An Exploratory Study on the Relationship between Autistic Traits, Sensory Sensitivity on Zoom Fatigue and the Potential Protective Effect of Extroversion

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Abstract

This exploratory study examined the interplay of autistic traits and sensory-sensitivity and their relationship Zoom Fatigue. Previous studies have shown that sensory-sensitivities are part of experiencing autistic traits and that sensory sensitivities are associated with different behavioral, psychological and somatic outcomes. This study expected an interplay of autistic traits and sensory-sensitivity to influence the amount of Zoom Fatigue experienced and potentially both directly and indirectly lead to Zoom Fatigue. Extroversion was examined as a possible protective effect. Cross-sectional sample data was collected in a non-clinical population, using the Autism-Spectrum Quotient, Glasgow Sensory Questionnaire, Zoom Exhaustion & Fatigue Scale and The Big Five Inventory -2. Multiple Regression showed that the interaction between autistic traits and sensory-sensitivity significantly increases Zoom Fatigue until Extroversion is present. Autistic traits indirectly potentially lead to Zoom Fatigue through sensory-sensitivities and Extroversion is a possible protecting factor. These findings support and build on current bottom-up models of autistic traits and support theories that environment is important in enabling well-being.

Introduction

The COVID-19 pandemic was unprecedented in recent history where there was a global need for remote working and learning environments due to social distancing safety measures. Video conferencing (VC) was a way to stay in touch and include people in e-health services, remote learning and working environments. Since the pandemic VC has still been implemented as an option to face-to-face meetings because of convenience (little travel time, time management, etc.) and although it differs for individuals, some individuals find VC more energy consuming compared to meeting in-person (Kong et al., 2022b).

The symptoms of mental and physical exhaustion that VC can cause in some individuals is a relatively recent phenomenon known as Zoom-fatigue (ZF). One of the plausible explanations for ZF is that the cognitive and sensory burden of VC is typically higher than face-to-face meetings. The intensity of ZF is different for each individual but some factors may make some people more susceptible. Individuals with increased autistic-like behavior may be particularly susceptible to ZF due to differences in sensory processing (including hyper- and hyposensitivity) and other symptoms associated with ASD related to non-verbal social behavior (staring, atypical eye gaze). Because VC is becoming more integrated in society, education and health services, it is relevant to explore how neurodivergent individuals are affected. Hence, this study will explore the relationship between ZF, autistic traits and sensory sensitivity. First, a review of the current literature on the topic will be discussed, followed by a description of the methodology and statistical analysis approach used in the current study.

Zoom Fatigue

Zoom Fatigue is not an official diagnosis, but it is a genuine experience due to the recent surge in VC as a result of the COVID-19 pandemic. It is a wide term referring to the general exhaustion from VC, regardless of the app used. For example, ZF can leave people feeling physically exhausted, due to the strain on eyes and posture due to things like viewing distance (Bailenson, 2021; Legerer-

Bratengeyer, 2021). Sustained attention is needed to establish and understand the expected communication norms during VC which can differ from face-to-face meetings (e.g., using raise hand function, turning on camera). This can be socially exhausting and lead to withdrawal or irritable behavior towards the surrounding social environment (Döring et al., 2022). The increased cognitive load due to the sensory processing of complex visual and auditory information can make it difficult to absorb the information being presented via the VC platform (Bailenson, 2021; Legerer-Bratengeyer, 2021).

There are thought to be several underlying mechanisms leading to ZF. The first has to do with interpersonal proximity and eye gaze. People tend to compensate for social cues depending on context. For example, in a small elevator space, people will often avoid looking strangers in the eye to compensate for the lack of interpersonal space. This proximity issue is imitated during VC because faces tend to appear larger and closer than they would be in a natural face-to-face setting. This can be stressful and tiring for the brain because there is prolonged eye gaze. A gallery of faces across the whole monitor which can mimic the feeling of being constantly stared at by many people in a closed space (Fauville et al., 2021).

There is an increase in cognitive demand due to being drowned in constant non-verbal communication. Additional cognitive resources are required for decoding visual information while there is simultaneously concentration needed for the auditory information coming in. The integration of multisensory information in VC can cause audiovisual fatigue, particularly when there is asynchrony of video and audio due to hindrances in connection or streaming segregation (Döring et al., 2022). Additionally, it can be difficult to monitor, receive and decode what is being said while looking at a presentation, along with the non-verbal cues of multiple faces that are on the screen. Likewise, to communicate a non-verbal response, often requires exaggerated gestures. This can lead to misinterpretations in perceiving and the sending of non-verbal cues like eye contact, facial expression, metalinguistic awareness and responses. During VC people tend to be engaged in multi-tasking and task switching behaviors which can decrease attention for these cues (Bailenson, 2021; Fauville et al., 2021). During face-to-face contact, (non)verbal responses are typically more automatic and hence require less attentional resources.

Sensory Sensitivity

Sensory sensitives can be categorized as hyper (over)- sensitivity and hypo (under)-sensitivity but run on a continuum in the population (Metz et al., 2019). Hyper-sensitivities have been thought to be linked with shy temperament and introversion (Aron & Aron, 1997, as cited in American Psychological Association, 2023; Aron et al., 2005; Bas et al. 2021; Ujiie & Takahashi, 2022).

Individuals can be both Hypo and hyper-sensitive and sensitives may run across all modalities (visual, auditory, gustatory, olfactory, tactile, vestibular, proprioception) (Kuiper et al., 2018). According to Dunn (1997) this happens due to high or low neurological tolerance of sensory processing. Hypersensitivity is a result of having low tolerance for sensory stimuli which can feel intolerable. This can result in the individual being distractable, having difficulty remaining on one task as their attention is diverted to different stimuli or trouble deviating attention from tasks may occur (Dunn, 1997; Giuliano, 2017). Hypersensitivity may cause emotional upset, anxiety or withdrawal to avoid the arousing stimuli (Dunn, 1997).

