Autistic Traits are Associated with Broader Tuning of Serial Dependence of Facial Identity

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Abstract

Face recognition difficulties are common in autism and could be a consequence of perceptual atypicalities that disrupt the ability to integrate current and prior information. We tested this theory by measuring the strength of serial dependence for faces (i.e., how likely is it that current perception of a face is biased towards a previously seen face) across the broader autism phenotype. Though serial dependence was not weaker in individuals with more autistic traits, more autistic traits were associated with greater integration of less similar faces. These results suggest that serial dependence is less specialised, and may not operate optimally, in individuals with more autistic traits and could therefore be a contributing factor to autism-linked face recognition difficulties.
Autistic Traits are Associated with Less Precise Perceptual Integration of Face Identity

Autism spectrum disorder (autism) is a neurodevelopmental disorder characterised by social and communicative impairments, as well as restricted and repetitive behaviours and interests (APA, 2013). More recently it has also been recognised that autistic individuals frequently experience sensory and perceptual atypicalities, with these atypicalities now included in the most recent diagnostic criteria (Diagnostic and Statistical Manual of Mental Disorders, 5th Edition; APA, 2013). Indeed, over 90% of autistic individuals have been found to exhibit some form of sensory and perceptual processing atypicalities, such as hypersensitivity, hyposensitivity, and atypical responses to sensory information (Crane et al., 2009; Leekam et al., 2007). The kinds of atypicalities seen in autism have also been found to extend to the general population, as examined through autistic traits. Autistic traits correspond to sub-clinical, milder levels of autistic symptoms that are distributed throughout the population, with autism representing the extreme end of this distribution (Baron-Cohen et al., 2001; Lundstrom et al., 2012). In the typical population, a greater number of autistic traits have also been found to be associated with greater sensory and perceptual processing sensitivities (A. E. Robertson & Simmons, 2013).

Pellicano and Burr (2012) have proposed a Bayesian theory of the sensory and perceptual atypicalities experienced by autistic individuals. It is argued that in typical perception, priors (i.e. previous information, expectations, or knowledge) act to improve precision and reliability. In contrast, a weakened reliance on prior expectations and/or an increased reliance on current perceptual information could contribute to the sensory and perceptual atypicalities common in autistic perception. Pellicano and Burr (2012) outlined three ways that a weakened use of priors could impact autistic perception. First, weakened priors would mean that perception is closer to the physical reality of the stimuli, being less biased by previously experienced stimuli, meaning that in some situations perception in
autism could be more accurate. Second, weakened priors could lead to poorer performance in situations where priors are useful in resolving ambiguity. Third, weakened priors could result in increased sensory sensitivity because priors act to smooth sensory input and reduced smoothing may therefore result in highly variable perception.

In both autistic individuals and non-autistic individuals with a higher number of autistic traits, the use of priors has been found to be weaker during social interactions, in perceiving the consequences of others’ movements, in perceived speed and motion, and in self-motion perception (Chambon et al., 2017; Powell et al., 2016; Turi et al., 2017; Zaidel et al., 2015). In contrast, intact prior knowledge for some situations (e.g. light source in an image; Croydon et al., 2017), has led to suggestions that the attenuated use of prior information in autistic individuals may be more specific to social than non-social stimuli and situations (Chambon et al., 2017; Lawson et al., 2018, but see Pell et al., 2016).

Weakened influence of prior information for social cues in autism is also evident in weaker perceptual adaptation. One example of this is face identity aftereffects, a type of perceptual bias where adaptation (prolonged exposure) to a face results in the perceived identity of a subsequent face being distorted and biased away from the characteristics of the adaptor face (Leopold et al., 2001). Autistic children have been found to have weakened face identity aftereffects compared to controls (Ewing et al., 2013; Pellicano et al., 2007; Rhodes, Ewing, et al., 2014), although this reduction is not always seen in autistic adults (Cook et al., 2014; Walsh et al., 2015). Parents and siblings of autistic individuals have also been shown to display weaker aftereffects as compared to relatives of typically developing individuals (Fiorentini et al., 2012). Similarly, research examining individual differences in the general population suggests that a higher number of autistic traits is associated with weaker face identity aftereffects, although this may be specific to males (Rhodes et al., 2013).
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Consistent with the weakened priors account, weakened face identity aftereffects suggests that perception in autism may be less biased by a previous stimulus. Here we ask whether another perceptual bias, serial dependence, may also be weakened. Serial dependence in visual perception occurs where current perception is biased towards what has previously been seen, and this integration causes an object to be perceived as more similar to a prior object than it really is (Fischer & Whitney, 2014). In contrast to typical aftereffects, serial dependence occurs across brief presentations. Serial dependence is thought to improve signal-to-noise ratio and promote perceptual stability for objects over time through the integration of information across “noisy” percepts (Burr & Cicchini, 2014; Cicchini et al., 2017, 2018; Fischer & Whitney, 2014; Kiyonaga et al., 2017; Liberman et al., 2016).

Previously, weakened serial dependence for auditory perception has been found in autistic individuals, suggesting that there is a reduced integration of auditory stimuli in autism (Lieder et al., 2019), however, this has not yet been examined for visual stimuli.

