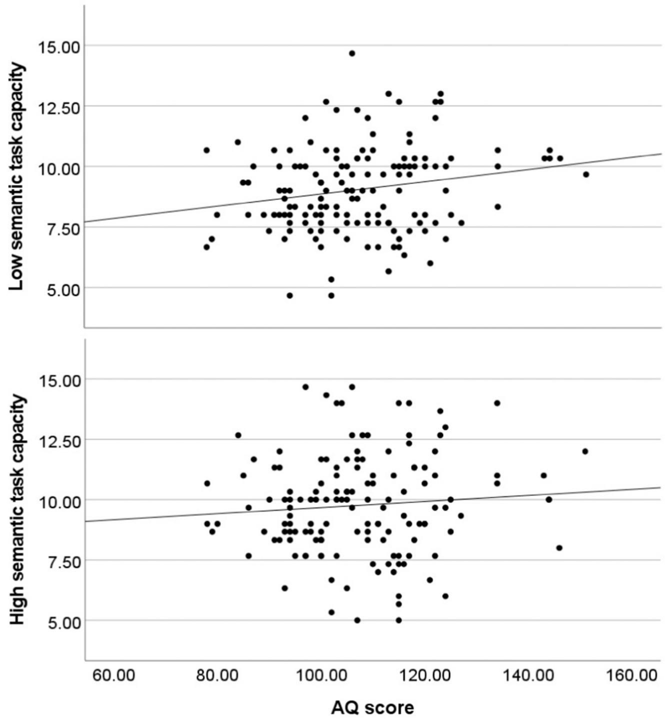

Fig. 2. Scatterplots illustrating the relationship between AQ score and low (top) vs high (bottom) semantic visual working memory task performance.

= .025) and Communication (r = 0.17, p = .048) showed significant relationships. We then followed up the significant regression model for low semantic task performance, replacing overall AQ with the subscales. Results were significant, and similar to the model using overall AQ, when using the Attention to Detail subscale, F(4,138) = 2.63, MSE = 3.05, p = .037, adjusted R^2 = 0.044, the Attention Switching subscale, F(4,138) = 3.23, MSE = 3.01, p = .014, adjusted R^2 = 0.059, and the Communication subscale, F(4,138) = 2.74, MSE = 3.05, p = .031, adjusted R^2 = 0.047 (see Table 3). However, the models using Social Skill and Imagination were not significant (all F < 1.84, all p > .12).

4. Discussion

This study investigated whether, due to enhanced processing of visual details, autistic traits, as measured by the Autism-Spectrum Quotient (AQ; Baron-Cohen et al., 2001), would be associated with increased visual working memory capacity. We assessed relationships between AQ and an abstract, 'low semantic' visual working memory task, in which visual processing and temporary storage must be relied upon to a greater extent than with a relatively 'high semantic' task. While still generally an abstract task, the high semantic task offered greater opportunity for supportive use of additional cognitive resources, especially long-term memory. This was expected to render any relative strengths in visual processing less beneficial, and therefore to be less likely to demonstrate an effect of autistic traits. The present findings support the hypothesis that higher autistic traits, especially regarding Attention to Detail, Attention Switching, and Communication, are positively associated with visual working memory capacity. However, this is specifically when stimuli have low semantic availability and rely more exclusively on processing and storage of visual details.

4.1. *The role of semantics in visual working memory*

Visual working memory tasks with greater availability of non-visual codes, including stimuli that can be verbalised more readily and resemble more meaningful shapes or patterns, result in increased capacity relative to tasks comprising more abstract patterns (Brown & Wesley, 2013; Hamilton, Brown, et al., 2018; Mammarella et al., 2014; Nicholls & English, 2020; Postle & Hamidi, 2007; Orme et al., 2017; Riby & Orme, 2013). This is understood to be due to the stimuli activating long-term knowledge that can support temporary storage of visual images. While verbal coding is itself associated with enhanced visual working memory performance (Forsberg et al., 2020; Plaska et al., 2022; Souza & Skóra, 2017), the activation of semantics and use of familiarity appears to be the key source of support for working memory (Brown & Wesley, 2013; see also Bower et al., 1975; Kowialiewski et al., 2021; Souza & Skóra, 2017; Verhaeghen et al., 2006).

It is important to note that verbal coding and rehearsal may be more beneficial for particular populations, such as older adults (Forsberg et al., 2020; Nicholls & English, 2020). This demonstrates that availability of multimodal codes is only beneficial if individuals are able to make use of them, and central executive resources are likely important for this. In addition to relatively automatic recognition of familiar shapes, which is more likely with the high semantic patterns, central executive resources can be used to develop strategies to help support visual working memory generally (Logie, 2011). These can include actively seeking out meaning or verbal recoding of visual material, and there are clear individual differences in this respect. Brown and Wesley (2013) showed that young adults who reported more active combining of strategies performed better overall, especially in the more challenging low semantic task. However, central executive suppression (via a random generation task) abolished the effect of semantic availability. This suggests that even automatically activated semantics (as opposed to semantics actively sought out via a semantic strategy) appear to require executive resources. This would be for attending to and engaging with the activated semantics, elaborating on them, and/or combining them with the temporary visual codes that are to be recalled (see also Riby & Orme, 2013). As an example, older adults show reliably poorer visual working memory capacity than young adults, and report focusing to a

Table 2
Linear regression models predicting visual working memory in low and high semantic tasks.