Hyposensitivity is damped by reactivity in registering stimuli due to a high tolerance. These individuals can appear lethargic due to not having enough neural response to stimuli, resulting in inattention, lack of capacity to process cues or complete tasks. These individuals may seek out stimuli due to the apathetic sensory processing because they need more stimuli to reach neural activation. They may crave movement and thus fidget, touch, chew, make noises or seek out visual stimuli. This is linked with poor motor control and impulsive behavior regulation the threshold of tolerance can differ depending on how rested a person is and how much their senses are engaged with other tasks (Dunn, 1997). Sensory-sensitivity has a gene-environment component and have been found to have some gender differences. Women have been found to be more sensitive and avoidant, while sensitive men experience a state of constant baseline of sensory arousal (Kerley et al., 2022; Taylor et al., 2018).

Autism spectrum disorder

Autism spectrum disorder (ASD) is a pervasive neurodevelopmental disorder characterized by difficulties in social communicative interactions, differences in sensory processing, multisensory integration alterations, repetitive behaviors, rigidness in routines and intense interests (American Psychiatric Association, 2013). These symptoms were thought to be largely due to alternations in social cognition in ASD but now it has been shown that sensory alterations in ASD often precede cognitive development and are predictive of cognitive symptoms. Sensory symptoms are found in ninety percent of autistic individuals (Hazen et al., 2014; (Pellicano & Burr, 2012; Siemann et al., 2020). Hyper and hypo-sensitives often co-exist within individuals with ASD, and can be both domain and stimulus specific (Bogdashina 2003).

ASD is also linked to alternations in proprioceptive and vestibular sensory systems (Blanche et al., 2012; Mansour et al., 2021). Proprioception alterations often occur in the integration of motor-planning and spatial feedback which leads to behavioral differences which can be disruptive (Blanche et al., 2012). This includes alternations biological markers like muscle tone, hypermobility of joints, but also behaviors related to posture, misperceiving objects in space or falling. (Blanche et al., 2012). Alterations with integrating visual and proprioceptive systems are common (Glazebrook et al., 2009). Vestibular alterations are linked with auditory sensitivities which may cause issues like individuals having trouble discriminating when someone is talking to them (Mansour et al., 2021.

In the visual domain, spatial attention and sensory integration is often altered in ASD which is expressed through registering and processing difficulties but also in behavioral response differences. There seems to be a general bias towards local over global features in visual perception, which may originate from low-level alterations in visual processing. This can lead to enhanced perception for details of simple stimuli but more impairment to the complexity of the task as a whole. Visual sensory discrimination difficulties could decrease the ability to detect visual boundaries and contrasts of objects. Binocular rivalry is also often slower and there is more ambiguity of perceptual low-level input. Tracking moving stimuli is therefore difficult and in order to do this, more signal-to-noise may be required to determine the direction (Gliga et al., 2015; Kong et al., 2022a; Ronconi et al., 2012; Vandenbroucke et al., 2008). The complex visual nature of VC which often includes multimedia presentations, a gallery of faces and various backgrounds and it could be difficult for those with ASD to modulate and discriminate sensory information. They may not be able to simultaneously attend to all the visual input since it is very complex and dynamic.

ASD has also been linked to sensory alterations in the auditory domain. Auditory processing and verbal responses can sometimes be disrupted or delayed in autistic individuals, which can be the grounds for communication difficulties. In children with ASD, a delayed neural response to auditory stimulation was found to be associated with difficulties differentiating the order of sound tones presented in proximity (Roberts et al., 2010). This delay in auditory response occurred with both pure tones and complex sounds including speech. Similar to the visual domain, individuals with ASD are often slower to resolve or discriminate ambiguity in auditory signals. For example, when communication involves words which could have several meanings, they often default to common pronunciation rather than using the context from sentences (Frith & Snowling, 1983). Since there are already delays in auditory processing during face-to-face communication, the technical limitations of VC could cause additional delays and make it progressively difficult to process auditory information, leading to ZF.

In addition to the alterations in unisensory auditory and visual processing, the integration of multi-sensory audiovisual stimuli is often altered in ASD as well. ASD is linked to decreased temporal of audiovisual speech (Noel et al., 2016). Combined with the technical and spatial limitations of VC, this could make it increasingly difficult for individuals with ASD to integrate visual information, for example social and emotional cues and facial expressions, with incoming auditory verbal information (Bailenson, 2021; Legerer-Bratengeyer, 2021; Malaia et al., 2019; Minshew et al., 2002). Spatial limitations of staying in camera view and alterations in motor systems may also cause difficulties with VC (Blanche et al., 2012; Glazebrook et al., 2009; Mansour et al., 2021).

Alterations in sensory sensitivity, can also impair the ability to register this sensory which may further impair the integration of multisensory stimuli during VC (Bogdashina 2003). Taken together, these factors suggest that individuals with increased autistic symptomatology might be more susceptible to symptoms of zoom fatigue.

Extroversion

Soto and John (2017) define Extroversion with three facets which are structurally linked: sociability (talkative, outgoing), assertiveness in social expression (preference to lead and influence) and positive energy levels (enthusiastic, excited, active). Extroverted people are more likely to feel comfortable with emotional self-disclosure on social media and 5% less likely to experience ZF (Fauville et al. ,2023; Seidman, 2013). Emotional relating is something that has been found to be altered in those with ASD (Baron-Cohen, 1988; Baron-Cohen & Belmonte, 2005). ASD has been negatively linked with extroversion, moreover, behaviors like aloofness are negatively linked with extroversion (Austin, 2005; Baranova et al., 2022; Lodi-Smith et al., 2018; Rahbar Karbasdehi et al., 2018; Saucier, 1994). Thus, those with higher autistic traits may have an emotional relating style which is more detached and be more withdrawn when it comes to social seeking behaviors. On the contrary, extroversion has also been found to mediate anxiety and extroversion in those with ASD and extroversion is a predictor of pain sensitivity (Bar-Shalita & Cermak, 2020; Grella et al., 2022).