Like aftereffects, serial dependence has been found to occur for a range of visual perceptual processes, including those subserving social cues such as facial identity (Hsu & Lee, 2016; Liberman et al., 2014; Turbett et al., 2019). For facial identity, serial dependence occurs where the perceived identity of a face is biased towards the identity of a previously presented face, such that the second face is perceived to look more like the first than it really is (Liberman et al., 2014). Serial dependence is suggested to play a functional role in face recognition, where it may be beneficial to integrate an individual’s identity, through serial dependence, to produce a more robust representation of that identity (Turbett et al., 2019).

One aspect of serial dependence of facial identity is the strength of this bias. This refers to the magnitude of the bias towards a previous face, and individual differences in the strength of serial dependence of facial identity have previously been found (Turbett et al., 2019). Pellicano and Burr’s (2012) weakened priors theory suggests that serial dependence of
facial identity should be weakened in autistic individuals, and individuals with a greater number of autistic traits. Less influence from a previously presented face would result in a weaker bias towards this face, reflected by weakened serial dependence (i.e. more veridical perception). Additionally, autistic individuals, and individuals with a higher number of autistic traits, are typically found to have poorer face recognition skills (Griffin et al., 2020; Halliday et al., 2014; Minio-Paluello et al., 2020; Rhodes et al., 2013; Weigelt et al., 2013; though results sometimes differ between genders and when examining different subsets of autistic traits, see Davis et al., 2017; Rhodes et al., 2013) and this has led to recent suggestions that significantly impaired face recognition abilities may reflect a core deficit in autism (Griffin et al., 2020; Minio-Paluello et al., 2020). Given stronger serial dependence of facial identity is associated with better face recognition abilities (Turbett et al., 2019), it is plausible that serial dependence strength would be negatively associated with autistic traits, across both typical individuals and those with a diagnosis of autism. Thus, we hypothesised that individuals with a greater number of autistic traits would show a weakened reliance on prior visual information and would therefore show weaker serial dependence of facial identity strength.

Although serial dependence is typically strongest when stimuli are more similar to one another (Alexi et al., 2018; Cicchini et al., 2018; Fischer & Whitney, 2014; Turbett et al., 2019), individuals can also vary in their tuning of serial dependence of facial identity, which refers to how the strength of the bias varies depending on the similarity between two consecutive faces (Turbett et al., 2019). Individuals can range from showing narrow tuning, where only more similar faces are integrated, to broad tuning, where a greater range of faces, including less similar ones, are integrated. Previously, narrower tuning of serial dependence of facial identity has been found to be associated with better face recognition abilities than broader tuning (Turbett et al., 2019). This leads to the novel prediction that the tuning of
serial dependence of facial identity could be broader in autistic individuals and individuals with more autistic traits, given that they typically have weaker face recognition skills. Broader tuning of serial dependence could either be the result of weaker serial dependence overall or stronger serial dependence for less similar faces, such that the strength is the same regardless of face similarity. The former result would be consistent with the theory of weakened use of prior information (Pellicano & Burr, 2012). The latter would not, but would rather be evidence of increased reliance on prior visual information.

In the current study, we examined whether individual variation in both the strength and tuning of serial dependence of facial identity was associated with autistic traits in typical adults. We chose to examine facial identity as previous research has suggested that a weakened reliance on prior information may only be evident for social stimuli (Chambon et al., 2017) and because facial identity, as outlined above, is a social cue that has previously been linked with difficulties in autism and individuals with a greater number of autistic traits. We measured individual variation in the strength and tuning of serial dependence of facial identity using a task developed for the current study and originally reported in Turbett et al. (2019) and measured autistic traits using the Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001).

The current study examined autistic traits across the general population, rather than focusing on individuals with autism. However, it is important to note that dimensional views of autism support a relationship between autistic traits and autism. Specifically, the broader autism phenotype refers to the distribution of subclinical autistic traits throughout the general population that are qualitatively similar to features of autism, with autism lying at the extreme end of this distribution (Baron-Cohen et al., 2001; Lundstrom et al., 2012). That is, autistic traits vary in their severity and extend throughout the entire population, ranging from nonclinical levels through to clinically significant levels as seen in individuals with autism.
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(Landry & Chouinard, 2016). Further, autistic traits are found to be associated with the clinical features of autism and are also suggested to share a common aetiology with these features (Ronald et al., 2006). Additional support for a dimensional approach to autistic traits and autism comes from research finding that alterations in brain structures in typical individuals with a high number of autistic traits resemble alterations previously found in individuals with a clinical diagnosis of autism (Schröder et al., 2021). Therefore, examining the broader autism phenotype provides insight into autism.

