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BRIEF REPORT

Sensory Processing and Executive Functioning in Autistic Adults

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Abstract

Purpose One of the core features that can be experienced by adults on the autism spectrum is hyper- and hyporeactivity to sensory stimuli. Research suggests that executive functioning (EF) impairments are related to sensory issues. In this study the relationship between sensory processing issues and EF was investigated. We expected sensory processing issues to predict EF impairments.

Methods Thirty men and 30 women on the autism spectrum, 20 men and 24 women without autism were included and matched on intelligence and age. Group comparisons were conducted to determine if groups differed regarding self-reported sensory processing issues (GSQ-NL) and self-reports on EF (BRIEF-A). Correlational and regression analyses were carried out to investigate the relationship between self-reports on GSQ-NL and BRIEF-A.

Results We found significant differences between men and women on the spectrum with regard to sensory processing issues and EF. Hyporeactivity to sensory information explained most of the EF problems.

Conclusion Clinicians should be aware of differences in sensory experiences between adults on the spectrum and non-autistic adults and differences between men and women during assessment and subsequent counselling.

Keywords Sensory processing · Executive functioning · Autism spectrum · Adults

Following the Diagnostic and Statistical Manual 5th Edition [DSM-5] Autism Spectrum Disorder (ASD) is characterised by persistent deficits in social communication/interactions and restricted, repetitive patterns of behavior, interests or activities. The phenotype incorporates features across cognitive, behavioral, affective and sensory domains (Weston, Hodgekins, & Langdon, 2016), ranging from mild to severe. The impact of ASD features can vary between individuals and during the lifespan. The prevalence of ASD is estimated to be around 0.97%, when based on 26 high-income countries (Fombonne et al., 2021). The DSM-5 classification-system describes ASD as a neurobiological developmental disorder, but this does not agree with the experience of those who advocate neurodiversity and the dismissal of negative language like ‘disorder’. However, others do advocate the use of negative language since this could emphasise the challenges in daily life for those on the spectrum (Kenny et al., 2016). Since there is no consensus about the usage of person-first (‘individual with ASD’) versus identity-first (‘autistic individual’) language (e.g. Wevers, 2020; Vivanti, 2020), we will alternate between both.

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Sensory Processing Issues in ASD

One of the core features of ASD is hyper- and hyporeactivity to (specific) sensory stimuli and general sensory overload (e.g. Crane et al., 2009). In the Diagnostic and Statistical Manual 5th Edition [DSM-5], atypical sensory processing issues are considered to be a potential core symptom within the cluster of restricted, repetitive patterns of behavior. This is described as follows: “hyper- or hyporeactivity to sensory input or unusual interests in sensory aspects of the environment (e.g., apparent indifference to pain/temperature, adverse response to specific sounds or textures, excessive smelling or touching of objects, visual fascination

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with lights or movement)" (American Psychiatric Association [APA], 2013, p. 27). Hyperreactivity (e.g. covering ears at noise), hyporeactivity (e.g delayed reaction to pain), and sensory seeking behavior (e.g. spinning in circles) can be present in multiple sensory systems including vision, audition, gustation, olfaction, proprioception and in the vestibular and tactile system (Baum et al., 2016).

Different models aim to explain atypical sensory reactivity in individuals on the spectrum: (1) an increased excitation-to-inhibition ratio (Rubenstein & Merzenich, 2003); (2) the predictive coding framework (see Ward, 2019, Sapey-Triomphe et al., 2019); (3) the intense world theory (Markram & Markram, 2010); (4) the temporal binding hypothesis (Brock et al., 2002); and (5) increased levels of endogenous noise (see Ward, 2019). However, none of these models can sufficiently explain sensory reactivity on a subjective, behavioral and neural level (Ward, 2019). As therefore noted by Simmons (2019), further research should focus on differentiating subjective, neural and behavioral sensory reactivity.