Although other researchers have also found that high autistic traits were linked with low extroversion, they also contend that autism and personality traits are independent of each other (Wakabayashi et al., 2006). Schriber et al. (2014) also found lower levels of extroversion in those diagnosed with ASD but argued that personality traits do not account for the distinguishing the variability of individual autistic symptoms. Personality traits are an enduring part of an individual's psychological makeup which is also adaptive to social situations (Costa & McCrae, 2008). Due to the variability in individual differences and the variability in the spectrum of autistic traits, it seems that those with autistic traits can also be extroverted. Extroversion may serve as a protective factor against ZF due to the tendency to have more friends, seek out social situations they find rewarding, and have a predisposition to positive emotions (Costa & McCrae, 2008; Watson & Clark, 1997)

Relevance and Implications

This study addresses the questions: how are autistic traits related to Zoom Fatigue and how is this influenced by sensory sensitivity? Do higher autistic traits lead to increased Zoom Fatigue and do alterations in sensory sensitivity lead to more Zoom Fatigue? What influence does Extroversion have? How do autistic traits, and sensory sensitivity lead to Zoom fatigue and what role does Extroversion play?

No study to date has examined how those with ASD traits experience ZF in relation to sensory sensitivities and extroversion as a possible protector, so whether this is indeed the case has yet to be determined. This is important because VC is becoming so integrated into education, working environment and e-health and ZF is a recent concept which is understudied in the ASD population. It is important to consider how those with ASD are affected by the biopsychosocial aspects. The social model of disability states that people are impaired by the way the environment is organized, thus providing an adaptive VC environment would make it more accessible for uses with higher autistic traits since sensory alterations influence their cognitive capacity (Davis et al., 2013; Robertson & Simmons, 2012). Research like this one can help understand how sensory sensitivities affect aspects integrated into daily life, as

Studies up until now have had varied results (Costa-López et al., 2021). Research like this could help understand how those with ASD experience this integration of the digital VC environment, so that VC experiences can be tailored to be less of a taxing sensory experience.

Study Aims

This study examined the relationship between autistic traits, sensory-sensitivity and Zoom fatigue while controlling on extroversion in the non-clinical, general population. Zoom Fatigue was investigated using the ZEF scale which is a self-report questionnaire to measure symptoms of ZF (Fauville et al., 2021). The ZEF scale accounts for physical and cognitive aspects of fatigue by measuring a total fatigue score through testing for fatigue types: general, emotional, visual and motivational and social fatigue. Individuals with higher scores experience more symptoms of physical and mental exhaustion induced by VC. For example, they may show more withdrawal or irritable behavior towards those around them and may be less likely to engage, focus or absorb the material being presented to them during the VC session (Fauville et al., 2021).

Autistic traits were measured using the Autism-Spectrum Quotient (AQ), a widely used self-report questionnaire that assesses autistic symptomatology in five domains, including: communication, imagination, social skills, attention switching and attention to detail. (Baron-Cohen et al., 2001; Constantino & Todd, 2003; Ruzich et al., 2015).

Finally, sensory sensitivity was assessed using The Glasgow Sensory Questionnaire (GSQ). The GSQ is a self-report questionnaire that tests sensory sensitivity and can reliably discern between hypo- and hyper-responsiveness to sensory stimulation in adults (Kuiper et al., 2018). It measures this in totality as well as in each sensory domain: visual, gustatory, auditory, olfactory, tactile, vestibular and proprioception.

Hypotheses

It was expected that increased levels of AQ and GSQ positively predicted higher levels of ZF. It is also expected that AQ-GSQ interaction would influence the strength of the relationship to ZF. It was expected that higher Extroversion would lead to less ZF. The relationship to ZF was expected to be directly linked with AQ but also indirectly because of the influence of GSQ. It was expected that increased Extroversion scores would influence ZF negatively, the direct relationship of AQ and ZF negatively as well as the indirect relationship of AQ to ZF through GSQ.

Methods

Participants

A total of 626 participants participated in the online survey via Qualtrics. Data was collected from September 2022 until March 2023. All participants were recruited at Tilburg University in the Netherlands. They were compensated for their participation with course credits as part of curricular requirements. The age ranged from 17 to 55 (M = 19.9, SD = 2.6). A total of 86 was excluded participants for having indicated to have no experience with the use of VC. A total of 17 participants were excluded from the dataset for not having correctly answered this control item. The final dataset included 523 subjects.

An International sample of English (38.2%) and Dutch-speaking (61.8%) participants was used. Participants most commonly reported being; Dutch (64.2%), German (7.7%), Polish (3.7%), Romanian (3.5%), English (2.7%), Turkish (2.7%), or other European nationalities (12.8%),
The sample consisted of males (14.1%), females (84.5%) and non-binary individuals (1.3%). No clinical data was collected in this study, thus an official distinction between individuals with a clinical diagnosis of ASD and those without could not be made. Hence, this study used a spectrum approach in which ASD was treated as a continuous scale of increased symptomatology.

Materials and procedure

All questionnaires were conducted online via Qualtrics as part of a larger battery of self-report questionnaires on personality and behavior. Besides the questionnaires used in this study (see below), the battery included questionnaires to measure or screen for ADHD, anxiety, caffeine use, alcohol use, depression, empathy, fatigue and personality. Some data from the personality questionnaire was also included this study.

Non-probability sampling was employed since participation was opt-in and participants were recruited through means of the University for curricular requirements, thus using convenience sampling methods. Requirements to participate included that participants be at least 16 years old, provide informed consent and speak adequate English or Dutch. Participants were excluded if they had any neurological or neuropsychiatric disorders as this study was focused on autistic traits in the general population. Data gathered in the questionnaire included demographics, total scores, mean scores and subscale scores of the measures described in the following section.

Zoom-Fatigue

Zoom-fatigue, the dependent variable, was accessed using the ZEF Scale which includes 15 items which measure five domains of fatigue. Each domain is measured with three questions which are scored on a 5-point Likert scale. The possible range of answers include: 1 = “Not at all”, 2 = “Slightly”, 3 = “Moderately”, 4 = “Very” to 5 = “Extremely”. The exception is two frequency enquiries which range from 1 = “Never”, 2 = “Rarely”, 3 = “Sometimes”, 4 = “Often” to 5 = “Always''. Examples of items were “How irritated do your eyes feel after videoconferencing?” and “How often do you feel too tired to do other things after videoconferencing?”. A total minimum and maximum score from 15 to 75 is possible. The average of the 15 items can be taken for a total mean score. A higher score is indicative of greater fatigue. Subscale scores can range from 3 (low fatigue) to 5 (high fatigue). Good internal consistency is indicated with each domain having a Cronbach's alpha of above .80 and a reliable average score (α =

0.95) across all 15 items. Discriminate validity is acceptable and convergent validity high (Fauville et al., 2021).