Traditionally, research has described three core symptoms of autism: impaired social interaction, impaired communication, and restricted and repetitive behaviours and interests. These autistic symptoms are only moderately correlated with one another (Ronald et al., 2005), leading to suggestions that researchers should examine the triad of symptoms separately as opposed to relying on global severity (Happe et al., 2006). However, despite autism being a heterogenous condition, in order to receive a clinical diagnosis, individuals must have significant difficulties in each of the core symptom domains of autism. Autistic individuals, therefore, may not necessarily show sufficient variability within each of the symptom domains to determine which specific features of autism could potentially be associated with serial dependence. Given this, a key benefit of examining the broader autism phenotype is that it allows researchers to examine larger samples of participants and obtain greater variability across the distribution of autistic traits than would be obtained by solely examining individuals with a clinical diagnosis of autism (for further discussion, see Landry & Chouinard, 2016). Further, within the broader autism phenotype, an individual may be elevated in only a single domain, which allows for a clearer examination of which specific traits may be driving any relationships observed (Landry & Chouinard, 2016).

Autistic traits, like the symptoms of autism, fall into distinct clusters. Within the broader autism phenotype, factor analyses of the AQ have identified three domains of autistic
traits that resemble the triad of symptoms of autism: ‘social skills’, ‘communication and mind reading’, and ‘attention to details and patterns’ (Austin, 2005; English et al., 2020; Hurst et al., 2007; Russell-Smith et al., 2011). As with the symptoms of autism, these autistic trait domains are at best only modestly correlated with one another, and in some cases the attention to details and patterns domain can even be found to not be associated with the other two domains, leading to recent suggestions that researchers should only interpret the AQ domains, and not rely on the total AQ score (English et al., 2020). Therefore, by examining the broader autism phenotype, we are better able to determine which specific domains of autistic traits, if any, are associated with serial dependence. It may be that either weakened and/or broader serial dependence of facial identity is a ubiquitous aspect of autistic perception and may therefore be associated with all domains of autistic traits. Alternatively, given serial dependence of facial identity is associated with face recognition, an important social ability, it might be expected that this bias would be associated with either of the two more social domains of autistic traits: social skills and/or communication and mindreading. Finally, serial dependence of facial identity may instead be related to the attention to details and patterns domain which measures a more detail-oriented processing style that would be consistent with an increased reliance on current visual perception and a weakened reliance on prior context and information, as proposed by Pellicano and Burr (2012).

In addition to the AQ and serial dependence of facial identity task, we also included a measure of sensory sensitivity, the Glasgow Sensory Questionnaire (A. E. Robertson & Simmons, 2013) to examine whether serial dependence strength was also associated with sensory sensitivity. Pellicano and Burr (2012) suggested that in autism, a weakened reliance on prior information is also associated with greater sensory sensitivity. The sensory sensitivity seen in autism may therefore reflect a perceptual system that is less able to stabilise current perception through prior visual information. Recently, Lawson et al. (2018)
found that individuals with more autistic traits showed weakened eye-gaze direction aftereffects, and that the magnitude of these aftereffects was associated with increased sensory sensitivity. Therefore, it could be possible that weaker serial dependence of facial identity (which would reflect a weaker reliance on prior visual information) would be associated with greater sensory sensitivity. Finally, we also aimed to examine whether any relationship found between autistic traits and sensory sensitivity was mediated by serial dependence strength.

Method

Participants

Two-hundred and forty-eight adults completed the study. This sample was originally reported on in Turbett et al. (2019). Participants were undergraduate students from the University of Western Australia who participated for partial course credit ($N = 150$) or were volunteers recruited by student researchers as part of an advanced undergraduate research training course ($N = 98$). An a priori power analysis determined that a sample of 200 individuals would be sufficient to detect a ‘typical’ effect of $r = .20$ at 80% power (Gignac & Szodorai, 2016). Additional participants beyond the suggested sample size were tested by the student researchers as part of their research training.

Participants were excluded from all analyses if they reported: having a neurological disorder ($n = 2$) or not having lived in a Caucasian country for at least 10 years ($n = 13$) in an effort to ensure our sample had sufficient experience with our Caucasian face stimuli and minimise any effects of the own-race bias (Meissner & Brigham, 2001). Additional participants were excluded due to poor testing conditions (e.g. excessive room noise, computer problems, excessive participant fatigue; $n = 6$) or because they were unable to learn the faces at the beginning of the serial dependence task ($n = 6$). The final sample consisted of
221 participants (127 female, $M = 20.04$ years, $SD = 2.79$). All reported normal or corrected to normal vision and were aged between 17 and 33 years old.

**Tasks and Measures**

*Serial Dependence of Facial Identity Task (Turbett et al., 2019; Turbett et al., 2021)*

A serial dependence of facial identity task (for full details see Turbett et al., 2019) was used to assess serial dependence strength and tuning. Participants were first trained to identify four target faces, two male (‘Tim’ and ‘Jon’) and two female (‘Mel’ and ‘Sue’), from a left 1/4 profile and frontal view. Different genders and identities were included in the current study to obtain a measure of serial dependence of facial identity less reliant on stimulus specific effects and therefore more likely to reflect face identity processing. The faces were selected from the Radboud Faces Database (Langner et al., 2010). Within each gender pair, the faces were morphed together, using Abrosoft FantaMorph 5 Deluxe (version 5.4.8), to produce a continuum of 23 faces where each face differed from the next by 4% (ranging from 6% to 94%). Higher percentages reflect faces that were more like Jon or Sue (for male and female faces, respectively). After participants had learnt the target faces, they were trained on weaker strength versions of each face (faces ±20% from the average, 50%, face) that were presented as ‘siblings’ of the target faces.