Sensory issues affect an estimated 45 to 95% of individuals on the autism spectrum (e.g. Ben-Sasson et al., 2019; Kern et al., 2007; Crane et al., 2009), which makes it one of the most prevalent features of ASD (e.g. Baum et al., 2016). Kern et al. (2007) suggest that all the main modalities appear to be influenced and that atypical processing in one modality could affect processing in other modalities. Furthermore, sensory processing issues are found across the autism spectrum and from childhood through adulthood (Dunn, Smith Myles & Orr, 2002; Crane et al., 2009). Simmons (2019, p.170) argues that research has clearly shown that sensory reactivity in individuals with autism can cause "pain, distress, discomfort, and, in some cases, endanger the personal safety of autistic individuals". Sensory issues are thought to have an impact on the development of social and cognitive abilities, executive functioning, (mal)adaptive functioning and are associated with severity of other core features of autism (e.g. van den Boogert et al., 2021; Dellapiazza et al., 2020; Ben-Sasson et al., 2019) and therefore negatively influence quality of life. Sensory issues are associated with co-occurring problems, e.g. symptoms of depression and anxiety (Ben-Sasson et al., 2019).

The most recent meta-analysis on sensory issues in individuals on the autism spectrum, carried out by Ben-Sasson and colleagues in 2019, included 55 studies on the subject. In general, the authors found that sensory over-responsivity differentiated autistic adults from all other groups. Sensory under-responsivity was the most prominent sensory profile and it differentiated between adults with autism and those with neurotypical development, but to a lesser extent to other clinical groups. Of the 55 studies included, only three investigated sensory reactivity in adults on the spectrum without intellectual disability. The first of the conducted studies was carried out by Crane, Goddard and Pring (2009), who found that almost all included adults with autism reported atypical reactions to sensory stimuli, much more than those not on the spectrum. Karhson and Golob (2016) found evidence for sensory reactivity explaining enhanced bottom-up attention in adults with autism. In the third study, conducted by Elwin et al. (2017), sensory subgroups (low, intermediate and high) were identified within a sample of autistic adults. A later study by Kuipers and colleagues (2019), found a strong positive relationship between self-reported autistic traits and sensory reactivity in a clinical Dutch sample. About 67% of their participants reported hypo- and/or hyperreactivity to sensory stimuli. Unfortunately, the study was not designed to determine sex differences. Taylor and colleagues (2020) focused on sensory reactivity in women on the spectrum specifically and found that they reported greater sensory hyperreactivity, but not hyporeactivity when compared to women not on the spectrum and mothers of children on the spectrum. Lai and colleagues (2011) reported that adult autistic women showed more lifetime sensory symptoms than autistic men. Overall, only very few studies focused on gender differences, making it important to take these into account. Also, little is known about what could help alleviate sensory issues in everyday life.

Executive Functioning and Sensory Processing

Executive functions [EF] are defined as: "the overarching regulation of goal-directed, future-oriented, higher-order cognitive processes" (Demetriou et al., 2019 p. 2). They include cognitive capacities like planning, working memory, impulse control, inhibition, and shifting set, as well as initiation and monitoring of action ((Hill, 2004a). In a meta-analysis conducted by Demetriou and colleagues (2018), the studies analysed point to an overall impairment in EF but also to high inter-individual variability in EF in ASD. Various studies found especially 'cognitive flexibility' to be impaired in those who are on the spectrum (for a meta-analysis see e.g. Xie et al., 2020).

Just and colleagues (2012) and Baum and colleagues (2016) indicate that sensory information forms the building blocks for higher-order cognitive functions. For example, following the sensory integration theory of Ayres (1979), sensory (lower order and stimulus driven) bottom-up processing is followed by cognitive (higher order and knowledge driven) top-down processing (Pastor-Cerezuela et al., 2020). So, in the foundation of the mental processes of executive functioning lies receiving, filtering and synthesizing of sensory information into a coherent whole. This process is used to interpret one's surroundings and act on it. When this process is flawed, for example due to sensory overload, it could then lead to problems in navigation and interacting with the environment (Stevenson et al., 2014; Kern et al., 2006) note that the degree of sensory difficulties in different domains can affect functioning in many different activities of daily life and therefore influence the capability to attain goals. For example, the inability to filter irrelevant sensory stimuli may impair performance on executive function tasks like planning or set-shifting (Adams et al., 2015). It seems reasonable to assume that, with the predictive coding theory (see Ward, 2019, Sapey-Triomphe et al., 2019) in mind, sensory issues can lead to prediction errors about the environment which then influence other mental processes that are needed to adequately react to the environment.