Autistic traits

Autistic traits, the independent variable, was measured using the self-report Autism-Spectrum Quotient (AQ) which includes 50 items that measure five domains of traits. Each domain is measured with ten questions which are scored on a 4-point scale. The possible range of answers include: 1 = "definitely agree", 2 = "slightly agree", 3 = "slightly disagree" to 4 = "definitely disagree". Examples of items were "I tend to notice details that others do not" and "I find it easy to work out what someone is thinking or feeling just by looking at their face". In non-clinical samples, the average score has been found to be 16.94 (95 % CI 16.4, 17.4) for the nonclinical sample (Baron-Cohen et al., 2001; Ruzich et al., 2015). A higher score is indicative of more autistic traits; 32 or above is indicative of clinical levels but a score or 26 has been suggested as a cutoff for a sample which is clinic referred (Crane et al., 2009). Moderate test-retest and inter-rater reliability is indicated along with internal consistency (α = 0.81) and reasonable construct validity is reasonable (Baron-Cohen et al., 2001).

Sensory Sensitivity

Sensory sensitivity, the moderating variable, was assessed with the Glasgow Sensory Questionnaire. It has 42 items measuring atypical sensory experiences. Each subscale measures hypo- and hyper-sensitivity in each of the seven senses. The possible range of answers include: 0 = "Never", 1 = "Rarely", 2 = "Sometimes", 3 = "Often" to 4 = "Always". Examples of items were "Do you react very strongly when you hear an unexpected noise?" and "''Do you find yourself fascinated by small particles?". A total minimum and maximum score from 0 to 168 is possible. Total subscale scores can range from 0 (low amount of hypo- or hyper-sensitivity) to 8 (high amount of hypo- or hyper-sensitivity). A higher score is indicative of greater sensitivity. Good internal consistency is indicated α = 0.94) across all 42 items (Robertson & Simmons, 2012). Convergent and divergent validity is good (r = 0.72) when compared to AASP, another sensory questionnaire and (r = 0.42) when compared to the STAI which measures anxiety (Kuiper et al., 2018).

Extroversion

Extroversion, was measured with the Extroversion subscale of The Next Big Five Inventory, second edition (BFI2-EXT). Twelve-items rated on a Likert scale from 1, disagree strongly, to 5, agree strongly. Examples of items were (e.g., "I am someone who is outgoing, sociable") and six reversed items (e.g., "I am someone who prefers to have others take charge"). Total subscale scores can range from 12 to 60. A higher score indicates higher levels of the trait extroversion. The Extroversion subscale of the BFI2-EXT has as test- retest reliability of .84 and Cronbach's alpha of .88 (Soto & John, 2017).

Ethical Considerations, Privacy and Data Handling

Confidentiality was essential, before any data was collected participants were given clarification on: consent, confidentiality, study intent and terms of participation. Participants were given the option to consent or object to participation. If they objected, the data was not collected. The privacy and data handling guidelines of Tilburg University were employed throughout the course of data collection and reporting. Data was anonymized and (in the case of transfer) encrypted to avoid confidentiality breach. Apart from the SONA identification number that was needed to grant course credits, no personal data was collected during this study. The dataset used for statistical analysis only included the fully anonymized raw data (i.e., random participant numbers were used). This datset will be archived for a minimum of ten years. All procedures in this study have been reviewed and approved by the Scientific and Ethical Review Board at Tilburg University (approval number: EC-2016.48a4).

Statistical Analyses Plan

Prior to the statistical analyses, all raw data was pre-processed using Microsoft Excel, version 16.73 (Microsoft, 2019). The raw total and subscale scores for the AQ, GSQ, BFI2-EXT Extroversion subscale, and ZEF scale were calculated. The data of all participants included in the analysis was checked to ensure user experience with Zoom. In addition, the data was filtered for inattentive response bias on the basis of an attention check item in the ZEF questionnaire.

Descriptive statistics

After pre-processing, the dataset was submitted to statistical analysis using in JASP software, version 0.16.3 (JASP Team, 2022). Boxplots were used to inspect potential outliers. The AQ, GSQ, ZEF and BFI2-EXT variables were treated as quantitative, discrete and non-categorical. Shapiro-Wilks Tests and Q-Q plots were used to verify the normality assumption. Skewness and kurtosis values indicated data distribution. Pearson's correlation coefficient *(r)* calculated association and variation between the variables within the range of 1.00 to + 1.00.

Moderation analysis

A fitted multiple linear regression model (y=bx or y=a+bx with α =0) was used to examine how AQ, GSQ and Extroversion predict ZF. An interaction was used to examine if the strength of that relationship is moderated by sensory sensitivity (GSQ). ZF was the outcome measure, with total AQ score and Total GSQ and Extroversion subscale scores as predictors. AQ and GSQ were mean-centered for the interaction terms.

Multicollinearity between independent variables was accessed with variable inflation factors (VIF) scores. Homoscedasticity, linearity and independence of errors assumptions were tested with Durbin-Watson, scatterplots, P-P plots, Q- plots, and a histogram of residuals. Cook's distance was inspected for influential data points.

A post-hoc statistical power calculation for F test will be used since a robust assumption F test was used for estimation in a multiple linear regression model with homogeneity of variances assumption (Lenth, 2007). A guideline of $F > 2.5$ will be used to reject the null hypothesis of at least one significant finding (Kissell & Poserina, 2017).

Mediation analysis

Structural equation modeling mediation analysis was performed to see how and which effects sensory sensitivity accounts for in the relationship between autistic traits and ZF while controlling for extroversion. This includes the direct effect of autistic traits on ZF, the indirect effect of autistic traits on ZF mediated by sensitivity and the total effect of autistic traits. Assumptions are the same for regression and mediation (Warner, 2021). Scatter plots and linear regression were used to check the assumption that each pair of variables had a linear relationship. A significant relationship is not necessary, as a relationship may not appear in regression if there is a negative correlation, this may show up later in mediation as significant suppression variable (Warner, 2021). Multicollinearity between independent variables was accessed with variable inflation factors (VIF) scores. Homoscedasticity, linearity and independence of errors assumptions were tested with Durbin-Watson, scatterplots, P-P plots, Q- plots, and a histogram of residuals. Cook's distance was inspected for influential data points.