	Unstandardised coefficients		Standardised coefficients	
	B	*SE*	*β*	*t (p)*
Low semantic task				
Gender	−3.94	0.305	−0.110	−1.29 (0.199)
Years of education	0.160	0.086	0.154	1.86 (0.064)
Trait anxiety	−0.018	0.019	−0.095	−0.99 (0.326)
AQ	0.033	0.012	0.256	2.77 (0.006)
High semantic task				
Gender	−0.580	0.362	−0.140	−1.60 (0.111)
Years of education	0.155	0.102	0.128	1.52 (0.132)
Trait anxiety	−0.006	0.022	−0.027	−0.28 (0.782)
AQ	0.016	0.014	0.110	1.17 (0.247)

Note. Gender, years of education, and trait anxiety were entered into block 1 of each model, with AQ entered at block 2. N = 143 in both models.

Table 3
Linear regression models predicting visual working memory in the low semantic task, based on AQ subscales.

	Unstandardised coefficients		Standardised coefficients	
	B	*SE*	*β*	*t (p)*
Attention to detail				
Gender	−0.599	0.305	−0.168	−1.97 (0.051)
Years of education	0.144	0.087	0.138	1.66 (0.100)
Trait anxiety	−0.001	0.017	−0.003	−0.04 (0.969)
Attention to detail	0.071	0.034	0.178	2.11 (0.037)
Attention switching				
Gender	−0.457	0.303	−0.128	−1.51 (0.134)
Years of education	0.156	0.086	0.150	1.81 (0.073)
Trait anxiety	−0.012	0.018	−0.064	−0.69 (0.492)
Attention switching	0.095	0.036	0.230	2.60 (0.010)
Communication				
Gender	−0.420	0.308	−0.118	−1.36 (0.175)
Years of education	0.151	0.087	0.145	1.74 (0.084)
Trait anxiety	−0.012	0.018	−0.062	−0.66 (0.513)
Communication	0.085	0.039	0.201	2.20 (0.029)
Imagination				
Gender	−0.511	0.326	−0.143	−1.57 (0.119)
Years of education	0.138	0.089	0.133	1.56 (0.121)
Trait anxiety	0.005	0.017	0.025	0.28 (0.778)
Imagination	0.011	0.041	0.023	0.26 (0.795)
Social skills				
Gender	−0.520	0.307	−0.146	−1.69 (0.093)
Years of education	0.167	0.090	0.160	1.85 (0.067)
Trait anxiety	−0.004	0.018	−0.019	−0.19 (0.846)
Social skills	0.046	0.039	0.113	1.20 (0.234)

NB: Gender, years of education, and trait anxiety were entered into block 1 of each model, with AQ subscale entered at block 2. $N = 143$ in each model.

great extent on visual refreshing than using multimodal coding, as compared with young adults (Hamilton, Brown, et al., 2018; Nicholls & English, 2020). The availability and efficacy of executive resources could therefore, to some extent, account for age-related differences and variation more generally in strategy and visual working memory capacity (Braver & West, 2008; Brown et al., 2012; Hamilton, Brown, et al., 2018; Reuter-Lorenz & Lustig, 2016).

4.2. Autistic traits and visual working memory capacity

Based on evidence that autism and autistic traits are associated with more efficient processing of visual details (Fugard et al., 2011; Grinter et al., 2009; Stewart et al., 2009), we predicted that autistic traits may be related to enhanced visual working memory capacity (Hamilton, Mammarella, et al., 2018; Richmond et al., 2013). We predicted that this would be observed specifically regarding performance of a more abstract/low semantic visual working memory task, and not for a high semantic task. During the latter task, we expected that those lower in autistic traits could effectively supplement visual processing with other cognitive resources. Furthermore, we expected that those higher in autistic traits would not as readily take advantage of semantics and/or verbal recoding to allow for a semantics-associated boost. For example, Mammarella et al. (2014) found a positive effect of semantic availability on performance of a visual matrix task for non-autistic children, but not for autistic children.

As expected, and for the first time in a young adult sample, we have shown that autistic traits are positively associated with visual working memory, specifically for abstract/low semantic visual working memory capacity, and not for more meaningful/high semantic task performance. We additionally observed moderate correlations between AQ and trait anxiety measures. Therefore, one strength of our study was that we controlled for trait anxiety, which has previously been found to be related to autism and autistic traits (Freeth et al., 2013; Liew et al., 2015), and could also be related to visual working memory capacity (Eysenck et al., 2007; Moran, 2016; Spalding et al., 2021). Our findings suggest that autistic traits are associated with enhanced processing and temporary storage of visual details, even when considering visual working memory. However, the advantage is removed when additional cognitive resources can supplement task performance. Specifically, the high semantic task is more likely to draw on multimodal resources, and may be more likely to tap into the episodic buffer component of working memory, drawing upon central executive resources (Baddeley, 2012; Darling et al., 2017; Logie, 2011).