Boyd and colleagues (2009) were the first to examine the relationship between sensory processing issues and executive dysfunction in school-aged children on the autism spectrum to determine whether these share the same mechanism. They found no evidence for a shared neurocognitive mechanism, but also state that further research is needed. Pastor-Cerezuela and colleagues (2020) found that sensory processing issues in autistic children predicted executive and other cognitive dysfunctions, especially in inhibition, sustained attention and short-term memory. Fernandez-Prieto et al. (2021) found a strong mediation effect of EF (especially emotion regulation) between sensory processing issues and externalising behavioral problems (for example aggression and obsessive behavior) in children and adolescents on the spectrum. However, scientific studies on this relationship are scarce and have not yet focused on adults on the spectrum.

The aim of this study is to investigate if there is a relationship between executive functioning and sensory processing issues and to gain insight in the characteristics of this relationship. The expectation is that self-reported sensory processing issues are related to self-reported issues regarding executive functioning and that sensory processing issues predict (part of) the variance in executive functioning. Men and women on the spectrum will be compared to non-autistic men and women, as it is expected that gender differences exist in sensory processing issues as well as executive functioning.

Table 1 Participant Characteristics: Age in Years, TIQ and VBI Scores on the WAIS-IV-NL

	Adults with ASD		Non-autistic adults	
	Men	*Women*	*Men*	*Women*
Age	40.49 (12.58)	36.64 (8.89)	39.30 (13.90)	35.26 (15.46)
Total intelligence (TIQ)	109.77 (10.88)	106.07 (9.74)	115.55 (10.76)	107.88 (13.50)
Verbal comprehension (VCI)	111.73 (11.02)	108.03 (8.55)	114.05 (11.44)	109.21 (11.61)

*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$

Methods

Participants

Participants were matched on age, total IQ (TIQ) and Verbal Comprehension (VCI), measured using the Dutch version of the WAIS-IV-NL (Wechsler, 2012; [Dutch Translation WAIS-IV-NL: Barelds et al., 2013]), in order to make a reliable comparison of their performance on the executive tasks and to ensure typical levels of cognitive function. Participants were also matched on verbal ability, since executive function is thought to be influenced by this ability (Crawford et al., 1992, 1993). Means and standard deviations for each variable are presented in Table 1. Results showed no significant effect of group and gender on age ($F(1, 98) = 1.348$, $p = .248$, *partial* $\eta^2 = 0.013$), TIQ ($F(1, 98) = 0.793$, $p = .375$, *partial* $\eta^2 = 0.008$) and VCI ($F(1, 98) = 0.3.140$, $p = .079$, *partial* $\eta^2 = 0.030$). These results indicate that assumptions to compare groups were met. Data of 30 men with ASD, 30 women with ASD, 20 non-autistic men and 24 non-autistic women were collected ($N = 104$). Participant characteristics are presented in Table 1.

Participants in the autistic adults group were recruited from the 'Autisme Kennis Centrum' (Utrecht, the Netherlands). Participants were assessed according to a standardized diagnostic process using DSM-5 criteria. Parents or siblings were interviewed using the Dutch version of the Autism Diagnostic Interview Revised [ADI-R] (Lord et al., 1994; Dutch Translation: de Jonge & de Bildt, 2014) to gather information about the early childhood and development of each participant. The ADI-R has good psychometric properties (e.g. Zander et al., 2017). Furthermore, participants took part in a semi-structured interview (DSM-5 ASS interview, Spek, 2015) to evaluate former and current traits and features of autism. This semi-structured interview is based on the criteria of the DSM-5 for ASD and has previously used in studies. Participants for the non-autistic group were recruited through different channels, like flyers, social media and the network of the researchers. Participants were excluded when having an ASD diagnosis or first-degree relative with ASD. In Table 2 the other inclusion and exclusion criteria for the ASD and non-autistic group are displayed.