ZF was the outcome measure, with total AQ score as the predictor, and total GSQ as the mediator. Extroversion subscale scores was the control variable. The mean-centered terms were used for AQ, GSQ and Extroversion variables. Due to its nature of robustness to violations of normality, coefficient estimates were based on 95% confidence intervals from bias corrected bootstrap with 5000 replications (Warner, 2021). This was used to calculate confidence intervals of the indirect effects, and these were inspected for direction.

Results

Descriptive Statistics

The mean AQ scores were in line with that in the average population (Hoekstra et al., 2008). GSQ, ZEF and Extroversion were also in line with the average population (Fauville et al., 2021; Kuiper et al., 2018; Soto & John, 2017). See Table 1 for the descriptive statistics.

Table 1

Descriptive Statistics

	AQ	GSQ	ZEF	BFI2-EXT
Median	108.00	53.00	31.00	40.00
Mean	109.04	55.79	32.81	39.24
Std. Deviation	13.51	18.63	12.26	7.59
IQR	17.00	23.00	18.00	10.00
Variance	182.58	347.00	150.33	57.57
Range	96.00	117.00	60.00	41.00
Minimum	69.00	14.00	15.00	19.00
Maximum	165.00	131.00	75.00	60.00
Sum	57028.00	29176.00	17160.00	20523.00

Note. Descriptive Statistics from Autism-Spectrum Quotient Total score, The Glasgow Sensory Questionnaire

Pearson's correlations showed a strong positive association between GSQ and ZF r = .60, p <.001, and a positive moderate association of GSQ with AQ, r = .46, p <.001. AQ had a positive moderate association with ZF, r = .40, p <.001, but was negatively associated with Extroversion, r = .49, p <.001. Extroversion had a negative small association with ZF, r = -.27, p <.001, as well as with GSQ, r = .13, (p = .003).

Assumption Testing

Boxplots were inspected for outliers, there were some scores which fell outside two standard deviations, no scores were removed since they still fell within the theoretical correct scale range. Standard residuals were checked to confirm the data distribution fell within the range of -.3 to .3, which showed that there was some influence of extreme scores on the data (Std. Residual Min = -3.077, Std. Residual Max = 3.099). The assumption of non-zero variances of predictors was met with predictors showing differences in variance which is noted in Table 1. There was no indication of influence on the model from individual cases with the Cook's distance being no greater than 1.

Shapiro-Wilks Test was significant (p < .001) rejecting the null hypothesis that the data was normally distributed, although Shapiro-Wilks test tend can be overpowered due to large sample sizes, thus robust analysis methods were employed so that this assumption could be met (Field et al., 2013;

Ghasemi & Zahediasl, 2012). Indeed, visual inspection of the Q-Q plots showed that most of the datapoints did not deviate much from normal distribution, except for extreme values at the ends. See Table 2 for the values of skew and kurtosis and figure for the distribution of the sample data. Histogram inspection showed that the data was approaching a normal bell curve but was skewed to the right.

Table 2

Skewness and Kurtosis Values

Variable	AQ	GSQ	ZEF	BFI2-EXT
Skewness	0.51	0.73	0.62	-0.06
Std. Error of Skewness	0.11	0.11	0.11	0.11
Kurtosis	0.86	0.86	-0.25	-0.46
Std. Error of Kurtosis	0.21	0.21	0.21	0.21

Note. Skewness and kurtosis values between range of 1.00 to + 1.00.

Inferential Statistics

Moderation Analysis

A fitted multiple regression (model 1) was used to examine whether higher levels of a AQ had a positive relationship with higher levels of ZF and if that relationship was positively moderated by higher levels of GSQ. The model was significant, $F(3, 520) = 33.55$, $p < .001$, $R^2 = .16$, explaining 16% of the variance in ZF. GSQ did positively influence the strength of the relationship between AQ and ZF as the interaction was significant, B(se) = -.97(.004), $t(520) = -8.49$, $p < .001$.

Extroversion was then added to the model (model 2) to understand how it predicts ZF. The model was significant, $F(4, 519) = 997.76$, $p < .001$, $R^2 = .87$, explaining 87% of the variance in ZF. GSQ did not positively influence the strength of the relationship between AQ and ZF as the interaction was non-significant when extroversion was present, B(se) = -.00(.002), $t(519) = .07$($p = .932$). The non-significant interaction was discarded and the model was run to examine the main effects. The model (model 3) was significant, $F(3, 520) = 33.50$, $p < .001$, $R^2 = .16$, explaining 16% of variance in ZF. There was a main effect of AQ on ZF B(se) = .53(04) $t(520) = 13.70$, $p < .001$, implying that higher AQ predicted higher ZF positively. There was a main effect of GSQ on ZF *B*(se) = .53(26) *t*(520) = 13.70, $p < .001$, implying that higher GSQ predicted higher ZF positively. Extroversion also had a main effect on ZF, *B*(se) = -.07(05) *t(*519) = -2.77, ($p = .006$), implying that higher Extroversion predicted lower ZF. See Table for unstandardized coefficients in Table 3, 4 and 5.

Table 3

Unstandardized coefficients model 1

	b	SE
AQ	-0.04	0.12
GSQ	0.21	0.09
AQ*GSQ	0.04	4.35×10^{-3}

Note. b = unstandardized regression coefficients; SE = standard error. $p < .05$.

Table 4

Unstandardized coefficients model 2

	b	SE
AQ	0.38	0.05
GSQ	0.31	0.03
BFI2-EXT	0.81	0.01
AQ ✻ GSQ	1.49×10^{-4}	1.74×10^{-3}

Note. b = unstandardized regression coefficients; SE = standard error. $p < .05$.

Table 5

Unstandardized coefficients model 3

Model 3		*b*	SE
AQ		0.38	0.04
GSQ	GSQ	0.31	0.03
BFI2-EXT		0.81	0.01

Note. b = unstandardized regression coefficients; SE = standard error. $p < .05$.