Exploratory analyses suggested that the Attention to Detail, Attention Switching, and Communication subscales of the AQ may underlie the observed relationship. The relationship between visual working memory task performance and the two attention–related subscales may be due to a more focused approach to the task and processing of the patterns themselves. For instance, Hamilton, Mammarella, et al. (2018) found that visual working memory performance was related to systemizing, a cognitive style which suggests a tendency to focus and exert attention to detail. Participants with greater attention-related autistic traits may also be more likely to use one strategy, and apply fewer resources to switching to other strategies. Fugard et al. (2011) suggested that lower scores on Attention Switching is related to improved ability to use different strategies. In the present study, then, higher Attention Switching scores may indicate use of a more focused (visual) strategy. Building upon this line of reasoning, the relationship with the Communication subscale may be due to a lower reliance on verbal skills or strategies.

Richmond et al. (2013) found that Attention to Detail related positively to young adults' visual working memory for novel objects, but was not related to verbal working memory. They suggested that this differential finding could be due to differences in task demands or complexity. A strength of the tasks used in the present study is that they involved the same levels of overall complexity, but differed in the potential meaning within the pattern configurations and the resources or strategies that could be employed. In support of Richmond et al., a relationship with autistic traits was observed for more novel or abstract stimuli. However, within the same sample, we were able to show that the opportunity for recruiting additional resources removed this effect. That semantic availability removed the positive effect of autistic traits also relates to the findings of Mammarella et al. (2014). They showed that visual working memory performance of non-autistic children (but not of autistic children), benefited from the availability of semantics in a visual matrix task. Thus, as the task more greatly draws on multimodal processing and storage, it may be that only those lower in autistic traits are readily able to benefit, removing any boost associated with focused attention to visual detail.

4.3. Limitations and future directions

A key strength of the present study was the use of parallel versions of a well-developed visual working memory task (Brown et al., 2006; Brown & Wesley, 2013; Della Sala et al., 1997; Orme et al., 2017; Riby & Orme, 2013). This allowed investigation of the role of semantics in task performance and as a potential moderator of any effect of autistic traits. However, the findings are necessarily restricted to this visual working memory task. Future research could assess the presently observed effect of autistic traits across a range of visual working memory tasks, perhaps with varying levels of demand, or cross-domain working memory tasks to determine the generalisability of the effect.

It is also important to note that the model for low semantic visual working memory performance accounted for a significant, albeit small, proportion of the variance in performance. Yet, this study highlights that there are variations in performance of visual working memory, related to autistic traits and task properties. Future research could usefully include additional predictors of performance, including, for example, additional mental health measures such as depression and stress (Spalding et al., 2021), as well as specific cognitive abilities such as processing speed, visuospatial processing or organisation, and executive control (Brown et al., 2012).

Although we suggest that focused attention may explain these differences, it would be useful for future research to test the relationship between autistic traits and the specific strategies reported during task performance (Brown & Wesley, 2013; Nicholls & English, 2020). Also, while the present study was limited to the young adult population, research could address these effects across the adult lifespan, to explore whether the effect changes with increasing age, and how strategies may be implemented to decrease the effects of cognitive ageing (e.g. Allen et al., 2021; Stewart et al., 2018). Finally, the current study investigated the relationships between visual working memory and autistic traits, but it is now important to test whether these findings are also apparent in autistic adults.

5. Conclusions and implications

Building upon earlier research showing that visual processing strengths are associated with autistic traits, the present study has shown that, in young adults, autistic traits are positively associated with visual working memory. This was specifically for an abstract task in which the opportunity to incorporate additional resources, particularly long-term memory (semantics), was minimised. Importantly, the effect is removed when the task stimuli feature more potentially meaningful configurations, thereby offering more opportunity to take advantage of these additional resources. This potentially implicates the episodic buffer component of working memory, which is more likely to be drawn upon, along with central executive resources, in the high semantic task. The present study therefore highlights specific processing strengths associated with autistic traits, namely focused attention to detail. It also demonstrates that greater interactive use of cognitive resources generally benefits visual working memory capacity, thereby removing the specific processing strengths of those high in autistic traits.

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Ethics approval

This study was conducted in accordance with the Declaration of Helsinki, excepting study pre-registration, and was approved by the relevant university ethics committee.

CRediT authorship contribution statement

Both authors contributed to the study conception and design, and material preparation. Data collection and dataset preparation was led by LN. Analyses were led by MS with contributions from LN. The first draft of the manuscript was written by LN with both authors contributing to subsequent versions and approving the final manuscript. We thank Nicola Brown, Jon Kirkwood, Amy McFadden, Chellsey McLaughlin, Caius Reza, and Lauren Thwaite for their assistance with data collection, and Dan Hale for his support with some of the analyses.

Conflicts of interest

The authors have no conflicts of interest to disclose.

Data availability

The data underlying this study are available on Open Science Framework (https://osf.io/zv3uf/).

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