On each trial, participants viewed two faces sequentially and were asked to identify the second face that appeared (for trial schematic, see Figure 1). Within each trial, Face 2 was one of the 11 faces from the centre of each morph continuum (faces ranging between 30% and 70% in morph identity strength). On each trial, Face 1 differed from Face 2 in one of four ways: -24%, -12%, +12%, or +24%, with each of these differences occurring in a quarter of trials. Face 1 could be any of the 23 morphs.

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1. Note that the final sample has different exclusions to the final sample reported on in Turbett et al. (2019).
Gender and viewpoint did not vary within a trial. Half of the trials used male faces and within each gender, half of the trials were forward facing. There were 176 trials, presented in a pseudorandom order so that the identity of the target faces was not the same for more than four consecutive trials. Each participant completed the same order to remove any potential influence of trial order on an individual’s performance. The trials were divided into 4 blocks of 44 trials to provide participants with regular breaks.

To calculate the serial dependence values, responses to stimuli were collapsed across gender and viewpoint. Serial dependence was expected to bias perception towards the previously seen identity, so we expected a greater proportion of Jon/Sue responses to Face 2 when Face 1 was more like Jon/Sue (trials where Face 1 and 2 differed by +12% and +24%) and a smaller proportion of Jon/Sue responses to Face 2 when Face 1 was less like Jon/Sue (Trials where Face 1 and 2 differed by -24% and -12%). Overall, differences of ±12% were when Face 1 and Face 2 were closer together on the morph continuum and therefore more similar to one another. Differences of ±24% reflect that Face 1 and Face 2 were further apart on the morph continuum and less similar to one another. For further details on calculating serial dependence values, see Turbett et al. (2019).

We first calculated serial dependence strength. Serial dependence strength refers to the magnitude of the bias towards the previous face. Serial dependence has been argued to promote perceptual stability in the visual system (Cicchini et al., 2018), with serial dependence of facial identity therefore argued to help to facilitate stable and robust representations of an individual’s identity (Turbett et al., 2019; Turbett et al., 2021). Typically, serial dependence is strongest for more similar stimuli (Alexi et al., 2018; Cicchini et al., 2018; Turbett et al., 2019). Given this, we calculated the strength of serial dependence specifically when Face 1 and 2 were more similar to one another (i.e. on the ±12% trials) in...
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order to obtain an estimate of the magnitude of facial identity integration when serial
dependence is typically expected to be maximal. To calculate the strength of serial
dependence (SDFI_strength) for each participant, a linear regression was fit to the ±12% trials (see Figure 2). A positive gradient indicated that serial dependence occurred and individuals were biased towards the previous identity, a value of zero indicated no serial dependence, while a negative value indicated that individuals were biased away from the previous identity (consistent with adaptation).

[Figure 2]

Next, we calculated serial dependence tuning. In contrast to strength, serial dependence tuning refers to how the magnitude of this bias varies depending on the similarity of consecutive stimuli. As mentioned earlier, serial dependence is typically strongest when faces are more similar to one another. However, individual differences occur, where individuals vary from only showing serial dependence for similar faces (narrow tuning) to showing this bias for all faces, regardless of similarity (broad tuning, Turbett et al., 2019; Turbett et al., 2021). Integrating stimuli that are less similar and more distinct has been suggested to result in larger errors in estimation (Cicchini et al., 2018). Broader tuning of serial dependence of facial identity specifically, i.e. integration across less similar percepts, is likely to result in an individual being less sensitive to the differences between individual faces, which in turn may cumulatively lead to poorer discrimination between individuals (Turbett et al., 2019). The tuning value (SDFI_tuning) was calculated by subtracting the gradient for the less similar faces (calculated by fitting a linear regression to the proportion of Jon/Sue responses on the ±24 trials) from the gradient for the similar more faces (±12 trials; see Figure 2). A larger, positive tuning value indicates that there is greater serial dependence for more similar faces than less similar faces (narrower tuning) and a value closer to 0 or a negative value indicates serial dependence increased as similarity decreased (broader tuning).
**The Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001)**

The AQ is a widely used self-report questionnaire used to measure autistic traits in adults. The AQ consists of 50 descriptive statements, with participants rating their agreement with each item using a 4-point Likert scale (definitely agree, slightly agree, slightly disagree, definitely disagree). For each participant, we calculated the three domains of the AQ as identified by Russell-Smith et al. (2011) in an Australian sample. The domains consist of Social Skills (AQ_social skill; maximum score of 52), Communication and Mind Reading (AQ_comm/mind; maximum score of 32), and Attention to Details and Patterns (AQ_detail/patterns; maximum score of 28) and these factors have previously been shown to have good reliability ($\alpha = .88, .62, \text{ and } .73$, respectively; Russell-Smith et al., 2011). A total AQ score was also calculated for each participant (AQ_total; maximum score of 200). For each domain, higher scores reflected a higher level of autistic traits.