A post-hoc statistical power calculation for a fixed-effect F test of linear models showed a large effect $\chi2 > 0.999$. This is based on a two-tailed test, $\alpha = .05$, this was calculated using the observed P-value, numerator, denominator degrees of freedom and level of alpha (Lenth, 2007).

Assumptions were checked, collinearity was met with no VIF values higher than 10, and a Tolerance of less than 0. Tolerance values ranged from .57 to .87 for the variables. VIF values ranged from 1.14 to 1.73. Durbin-Watson value (1.9) was close to two with no significant evidence ($p = .384$) of autocorrelation in the residuals, thus independent errors were assumed in the full factor model which included the interaction and extroversion. In models 1 and 3, Durbin-Watson were significant, $p < .001$ and under 1, which indicate some correlation between residuals.

Reviewing a scatterplot of standardized residuals showed some heteroskedasticity in model 1 and 3, thus a violation of the homogeneity of variance. Model 2 met the assumptions of homogeneity. Scatterplot inspection of the variables showed a linear relationship between the predictors and outcome variable. Q-Q plots of variables and standardized residuals were used to review linearity assumptions, which showed no extreme deviations from the line in model 2, however models 1 and 3 showed some deviations.

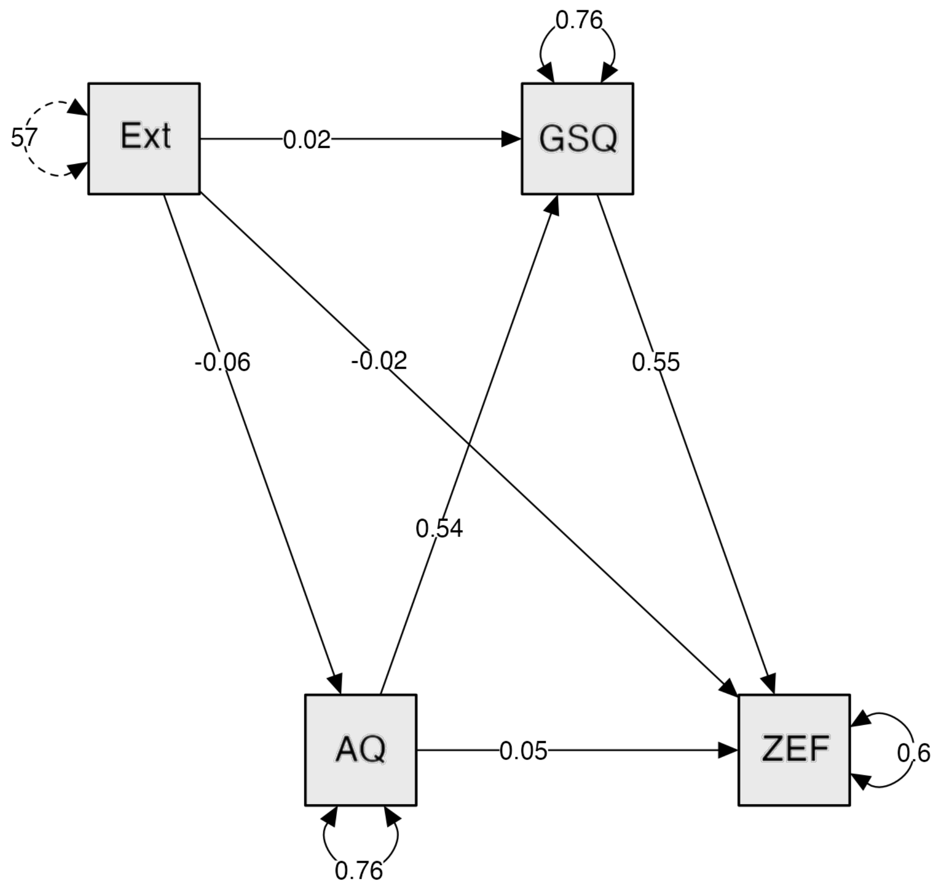
Mediation Analysis

Structural Equation Modeling in JASP was used to perform a bias corrected bootstrapping was performed, with 5,000 replications and 95% confidence interval was used to look at the possible mechanisms accounting for the relation of ZF through AQ, GSQ and the protective factor of Extroversion. All predictor variables were mean centered. The total effect of autistic traits (AQ) with GSQ as a mediator, while controlling for extroversion was significant, *c*(se) = .35(.04), $p < .001$, 95% CI [.25, .44], accounting moderately for 40% of variance in zoom fatigue (R^2 = .40). AQ significantly predicted ZF through the indirect effects of GSQ, a*b*(se) = .30(.03), $p < .001$, 95% CI [.24, .37].

The direct effect of AQ on ZF independent GSQ and Extroversion was not statistically significant: *c* (se) = .05(.04), ($p = .226$), 95% CI [-.04, .14), implying that AQ did not directly account for the relationship with ZF when Extroversion was accounted for. The relationship of AQ with ZF was thus in this model fully mediated by GSQ while controlling for extroversion. See Figure 1 for the full standardized mediated pathway.

Figure 1

Mediation Path Plot



Note. Full mediation effect of AQ on ZEF through indirect path of GSQ while controlling for BFI2-EXT.

The effect of AQ to GSQ was significant, *b*(se) = .54(.04), $p < .001$, 95% CI [.45, .63], as well as the effect of GSQ on ZEF, *b*(se) = .55(.04), $p < .001$, 95% CI [.47, .63], GSQ functioned as a pathway for AQ to ZF. Extroversion's negative effect on AQ was significant, *b*(se) = -.07(.00), $p < .001$, 95% CI [-.07, -.06], although extroversion showed a significant positive effect on GSQ, *b*(se) = .01(.00), *p* = (002), 95% CI [.00, .03]. Extroversion had a significant negative effect on ZEF, *b*(se) = -.02(.00), $p < .001$, 95% CI [-.03, -.01], showing that as extroversion increased that AQ decreased and GSQ increased but ZEF decreased. This implies that Extroversion confounds the relationship between AQ, GSQ and ZF.