Materials

Wechsler Adult Intelligence Scale IV - NL (WAIS-IV-NL)

The WAIS-IV-NL is the Dutch adaptation (Barelds et al., 2013) of the original WAIS-IV (Wechsler, 2012), an instrument to examine intellectual abilities in adolescents and adults. It takes approximately 1.5-2 h to complete it. The WAIS-IV-NL consists of at least 10 subtests that are needed

Table 2 Criteria for Inclusion and Exclusion in Both Groups

	ASD group	Non-autistic group
ASD diagnosis	Inclusion	Exclusion
TIQ & VBI ≥ 85 points	Inclusion	Inclusion
Between 18 and 65 years of age	Inclusion	Inclusion
Prior institutionalization for mental health problems	Exclusion	Exclusion
Substance abuse/dependency	Exclusion	Exclusion
Neurological/sensory disorders	Exclusion	Exclusion
Co-occurring disorders (e.g. anxiety disorders, depression)	Inclusion	Exclusion

to calculate full-scale intelligence. Full-scale intelligence is divided into verbal intelligence and performance intelligence. Verbal intelligence provides two sub-indexes: verbal comprehension index and working memory index. Performance intelligence provides the perceptual organization index and processing speed index. In this research full-scale intelligence and verbal comprehension index needed to be 85 points or higher to ensure average or above-average cognitive abilities in all participants.

Glasgow Sensory Questionnaire (GSQ-NL)

The GSQ (Robertson, 2012) is a self-report questionnaire aiming to measure sensory reactivity that has been constructed on the basis of reports in the literature of sensory features common in autism, reports by parents of children on the spectrum, consulting autism researchers and a psychiatrist, a participant with autism of the pilot group (Robertson & Simmons, 2008). Robertson and Simmons (2012) reported significant correlations between scores on the GSQ and the Autism Questionnaire (AQ; Baron-Cohen et al., 2001).

The questionnaire has been translated into Dutch and validated by Kuiper, Verhoeven and Geurts (2019). Kuiper and colleagues found the GSQ-NL to be as reliable and valid as the GSQ, for adults without intellectual disability, and therefore the GSQ-NL to be suitable for usage in scientific research and clinical practice. The GSQ-NL can be used to assess sensory characteristics in adolescents and adults. The questionnaire consists of 42 items that can be used to measure hyper- and hyporeactivity on seven sensory domains: vision, audition, gustation, olfaction, touch, vestibular processing and proprioception. For each item the intensity is reported on a five-point scale. Responses are coded from 0 ('never') to 4 ('always'). Scores can be derived for general hyper- and hyporeactivity as for each modality. The GSQ was found to be highly reliable in all subgroups: men on the spectrum ($\alpha = 0.804$), women on the spectrum ($\alpha = 0.836$), men without autism ($\alpha = 0.860$) and women without autism ($\alpha = 0.819$).

Behavior Rating Inventory of Executive Function - Adult Version (BRIEF-A)

The BRIEF-A is a self-report instrument that can be used as a standardized instrument to assess executive functions in daily life. The questionnaire consists of 75 items from which a total score that represents overall executive function, nine sub-scales, two index-scales and three validity scales can be derived. Participants filled out the form at home. In this research all sub-scales and index scales were used. The BRIEF-A showed very high reliability for all groups: men with autism ($\alpha = 0.904$), women with autism ($\alpha = 0.952$), men without autism ($\alpha = 0.952$) and women without autism ($\alpha = 0.961$).

Procedure

The Social and Societal Ethics Committee of the KU Leuven (Belgium) approved the protocol before the start of the data collection. All data collection took place at the Autisme Kennis Centrum. Informed consent was obtained from all participants before testing started.

For participants with autism, additional measures were integrated in the standard diagnostic protocol. After administering the instruments required for data collection, other parts of the standard diagnostic protocol were taken. non-autistic controls only took the instruments needed for the data collection for this research. Self-reports on sensory processing [GSQ-NL] (Robertson & Simmons, 2012; Dutch Translation: Kuiper et al., 2014) and executive functioning [BRIEF-A] (Roth, Isquith & Gioia, 2008; Dutch Translation: Scholte & Noens) were examined. Trained psychologists collected the data for each participant in one sitting of 3 h on average. To avoid fatigue, one break halfway the protocol was provided. All standardized tests were administered in line with the respective manuals. Self-reports had written instructions for participants to follow, but in case of any questions the psychologist could provide help.