**The Glasgow Sensory Questionnaire (GSQ; A. E. Robertson & Simmons, 2013)**

The GSQ is a self-report questionnaire used to measure sensory sensitivity in adults. The questionnaire was originally developed based on the types of sensory sensitivities that are commonly experienced in autistic individuals. The GSQ consists of 42 descriptive statements, with participants rating their agreement with each item using a 5-point Likert scale (never, rarely, sometimes, often, always). The 42 items are distributed equally among hypersensitivity and hyposensitivity in seven sensory modalities: visual, auditory, gustatory, olfactory, tactile, vestibular, and proprioceptive. The GSQ has previously been used in individual differences studies and has shown good reliability ($\alpha = .94$; A. E. Robertson & Simmons, 2013). Factor analyses of the GSQ indicate that the majority of items load most strongly onto one single factor examining overall sensory sensitivity, therefore the total GSQ score was interpreted (A. E. Robertson & Simmons, 2013). For each participant, we
calculated a total score (GSQ_total; maximum score of 168), with higher scores reflecting a higher level of sensory sensitivity.

**Procedure**

Participants were tested individually in a 1-1.5-hour session with regular breaks. After written and informed consent had been obtained, participants were seated in a quiet cubicle approximately 60cm from an iMac. Participants first completed the serial dependence of facial identity Task (programmed and presented via SuperLab 4.5, Cedrus Corp) followed by a face recognition task. This was followed by a 15-minute break in which the participant completed demographic information and the AQ and GSQ. Participants then completed a face identity aftereffect task and an object recognition task and finally were debriefed at the end of the session. Results for the face recognition, object recognition, and face identity aftereffect tasks are reported in Turbett et al. (2019) and see Supplementary Materials for relationships between autistic traits and face recognition abilities. The experimental procedure was approved by the University of Western Australia’s Human Research Ethics Committee and the experiment was performed in accordance to their guidelines and regulations.

**Results**

**Preliminary Analyses**

**Distribution**

As suggested by Hoaglin and Iglewicz (1987), we defined univariate outliers as scores 2.2 times the interquartile range. Five univariate outliers were identified: two on the AQ_total variable, one on the AQ_comm/mind variable, and two on the GSQ_total variable. These

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2 We note that in our supplementary analyses (see Table S2) we find a trend towards a negative relationship between domains of autistic traits and face recognition in males and significant positive relationship between domains of autistic traits and face recognition in females, which is consistent with Rhodes et al.’s (2013) findings and partly consistent with Davis et al. (2017).
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Outliers were winzorised by replacing them with the next highest non-extreme value. Using the Mahalanobis Distance, two multivariate outliers were identified and were removed. All variables were normally distributed (skew less than |2|, kurtosis less than |9|; Gignac, 2019). See Table 1 for descriptive statistics.

[Table 1]

**Reliability**

Reliabilities are reported in Table 1. Reliability for the strength of serial dependence was calculated by correlating the strength of serial dependence for female and male face pairs at each viewpoint, calculating the average correlation, and then applying the Spearman-Brown correction to account for the reduced trial numbers relative to the task overall (Turbett et al., 2019). Reliability for the estimation of serial dependence strength is consistent with previous research examining perceptual biases (Engfors et al., 2017; Rhodes, Jeffery, et al., 2014). The serial dependence tuning value was calculated using difference scores, therefore to calculate the reliability of tuning a formula was applied to account for the correlation ($r = .486, p < .001$) between the two conditions (more similar and less similar faces) being compared (Trafimow, 2015; Turbett et al., 2019). Reliability for the tuning of serial dependence score was poor, partially due to the large correlation between the serial dependence for more similar and less similar faces (Trafimow, 2015). Reliabilities for the AQ domains and the GSQ total score were calculated using Cronbach’s alpha and were all good and consistent with previous research (Bothe et al., 2019; A. E. Robertson & Simmons, 2013; Russell-Smith et al., 2011; Sapey-Triomphe et al., 2018; Takayama et al., 2014).

**Participant Gender Differences**

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3 Descriptive statistics and reliability for the total overall AQ score are included in this table. However, given recent psychometric analyses not supporting the use of the total AQ score (English et al., 2020), this score is not included in subsequent analyses.
Previous research has suggested that males generally show higher AQ scores than females (Baron-Cohen et al., 2001; Rhodes et al., 2013; A. E. Robertson & Simmons, 2013, but see Bothe et al., 2019). In the current study, we found no gender differences on any measure, including the AQ (see independent samples t-tests in Table 1). Thus, all subsequent analyses were collapsed across gender.

**Autistic Traits and Sensory Sensitivity**

Prior to examining whether serial dependence was associated with either autistic traits or sensory sensitivity, we first sought to replicate the previously found positive association between autistic traits and sensory sensitivity (Horder et al., 2014; A. E. Robertson & Simmons, 2013) in our current sample. Consistent with previous research, autistic traits and sensory sensitivity were significantly, positively associated (all \( r_s > .221, p_s < .001 \)), indicating that greater autistic traits in every domain were associated with a greater frequency of sensory processing sensitivities.