The indirect effect, ab, was statistically significant for the increase of ZF thorough the effects of AQ level on GSQ: *b*(se) = .299(.032), $p < .001$. The effects of ZF are fully mediated through sensory sensitivities and Extroversion, and extroversion directly effect ZF negatively. See Table 6 for standardized path coefficients.

To meet assumptions for mediation; scatterplots were reviewed for a linear relationship between each pair of variables, which showed some deviation in GSQ, this was negative and less linear. There was a steep linear negative relationship between extroversion and AQ. Regression was also done in the previous step, each variable showed a linear relationship as noted in the noted in moderation, although not significant in the case of AQ and ZF or the interaction. In a significant linear regression model, $F(2,521) = 9.22$, (p = .010), R^2 = .02, extroversion significantly predicted a negative relationship with GSQ, b(se) = -.13 (.11), t(521) = -3.04, (p =.003). In a significant linear regression model, $F(2,521) = 166.300$, p < .001, R2= .24, extroversion significantly predicted a negative relationship with AQ, in a model that was statistically significant, b((se) = -.49 (.11), t(521) = -12.90, p < .001.

Table 6

Path coefficients

							95% Confidence Interval	
			b	SE	z-value	p	Lower	Upper
GSQ	→	ZEF	0.55	0.04	14.21	< .001	0.47	0.63
AQ	→	ZEF	0.05	0.04	1.21	0.23	-0.04	0.14
AQ	→	GSQ	0.54	0.04	12.34	< .001	0.45	0.64
BFI2-EXT	→	AQ	-0.06	5.02×10^{-3}	-12.92	< .001	-0.07	-0.06
BFI2-EXT	→	GSQ	0.02	5.77×10^{-3}	3.06	2.20×10^{-3}	5.87×10^{-3}	0.03
BFI2-EXT	→	ZEF	-0.02	5.19×10^{-3}	-4.20	< .001	-0.03	-0.01

Note. Delta method standard errors, bias-corrected percentile bootstrap confidence intervals, ML estimator.

The data met the assumption of collinearity was met with no VIF values higher than 10, and a Tolerance of less than 0. Tolerance values were 1. VIF values were 1. Durbin-Watson values were (= 1.88) and (= 2.03) and were close to two with no significant evidence (p = .015); (p = .707) of autocorrelation in the residuals, thus independent errors were assumed.

Reviewing a scatterplot of standardized residuals showed heteroskedasticity, thus a violation of the homogeneity of variance. Q-Q plots of variables and standardized residuals were used to review linearity assumptions, which showed no extreme deviations from the line.

Discussion

This study investigated the degree that autistic traits, sensory sensitivity and the interplay of the two, influenced the strength of a possible relationship with ZF and how extroversion could serve as a protective factor. The relationship as a potential underlying framework of ZF was also investigated.

It was expected that the higher levels of ZF would be experienced by those who had higher scores on AQ and GSQ and that the interplay of the two would regulate the relationship with ZF. The interplay between AQ and GSQ had a strong influence, increasing ZF. This was expected when looking at research which characterizes sensory sensitivity alterations as a core feature of ASD which can be both hyper or hypo and domain specific (Bogdashina 2003; Hazen et al., 2014; Siemann et al., 2020; Robertson & Simmons, 2012).

Once Extraversion was present the interaction between AQ and GSQ disappeared, and once this interaction was gone then Extraversion negatively influenced ZF. It was expected that those with more extraversion would experience less ZF, and indeed ZF was found to decrease as extraversion levels increased. This suggests that extraversion is a suppressor variable, since the nature of the relationship between AQ and ZF through GSQ went from positive to negative, changing directions. This was expected because it has been shown that personality can have both predictive and moderating effects on stress experienced from using technology (La Torre et al., 2019; Srivastava et al., 2015). This finding in this study contributes to the work of Bailenson (2021) and Fauville et al. (2021) which found that attributes like personality and sociodemographic variables and cognition may contribute to ZF. For example, women and introverts have been found to be more vulnerable to ZF.

Extraversion thus played an influential role in interrupting the strength of the AQ-GSQ relationship to ZF, but also accounting for more explanation of the strength. This is because AQ and GSQ both independently increased ZF positively when Extraversion levels were low. The increase in ZF due to higher AQ scores was expected based on how ASD traits can manifest. These were also measured as part of the AQ; differences in social communicative expression but also interpretation can result in misinterpretations due to altered eye contact, articulation, bluntness, non-appropriate contextual responses or social anxiety. Imagining someone's intentions or feelings can be difficult and communication between ASD individuals and neurotypicals had been found to be unclear and disrupted when compared to communication within their own neurotype group (Crompton et al., 2020; Lewis, 2018; Neumann et al., 2006). This could create fatigue responses in those with ASD which might potentially also be misinterpreted by neurotypical participants in the VC session, creating additional cognitive demands on top of that which the VC technology limitations. This is why individuals with more ASD could be more susceptible to symptoms of Zoom fatigue (Crompton et al., 2020; Dawson et al., 2004; Northam et al.).

The increase seen in ZF due to higher levels of GSQ, was expected because individuals are not engaged in a real sensory tactile environment with each other when they use VC, so cognitive effort is required (Fauville et al., 2021). This study's findings contribute to this finding; that ZF is related to sensory-sensitivities and that cognitive fatigue can result because sensory-sensitivities. This is supported by (McGarrigle & Mattys, 2023), who found that those who have sensory-sensitivities when processing stimuli experience fatigue as a result of cognitive fatigue because of processes like attention. Van den Boogert et al (2022) found that individuals who are hypersensitive for sensory-stimuli experiencing psychological and psychosomatic symptoms like fatigue which manifests mentally, emotionally and cognitively in ways like impairment or distancing. Hyposensitive individuals also experienced more stress (Van den Boogert et al. 2022)

As for possible explanations of how the relationship to ZF is setup; AQ was expected to directly relate to ZF but also indirectly through GSQ. AQ did not directly relate to AQ, but it related to ZF through GSQ. Thus, experiencing a higher degree of sensory symptoms was related to having higher autistic traits and higher ZF. This finding is supported by what research has found about bottom-up sensory alterations in ASD and supports the notion that sensory-sensitives may proceed the cognition that follows (Pellicano & Burr, 2012; Siemann et al., 2020).