Statistical Analyses

Statistical analyses were conducted using SPSS version 25 [IBM, 2017]. Gender (1. male; 2. female) and diagnoses (1. autism; 2. no autism) were used as fixed factors. The assumptions for group comparison and correlational analyses have been met. First, group comparisons were conducted using one-way analyses of variance (ANOVA) tests, whereas no post-hoc tests were needed. Second, two-tailed bivariate correlational analyses were conducted to examine whether the scales of the GSQ-NL are related to scales of the BRIEF-A. Then, regression analyses were conducted to determine whether results on the GSQ-NL scales predict the outcome on the EF variables.

Results

In Table 3 the means and standard deviations on the variables for each group are displayed.

Group Comparisons GSQ-NL and BRIEF-A

Analyses of variance for self-reported executive functioning showed that both men and women with autism reported significantly more problems in executive functioning than those without ASD. Furthermore, women with autism reported more behavioral regulatory issues than men with autism, but their reports on metacognition and global executive functioning did not differ. Regarding self-reports on hypo- and hyperreactivity, we found significant differences in both the gender and the diagnostic status comparisons. Group comparisons can be found in Table 4.

Correlational Analyses GSQ and BRIEF-A

The results indicated a much higher number of significant correlations between sensory reactivity and EF for women than for men on the spectrum. In men, most of the correlations were found for hyporeactivity and EF. For women however, significant correlations were found for almost all sensory domains and these were especially related to behavioral regulation and global executive functioning. The results indicate that women with autism experienced more sensory issues and more behavioral regulatory issues than women without autism and that both seem related to each other. This seems to apply much less to autistic men. Correlational analyses are displayed in Tables 5 and 6.

Regression Models GSQ and BRIEF-A

In the first regression models for both men and women with autism, only the variables with the highest variance that significantly attributed to the model were included. In the second model, verbal comprehension was taken into account since this could explain (part of) the variance. For both men and women, the results indicate that verbal comprehension only accounts for a small and non-significant part of variance.

The regression models indicate that hyporeactivity to visual information explains most of the variance of problems with executive functioning. As for the autistic men, visual hyporeactivity explains a fair amount of variation (roughly a third of the variance) in EF problems. For women, however, proprioceptive hyporeactivity explains most of the variance, but this is also an important predictor for metacognitive problems in women with autism. Hyporeactivity to proprioceptive information thus seems to play a key role in behavioral regulatory and overall EF problems. Regression models are displayed in Tables 7 and 8.

Discussion

Results of group comparisons showed that both men and women on the autism spectrum reported significantly more problems in executive functioning than men and women not on the spectrum, which is in line with earlier findings (for a

Table 3 Means and Standard Deviations for Men and Women in Both Groups on GSQ-NL and BRIEF-A

	Adults with ASD		Non-autistic adults	
GSQ-NL ↓	*Men*	*Women*	*Men*	*Women*
Visual +	5.23 (2.54)	6.30 (2.83)	2.50 (1.99)	3.21 (1.82)
Visual -	6.40 (1.91)	7.70 (3.69)	3.45 (2.24)	4.33 (2.28)
Auditory +	7.50 (2.64)	9.27 (2.03)	4.40 (2.76)	5.46 (2.89)
Auditory -	3.70 (1.82)	4.80 (1.65)	2.35 (1.84)	3.08 (1.50)
Gustatory +	2.97 (2.16)	4.83 (2.93)	1.40 (1.23)	2.46 (1.62)
Gustatory -	4.30 (1.54)	4.70 (2.56)	2.20 (1.51)	2.50 (1.41)
Olfactory +	4.10 (2.48)	6.83 (3.41)	2.35 (2.46)	3.04 (2.26)
Olfactory -	2.67 (1.90)	3.33 (1.32)	1.55 (1.64)	2.54 (1.56)
Tactile +	4.70 (2.48)	6.87 (2.16)	1.95 (1.19)	4.00 (2.13)
Tactile -	3.66 (2.16)	3.90 (2.59)	2.15 (1.755)	1.13 (1.26)
Vestibular +	3.87 (1.78)	5.67 (2.87)	1.25 (1.29)	2.67 (2.58)
Vestibular -	1.17 (1.29)	2.50 (2.22)	0.65 (1.04)	1.42 (1.28)
Proprioception +	1.23 (1.33)	2.07 (2.42)	0.50 (0.95)	0.83 (1.20)
Proprioception -	4.90 (2.58)	7.20 (3.61)	2.60 (2.01)	2.54 (1.98)
BRIEF-A ↓				
Behavioral Regulation Index	60.83 (10.68)	71.70 (10.41)	47.50 (9.77)	49.42 (10.47)
Metacognition Index	65.93 (10.64)	70.30 (14.30)	55.60 (10.81)	53.25 (10.51)
Global Executive Composite	65.57 (10.04)	72.27 (12.43)	52.20 (10.63)	51.92 (10.37)