**Serial Dependence of Facial Identity Strength**

To determine whether our sample showed significant serial dependence, we compared the mean gradient from the ±12% trials to zero (which would indicate no serial dependence). A one-sample t-test indicated that the strength of serial dependence was significantly different from zero, \( t(218) = 17.513, p < .001, d = 1.183 \), indicating that as a group, participants showed serial dependence of facial identity.

**Serial Dependence Strength, Autistic Traits, and Sensory Sensitivity**

We hypothesised that a greater number of autistic traits would be associated with weaker serial dependence strength. Likewise, we predicted that weaker serial dependence strength would be associated with greater sensory sensitivity. Contrary to these hypotheses, no significant relationships were found between serial dependence strength and any of the AQ domains (all \( r_s < .033 \), \( p_s > .623 \); see Table 2), nor with sensory sensitivity (\( r = .052, p \))
Thus, these results provide no evidence that the strength of serial dependence of facial identity is associated with either autistic traits or sensory sensitivity.

Due to Pellicano and Burr’s (2012) theory proposing that a weakened reliance on prior information may be associated with the sensory atypicalities seen in autism, we had originally intended to examine whether the relationship between autistic traits and sensory sensitivity was mediated by serial dependence strength. However, given that there was no significant relationship between serial dependence strength and either autistic traits or sensory sensitivity, this mediation analysis was not conducted.

**Serial Dependence Tuning, Autistic Traits, and Sensory Sensitivity**

Our second aim was to examine whether autistic traits were associated with serial dependence of facial identity tuning. We found that AQ_details/patterns was significantly, negatively correlated with serial dependence tuning ($r = -.143, p = .035$, see Table 2). Specifically, a greater number of autistic traits on the attention to details and patterns domain of the AQ was associated with broader tuning, i.e. a more similar strength of serial dependence for both similar and less similar faces. No significant relationship was found between autistic traits on either the social skills or communication and mind reading domains and tuning of serial dependence of facial identity ($rs < |.054|, ps > .424$). We also found no relationship between serial dependence tuning and sensory sensitivity ($r = -.052, p = .447$).

In principle, broader tuning of serial dependence in individuals with more autistic traits could reflect one of two things: generally weakened serial dependence across all levels of stimulus similarity, or relatively stronger serial dependence for less similar faces. This is because the tuning score for each individual is a difference score calculated from subtracting the strength of serial dependence for more similar faces (faces that differed within a trial by
±12%) from that for less similar faces (faces that differed within a trial by ±24%). To examine these contrasting explanations, we examined the relationship between attention to details and patterns autistic traits and serial dependence for just the less similar faces. Here, we found weak evidence of a modest positive association \((r = .131, p = .053)\). This contrasts with the very small and negative association found for the strength of serial dependence \((r = - .033, p = .623)\), which is based on serial dependence for more similar faces. Together, these results provide tentative evidence that the broader tuning we observed in individuals with a higher level of autistic traits reflects stronger serial dependence for less similar faces, rather than an overall weaker bias.

**Discussion**

The current study measured two aspects of serial dependence for face identity, the strength and tuning of this bias, and found that only the tuning was associated with autistic traits. Specifically, a higher number of autistic traits on the attention to details and patterns domain was associated with broader tuning of serial dependence of facial identity. As we found no relationship between autistic traits and serial dependence strength, the results of the current study are not supportive of the theory of weakened reliance on prior information in autism proposed by Pellicano and Burr (2012). Further, these results are not consistent with previous research examining serial dependence for auditory perception (Lieder et al., 2019). However, this may be in part due to the different stimuli examined, both in the sensory modality (visual vs. auditory) and the complexity of the stimulus (facial identity vs. pitch discrimination). Despite this, our results are consistent with a growing body of recent research examining autistic perception (Croydon et al., 2017; Pell et al., 2016). For example, Pell et al. (2016) examined participants’ bias in perceiving eye gaze direction and found no evidence that this bias was reduced in either autistic individuals or typical controls with a greater number of autistic traits.
Pellicano and Burr (2012) additionally suggested that the sensory and perceptual atypicalities that are common in autism could be the result of a weakened use of prior information. However, we also found no evidence that a weakened use of prior information, as measured by serial dependence of facial identity, is associated with greater sensory sensitivity. One potential explanation for the lack of association in this study could be that biases in the perception of low-level visual cues (such as orientation, luminance) may be more predictive of basic sensory sensitivity than facial identity, a relatively higher-level perceptual cue, as previously suggested by Lawson et al. (2018). Thus, although previous research found that weakened eye-gaze direction aftereffects are associated with greater sensory sensitivity (Lawson et al., 2018), eye-gaze direction is a visual cue to direction whereas serial dependence of facial identity taps biases in the perception of identity, a higher-level perceptual cue. This explanation is also consistent with recent neuroimaging evidence indicating that the sensory symptoms apparent in autism arise from differences in low-level sensory processing (C. E. Robertson & Baron-Cohen, 2017). Therefore, while we found no relationship between serial dependence of facial identity, it may be that serial dependence for low-level visual cues could instead be associated with the type of sensitivity in basic sensory modalities (such as sensitivity to light and sounds) that is measured by the GSQ. This remains to be systematically examined.