Sensory based motor sensitives in ASD could explain the indirect pathway from AQ to GSQ to ZF. These could make it hard for example to organize their gaze and position to remain still in view for hours or to distinguish what is being said which can be tiring. Often the behavioral response of sensory-sensitivities found in ASD include propping oneself up on the desk, making rocking movements, fidgeting, etc. (Bailenson, 2021; Blanche et al., 2012; Dunn, 1997; Glazebrook et al., 2009; Lewis, 2018; Mansour et al., 2021; Sato et al., 2020). So, this could defiantly hinder which non-verbal language they are sending out to others but also their attention for to what others are saying during the Zoom-meeting (Baron-Cohen, 2017; Döring et al., 2022; Lewis, 2018; Neumann et al., 2006).

The audio-visual sensory integration alternations in ASD and listening fatigue further explain this finding (McGarrigle & Mattys, 2023; Stevenson et al., 2014). Also, the lack of knowledge to how the situation is going to be or knowing it will be draining can create sensory-sensitivities in those with ASD, which is the reason why adaptation flexibility in such sensory situations can be difficult for those with ASD (Pellicano & Burr, 2012). The high number of Zoom-meetings experienced by our sample size due to COVID-19 restrictions supports this.

The expected a negative relationship with AQ and ZF and Extroversion was found, being thus a possible protective factor to ZF. This was protective effect of Extroversion was expected because Extroverts tend to look for social interactions, because they find it rewarding and they are able to do this through proficiently adapting to and mastering social situations. They also have a positive outlook and the energy to accomplish this (Costa & McCrae, 2008; Watson & Clark, 1997). This is an interesting finding for speculation in regards context of the circumstances of COVID-19 measures, the high frequency of VC and sensory-sensitivity. It could be speculated that despite these circumstances, that traits that extroverts saw the contact via VC as an opportunity for social contact and that their extroversion led to less ZF, even though they experienced sensory-sensitivities. Judge et al. (2004) found that Extroversion is moderately linked with leadership. This could be another possible link in explaining why Extroversion seemingly helped adaptation during the context of this study.

Extroversion was expected to have a negative relation to GSQ, but there was a positive found. This was unexpectedly since extroversion has been found to moderate the relationship with pain and anxiety and extroverts tend to experience more positive emotions, thus it would be expected to be a possible guard against sensory-sensitivity in this study (Bar-Shalita & Cermak, 2020; Grella et al., 2022; Watson & Clark, 1997). There are some alternative explanations for this; Bas et al (2021) explains that those with high hyper-sensitivity tend to think of themselves as introverts, avoiding busy environments because of the threat of overstimulation. It is possible that extroverts experience more hypo-sensitivities, thus the higher score or that they engage in sensory-seeking. As Dunn (1997) explained, there are different behavioral responses with the degree of sensory threshold, thus also sensation-seeking and this is confirmed by Bas et al (2021) who reported that people feel like their levels of extroversion may differ depending on how overwhelmed they are by sensory sensitivity. As Nigg et al. (2002) indicated, extroversion has been a difficult trait to associate with certain conditions, it really also depends on what scale is being used. Since some like hypersensitivity seem to be related to the construct of introversion, it is worth further investigating how personality is measured and presents itself in those who have ASD but also sensory-sensitivities since results are conflicting until now.

The context of this study is also important here; a majority of participants were participating in VC as a result of preventive Corona measures or lockdown. It is possible that the experienced hinder of the prevention measures on their daily lives may have reduced the number of sensory experiences they were used to, hence increased sensation-seeking to compensate. The high amount of VC every day, over long period of time may have increased sensory-sensitivity as well, since other factors like coping, environment, technical literacy and general health can have an effect (Döring et al., 2022; Fauville et al., 2021). Another explanation would be that ADHD traits, which were not controlled for in this sample, are associated with co-morbid sensory-sensitivities and hyperactivity is associated with extroversion (Bijlenga et al., 2017; Nigg et al., 2002; Panagiotidi et al., 2018). This is a limitation of the study.

As mentioned before that during some the data collected in this study was during the COVID-19 pandemic where restrictions measures were in place, so these participants used Zoom with high frequency which could create a bias result in ZEF scores. Caution should be taken therefore when generalizing results. Intercept free multiple regression was used to explain how these variables in particular explain variation in relationship to each other without the explanation of other possible factors, meaning both predictor and outcome variables were set to zero. This can create some heteroscedasticity or biased autocorrelation of residuals as Krämer (1985) notes, which can have some effect on the Drubin-Watson values, however it should be noted that the model had satisfactory values once Extroversion was included. Since no randomization, restriction or matching participants was done due to the sampling method of this study design, statistical methods like regression were used which bring proper comparison of how much distortion covariates bring add to relationships (Pourhoseingholi et al., 2012).

This study adds to research like Van den Boogert et al (2022) which found that sensory-sensitivity can lead to burn out and stress due to cognitive factors. This study looks at similar constructs and confirms similar findings but goes a step further to look at possible underlying mechanisms. This study is also contributing to research that is needed into sensory-sensitives because this can affect so many areas of an individual's health, well-being and mental health (Costa-López et al., 2021). Individuals with sensory-sensitivities are more likely to be less aware of hyperarousal, feelings of helplessness, low self-efficiency, depression, anxiety and negative affect within themselves (Aron & Aron, 1997, Brindle et al., 2015; van den Boogert et al., 2022). Sensory sensitivities are associated with ASD, which is associated with depression and depression is part of global health burden (Santomauro et al., 2020; van Heijst et al., 2019). This has a cascade effect for everyone, affecting not only the individual but their environments, the companies they work for and the costs society has for health care. Psycho-education on a social, environmental to inform policy makers, software developers, organizations, schools and healthcare about the implications is imperative, as well as ensuring that the individual is aware (Ormel, 2020). Since ASD traits and sensory sensitivities appear on a continuum in the general population, without a clinical diagnosis, ZF can affect even those who think they have no special needs. Taking these needs into account can help ensure that the environment is enabling and not disabling (Davis et al., 2013).

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