Table 4 Group comparisons for GSQ-NL and BRIEF-A, displayed for men and women with and without ASD

GSQ-NL ↓	Men and women with ASD	Non-autistic men and women	Men with and without ASD	Women with and without ASD
Visual +	< 0.001***	1.523	0.003**	0.030*
Visual -	< 0.001***	1.668	< 0.001***	0.077
Auditory +	0.225	1.524	0.005**	< 0.001***
Auditory -	0.664	2.117	0.094	0.106
Gustatory +	0.777	5.782*	0.087	0.154
Gustatory -	< 0.001***	0.462	0.002**	0.134
Olfactory +	0.021*	0.947	0.621	0.001***
Olfactory -	< 0.001***	4.215*	0.520	< 0.001***
Tactile +	0.005**	14.704**	< 0.001***	< 0.001***
Tactile -	< 0.001***	5.058*	0.046*	0.020*
Vestibular +	< 0.001***	3.989	< 0.001***	0.032*
Vestibular -	0.330	4.613*	< 0.001***	< 0.001***
Proprioception +	< 0.001***	1.011	0.237	< 0.001***
Proprioception -	< 0.001***	0.009	0.020*	< 0.001***
BRIEF-A ↓	0.225		0.005**	< 0.001***
Behavioral Regulation	0.001***		< 0.001***	< 0.001***
Metacognition	0.933		0.019*	< 0.001***
Global Executive Composite	0.119		< 0.001***	< 0.001***

*p ≤ .05; **p ≤ .01; ***p ≤ .001

Table 5 Correlations between GSQ-NL and BRIEF-A - Pearson's r for men with ASD

BRIEF-A →	Behavioral Regulation	Metacognition	Global Executive Composite
GSQ-NL ↓			
Visual +	0.175	0.034	0.126
Visual -	0.190	0.323	0.370*
Auditory +	− 0.008	− 0.026	0.028
Auditory -	0.272	0.458*	0.485**
Gustatory +	− 0.006	0.120	0.058
Gustatory -	0.024	0.253	0.237
Olfactory +	0.079	− 0.055	0.041
Olfactory -	0.313	0.147	0.294
Tactile +	− 0.117	− 0.081	− 0.039
Tactile -	0.387	0.166	0.258
Vestibular +	0.310	0.268	0.337
Vestibular -	0.032	0.255	0.112
Proprioception +	− 0.247	− 0.447*	− 0.351
Proprioception -	− 0.240	0.207	0.257

*p ≤ .05; **p ≤ .01; ***p ≤ .001

Table 6 Correlations between GSQ-NL and BRIEF-A - Pearson's r for women with ASD

BRIEF-A →	Behavioral Regulation	Metacognition	Global Executive Composite
GSQ-NL ↓			
Visual +	0.485**	0.351	0.424*
Visual -	0.495**	0.459*	0.505**
Auditory +	0.503**	0.320	0.426*
Auditory -	0.521**	0.295	0.405*
Gustatory +	0.381*	0.181	0.272
Gustatory -	0.405*	0.258	0.325
Olfactory +	0.614***	0.326	0.473**
Olfactory -	0.228	0.080	0.137
Tactile +	0.216	− 0.098	0.012
Tactile -	0.474**	0.405*	0.469**
Vestibular +	0.434*	0.354	0.411*
Vestibular -	0.431*	0.590**	0.571**
Proprioception +	0.565**	0.382*	0.474**
Proprioception -	0.572**	0.348	0.457*

*p ≤ .05; **p ≤ .01; ***p ≤ .001

recent meta-analysis see Xie et al., 2020). This indicates that men and women on the spectrum experience more problems in behavioral regulation (regulating emotional and behavioral responses through inhibition, flexibility, emotion regulation and self-evaluation), metacognition (problem solving by planning, organization and with help of memory) and overall executive functioning. Women with autism reported even more behavioral regulatory issues than men with autism, and this difference was not found in the comparison of non-autistic men and women, meaning that women with autism reported most of all problems in regulating emotional and behavioral responses. This difference is also in line with earlier findings (e.g. Kiep & Spek, 2016) and shows how many problems women with autism experience in regulating their behavior.