We also found that greater autistic traits on the attention to details and patterns domain was associated with broader tuning of serial dependence of facial identity, i.e. showing similar serial dependence for all faces, regardless of their similarity. As mentioned earlier, broader tuning can occur due to either generally weakened serial dependence across all levels of stimulus similarity or, relatively stronger serial dependence for less similar faces. Our results provided tentative evidence that the broader serial dependence tuning in individuals with a greater number of attention to details and patterns autistic traits is due to relatively
stronger serial dependence for less similar faces and not due to a general weakening of this bias. This trend for an increased use of serial dependence of facial identity would be in contrast with Pellicano and Burr’s (2012), as an increased use of serial dependence would imply that individuals with a greater number of autistic traits were more influenced by prior information than those with fewer autistic traits.

While serial dependence tuning was found to be related to autistic traits in the attention to details and patterns domain, we found no relationship between this bias and either the social skills and communication or mind reading domains. This highlights the importance of examining the domains of autistic traits separately, as associations may be unique to one domain and could potentially be overlooked in an examination of total autistic traits (English et al., 2020). We originally suggested that any relationship with the attention to details and patterns domain could be due to a detail-oriented processing style, which would be consistent with the weakened priors theory, in which there is less reliance on prior information. However, our tuning results (trend towards stronger serial dependence for less similar faces) did not support the weakened priors theory, and instead suggested a greater reliance on prior information. An alternative explanation is that individuals with a detail-oriented processing style might be less sensitive to the holistic information of a face used to distinguish between similar identities (Engfors et al., 2017), and this weaker sensitivity might lead to greater integration of faces, even when they are less similar, resulting in broader tuning of serial dependence of facial identity in the broader autism phenotype, and potentially in autism as well.

Broader tuning in individuals with more autistic traits is in line with a recent suggestion that many of the perceptual differences that are found in people with autism could be the result of reduced perceptual specialisation (e.g., Hadad et al., 2017; Hadad et al., 2019). Perceptual specialisation refers to the process whereby perceptual systems and processes
become more narrowly tuned for specific tasks and stimuli (Johnson, 2000, 2011). Our finding of broader tuning in individuals with a greater number of autistic traits may reflect that this perceptual bias is less specialised in individuals with more autistic traits (albeit particular autistic traits). Serial dependence of facial identity has previously been found to be tuned to the similarity of stimuli, whereby this bias is strongest when two sequential faces are more similar to one another (i.e., narrowly tuned; Turbett et al., 2019; Turbett et al., 2021). That this bias is typically narrowly tuned is an indication that, while integrating visual information is beneficial across small differences in stimuli, integrating across larger stimuli differences could result in greater errors in estimation (Cicchini et al., 2018; Turbett et al., 2019). Broader serial dependence of facial identity tuning has been previously been found to be associated with poorer face recognition abilities (Turbett et al., 2019). One potential explanation for this is that integration across larger differences in facial identity (i.e., broader tuning) is likely to result in an individual being less sensitive to the subtle differences between individual faces that are needed to accurately discriminate between and recognise individuals (Turbett et al., 2019). Therefore, broader tuning could contribute to individuals with a greater number of autistic traits, and possibly autistic individuals, also displaying poorer face recognition abilities. That is, greater integration of less similar faces may lead to difficulties in discriminating between different identities².

Recently, it has been suggested that more than one third of autistic individuals have significantly impaired face recognition abilities (Minio-Paluello et al., 2020). Face recognition deficits in autism have also been found to generalise across age, sex, intellectual functioning, and specific task paradigms, suggesting that impairments in face recognition may reflect a core deficit in autism (Griffin et al., 2020). By examining processes in the broader autism phenotype that have previously been found to underlie face recognition abilities (like serial dependence of facial identity), we are better able to understand the nature
Autistic traits and serial dependence

and extent of the face recognition deficits commonly observed. Previous research has found that other face processing mechanisms, like holistic processing and face identity aftereffects, are disrupted in the broader autism phenotype and in autism (Ewing et al., 2013; Fiorentini et al., 2012; Gauthier et al., 2009; Joseph & Tanaka, 2003; Pellicano et al., 2007; Rhodes, Ewing, et al., 2014; Rhodes et al., 2013; Teunisse & de Gelder, 2003). Therefore, while here we only examined typical individuals, our results raise the possibility that serial dependence of facial identity could likewise be more broadly tuned in autistic individuals, leading to greater integration of less similar facial identities, which in turn might contribute to the face recognition difficulties commonly observed in autism. If serial dependence of facial identity is found to be more broadly tuned in autism, this would present this bias as an additional process to potentially target, alongside other face mechanisms, in training to improve face recognition difficulties in individuals with autism.