Regarding the reported sensory processing issues, we found that people on the spectrum reported more sensory issues than non-autistic adults, and this is concordance with earlier findings (e.g. Ben-Sasson et al., 2019). We found that sensory processing issues were present in various sensory

Table 7 Regression models for men with ASD

		GSQ	R^2	B	SE B	β
BRIEF-A						
Behavioral regulation	1	Visual hyporeactivity	0.353	2.596	0.829	0.594**
	2	Visual hyporeactivity	0.368	2.666	0.850	0.610**
		Verbal Comprehension Index		−0.106	0.166	−0.124
Metacognition	1	Visual hyporeactivity	0.272	2.523	0.972	0.522*
	2	Visual hyporeactivity	0.284	2.456	1.001	0.508*
		Verbal Comprehension Index		0.103	0.196	0.109
Global Executive composite	1	Visual hyporeactivity	0.353	2.825	0.902	0.594**
	2	Visual hyporeactivity	0.353	2.817	0.936	0.592**
		Verbal Comprehension Index		0.011	0.183	0.012

*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$

Table 8 Regression models for women with ASD

		GSQ	R^2	B	SE B	β
BRIEF-A						
Behavioral regulation	1	Proprioception hyporactivity	0.404	3.364	0.871	0.636***
	2	Proprioception hyporactivity	0.405	3.341	0.896	0.631***
		Verbal Comprehension Index		−0.035	0.153	−0.038
Metacognition	1	Visual hyporeactivity	0.272	2.523	0.972	0.522**
	2	Visual hyporeactivity	0.284	2.456	1.001	0.508*
		Verbal Comprehension Index		0.103	0.196	0.109
Global Executive composite	1	Proprioception hyporactivity	0.311	2.925	0.927	0.558**
	2	Proprioception hyporactivity	0.312	2.940	0.955	0.561*
		Verbal Comprehension Index		0.024	0.163	0.027

*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$

domains (for example in vision and the vestibular system), and that hyperreactivity as well as hyporeactivity were present in most of the sensory domains. These findings are in line with the notions made by Kern et al. (2007) and these findings underline the importance of sensory processing issues included as a core features of the autism spectrum. Men and women without autism differed in a minor way with regard to their sensory experiences, but the sensory experiences of men and women with autism differed significantly. Women on the spectrum again experienced, just as with regard to executive functioning, much more sensory processing issues than men on the spectrum. This does coincide with findings of Osório et al. (2021), where girls showed more severe sensory processing issues than boys, and Lai et al. (2011) who found that women had more lifetime sensory issues than men (Lai et al., 2011). Osório and colleagues note that in the study of Cummings et al. (2020) it was found that in women 'sensory over-responsivity was strongly associated with increased connectivity in the salience network and the prefrontal cortex, while in males it was associated with increased connectivity between salience and primary sensory networks, suggesting that underlying mechanisms for sensory over-responsivity might be sex-specific'. The authors therefore suggest that sensory issues could be a determinant aspect of a female phenotype of autism and that the incorporation of sensory processing issues could lead to better and earlier recognition of autism in women. However, it remains unclear whether there is also an underlying neurological difference between men and women that could explain differences in hyporeactivity (or under-responsivity) to sensory stimuli. Since we did not find these differences in the comparison of non-autistic men and women, this does not seem to be a likely explanation.

Another explanation for the gender difference found could be that women have to display more prominent autism features to be recognized as on the autism spectrum (e.g. Frazier et al., 2014), meaning that sensory processing issues need to be more prominent for women to even be included in the current (and other) studies when compared to men. Furthermore, it is possible that women on the spectrum experience more co-occurring symptoms. We often see women with burnout symptoms applicating for diagnostic assessment or seeking counselling in our clinical practice. Burnout in general is often accompanied by sensory sensitivity. However, autistic burnout seems to be different from occupational burnout and for those on the spectrum sensory sensitivity that already existed often increases further (Raymaker et al., 2020). Raymaker and colleagues state in their abstract: "Autistic adults described the primary characteristics of autistic burnout as chronic exhaustion, loss of skills, and reduced tolerance to stimulus. They described burnout as happening because of life stressors that added to the cumulative load they experienced, and barriers to support that created an inability to obtain relief from the load. (Raymaker et al., 2020, article abstract). Raymaker and colleagues found that camouflaging plays a key role in the development of an autistic burnout. Camouflaging can be described as: 'the use of conscious or unconscious strategies, which may be explicitly learned or implicitly developed, to minimise the appearance of autistic characteristics during a social setting' (Hull, 2020 p. 4). Camouflaging seems to be specific for the female autism phenotype (Hull, 2020). Maybe the vulnerability women on the spectrum seem to have for developing an autistic burnout and the increase of sensory processing issues when having such an autistic burnout, could explain the differences between men and women on the spectrum. Nonetheless, this does not directly seem to explain the differences we found with regard to hyporeactivity. One possible explanation might be that hyporeactivity to sensory input could be a risk factor for the development of an autistic burnout, since an adequate reactivity to sensory input could help to regulate one's behaviors and hold boundaries. We unfortunately did not match the groups on (co-occurring) symptom severity, which could have helped to determine whether this is a compelling explanation. However, sensory reactivity is found to correlate with autism severity in children (Hilton et al., 2010). We however strongly suggest that further research is conducted to test this hypothesis.

Results furthermore indicated that in women on the spectrum problems in executive functioning were related to sensory processing issues in general (hyper- and hyporeactivity), but for men these were only related to hyporeactivity to sensory stimuli and also to a lesser extent. This supports the former, that women with autism have to display more autistic features and probably co-occurring symptoms to even be included in a study like the current. Also it underlines the female autism phenotype with regard to women's sensory experiences and problems in executive functioning. Unfortunately, we did not measure differences in autism features or severity of co-occurring symptoms in men versus women. Future studies should take this into account.

What is especially interesting, is that most of the problems in executive functioning could be explained by hyporeactivity to sensory input for both men and women with autism. Hyporeactivity thus seems to play a key role in behavioral regulatory and overall EF problems. This supports the predictive coding theory since sensory issues can lead to prediction errors, which influences other mental processes that are needed to adequately react to the environment. Flaws in adequate reacting to the environment leads to problems in navigating in and interaction with the environment and in the long run may lead to symptoms of burnout and thus an increase of sensitivity to sensory input.

It has almost been 10 years since sensory processing issues were considered a core feature of autism (American Psychiatric Association [APA], 2013, p. 27) and the current findings underline this. Clinicians should also be aware that sensory issues can be different for men and women on the spectrum. It is important to keep this in mind during the diagnostic process and also during subsequent counselling. Unfortunately, our findings do not answer the question about what could be helpful in alleviating sensory processing issues and associated executive functioning problems. There are no good, evidence-based interventions to alleviate sensory processing issues for adults on the autism spectrum. We want to stress the importance of developing and investigating methods that could help, not only to lessen the direct problems linked to sensory processing issues, but also to prevent problems associated with higher order functions.

The current study has several limitations. We used self-reports to establish sensory processing issues and executive functioning problems, which arguably leads to less valid results than if tasks (to establish executive functioning problems) would also have been integrated. Our sample size was relatively small and therefore this study should be replicated with larger sample sizes. Participants were matched on total intelligence and verbal comprehension, which ensured that intelligence was not a confounding factor. However, participants had average to above average IQ levels. The results and conclusions in this study are probably less applicable to adults with lower IQ levels. In future research participants with lower and higher intelligence should be included to determine the influence of IQ on the current findings. Also, in future studies the influence of the age of diagnoses could be incorporated, since the current participants were diagnosed as adults and this often means that the core features of autism are milder (e.g. Vermeulen, 2002). Furthermore, men and women with autism were not matched on the prominence of autistic features. This could also restrict the generalizability of our findings and therefore it would be advisable to take this to account as well.

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