Therefore, it will be important for future research to examine serial dependence of facial identity in individuals with a clinical diagnosis of autism in order to determine whether the relationship observed here is also present in autistic individuals, as it is possible that qualitatively different relationships may be present in autism (Gregory & Plaisted-Grant, 2016). We would predict that the results of the current study might extend to autistic individuals, given that the broader autism phenotype in the typical population appears to be both a continuous expression of, and qualitatively similar in aetiology to, the symptoms observed in autism (Lundstrom et al., 2012; Ronald et al., 2006), but this remains to be examined. Based on our current results, we would predict that the tuning of serial dependence of facial identity might be broader in autistic individuals, resulting in a greater integration of less similar face’s identities. Given the association found here was only observed for the attention to details and patterns domain, it is possible that only autistic individuals with a greater amount of restricted and repetitive patterns of behaviours or interests would have
broader tuning of serial dependence, as this symptom domain is suggested to have the same origin as the detail-oriented processing style reflected by the attention to details and patterns domain (Chen et al., 2009; Happe & Frith, 2006). It is important to note that as our measure of serial dependence was only based on two steps between Face 1 and Face 2, only a coarse estimate of tuning could be obtained. Future research would therefore benefit from the inclusion of additional steps of difference between Face 1 and Face 2, in order to obtain a more precise measure of tuning to determine whether individuals with autism do show greater integration of faces that are less similar.

In conclusion, we found that the strength of serial dependence was not significantly associated with autistic traits or sensory sensitivity, as was predicted from Pellicano and Burr’s (2012) theory that autism is associated with a weakened reliance on prior visual information. In addition to this, we found that more autistic traits in the attention to details and patterns domain was associated with broader tuning of serial dependence of facial identity and there was a trend for this broader tuning to be due to an increased use of serial dependence for less similar faces. Taken together, these results do not support Pellicano and Burr’s (2012) weakened priors theory. Our finding of broader tuning in individuals with a greater number of autistic traits is consistent with more recent suggestions that many of the perceptual differences that are found in individuals with autism could be the result of reduced perceptual specialisation (e.g., Hadad et al., 2017). In individuals with a greater number of autistic traits, broader tuning of serial dependence of facial identity may therefore reflect a less specialised perceptual process that results in greater integration of less similar facial identities and could be contributing to the face recognition difficulties frequently observed in autism.
References


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https://doi.org/10.1007/s10803-008-0663-6


Ewing, L., Leach, K., Pellicano, E., Jeffery, L., & Rhodes, G. (2013). Reduced face aftereffects in autism are not due to poor attention. *PloS One, 8*(11), e81353. https://doi.org/10.1371/journal.pone.0081353


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Weigelt, S., Koldewyn, K., & Kanwisher, N. (2013). Face recognition deficits in autism spectrum disorders are both domain specific and process specific. *PloS One, 8*(9), e74541. https://doi.org/10.1371/journal.pone.0074541

Figure Captions

Figure 1

*Schematic showing one trial*

*Note.* On each trial, participants were presented with a face (300ms), followed by a visual noise mask (500ms) and inter-stimulus interval (500ms). Participants are then presented with a second face (300ms) that, following a visual noise mask (500ms), they are asked to identify. Following their response, there was an inter-trial interval (500ms). Figure from Turbett et al. (2019), licensed under CC BY 4.0.

Figure 2

*Group mean responses as a function of the percentage difference between Face 1 and Face 2*

*Note.* Regression slopes fit to the group means for illustrative purposes. A larger, positive gradient indicates stronger serial dependence. A linear regression was fit separately for when Face 1 and 2 were more similar (±12%; Inner triangle data points and dashed line, slope = .005, $R^2 = 1.0$) and for when they were less similar (±24%; Outer circle data points and solid line, slope = .003, $R^2 = 1.0$). Error bars represent standard error.
Figures

Figure 1 top
Figure 2 top
Table 1

Descriptive statistics and reliabilities for the Serial Dependence of Facial Identity Task, Autism Quotient, and Glasgow Sensory Questionnaire

<table>
<thead>
<tr>
<th>Task</th>
<th>Full Sample</th>
<th>Gender Differences</th>
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<tbody>
<tr>
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<td>Min</td>
<td>Max</td>
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<td>AQ_social skills</td>
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<td>AQ_comm/mind</td>
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<tr>
<td>AQ_details/patterns</td>
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<td>27</td>
</tr>
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<td>AQ_total</td>
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<td>150</td>
</tr>
<tr>
<td>GSQ_total</td>
<td>15</td>
<td>102</td>
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</table>

Note. N = 219; t statistics represent independent samples t-tests testing for sex differences on each measure, all ps > .066 (two-tailed), N Male = 92, N Female = 126; SDFI = Serial Dependence of Facial Identity Task; AQ = Autism Quotient; GSQ = Glasgow Sensory Questionnaire
<table>
<thead>
<tr>
<th></th>
<th>SDFI_strength</th>
<th>SDFI_tuning</th>
<th>AQ_social skills</th>
<th>AQ_comm/mind</th>
<th>AQ_detail/patterns</th>
<th>GSQ_total</th>
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<td>-.052</td>
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<td>.221**</td>
<td>.349**</td>
<td>1</td>
</tr>
</tbody>
</table>

*Note. N = 219; *p < .05, **p < .005; SDFI = Serial Dependence of Facial Identity Task; AQ = Autism Quotient; GSQ = Glasgow Sensory Questionnaire*