Acta Psychologica 222 (2022) 103463

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Sensory processing sensitivity predicts performance in an emotional antisaccade paradigm

Alexandra Hoffmann *, Robert Marhenke, Pierre Sachse

University of Innsbruck, Department of Psychology, Innrain 52a, 6020 Innsbruck, Austria

ARTICLE INFO

Keywords:
Sensory processing sensitivity
Antisaccade paradigm
Inhibitory control
Emotional stimuli

ABSTRACT

Sensory Processing Sensitivity (SPS) is a common, heritable, and evolutionarily conserved trait, describing inter-individual differences in responsiveness and a more cautious approach to novel stimuli. It is associated with increased activation of brain regions involved in awareness, integration of sensory information, and empathy during processing of emotional faces. Furthermore, SPS is related to better performance in a visual detection task. Even though SPS is conceptualized to be closely related to traits characterized by pausing before acting, no study to date has assessed the relation between SPS and inhibitory control in a behavioral inhibition task. The present study fills this gap by investigating how SPS influences individual performance on two different antisaccade paradigms including emotional face stimuli. In addition, we assessed self-reported mood, anxiety, and depressiveness. Results showed that SPS was related to faster processing speed on the emotional, but not the classic antisaccade paradigm. Moreover, SPS predicted inhibitory control speed above mood and depressiveness. Our results provide evidence that higher SPS participants show superior inhibitory abilities, especially during the processing of emotional stimuli. This is in line with earlier findings showing better performance in a visual detection task as well as increased brain activation during emotional face processing.

1. Introduction

Sensory processing sensitivity (SPS) is a common, heritable, and evolutionarily preserved trait associated with greater awareness of sensory stimulation, deeper and more reflective cognitive processing, higher emotional and physiological reactivity, and more behavioral inhibition towards novel stimuli (Aron & Aron, 1997; Greven et al., 2019). Aron and Aron (1997) based their concept of SPS on biological evidence, showing sensitivity to the environment has consistently evolved as two different behavioral patterns in the face of novel stimulation: One is 'pausing before acting' to assess survival-related subtleties of the situation and compare them to earlier experiences, resulting in more timid, and introverted behavior. The other is 'acting first', allowing to respond faster to opportunities and discover survival-relevant cues through motor exploration, resulting in bolt and more extraverted behavior (Boyce & Ellis, 2005; Wolf, van Doorn, & Weissing, 2008); this may also be described as responsiveness to the environment (Aron, Aron, & Jagiellowicz, 2012). SPS is especially related to high inhibitory functioning and other traits characterized by pausing before acting. Individual differences in sensitivity of three major neurological systems underlie the most fundamental personality differences (Gray, 1981; McNaughton & Gray, 2000). The Behavioral Activation System (BAS), the Behavioral Inhibition System (BIS) and a fear system based in the amygdala (Fight, Flight, Freezing System, FFFS). While the BAS as a reward system is sensitive to reward and escape from punishment and thus initiates goal directed behavior towards appetitive stimuli, the FFFS is regarded to modulate responses to all aversive stimuli. The BIS, as a negotiator, produces alert interest and a pause in activity that allows for the processing of conflicting information. Thus, the BIS is balancing between the urge to approach and to satisfy needs and the urge to stop, consider risks and consider how best to make use of an opportunity. Building on Gray's original theory (1981), Kagan (1994) developed the term *behavioral inhibition to the unfamiliar* and found similar broad physiological and cognitive differences between what he called inhibited and uninhibited children. These include behavioral inhibition (Carver & White, 1994), biological sensitivity to context (Boyce & Ellis, 2005), differential susceptibility (Pluess, 2015), as well as introversion and neuroticism (Aron & Aron, 1997).

The inhibition of behavior as a way to forestall rash responses to the environment allows for deeper and more elaborate processing and thus

* Corresponding author at: University of Innsbruck, Institute of Psychology, Innrain 52a, 6020 Innsbruck, Austria.
E-mail addresses: alexandra.hoffmann@uibk.ac.at (A. Hoffmann), robert.marhenke@uibk.ac.at (R. Marhenke), pierre.sachse@uibk.ac.at (P. Sachse).

https://doi.org/10.1016/j.actpsy.2021.103463
Received 5 October 2021; Received in revised form 6 December 2021; Accepted 9 December 2021
Available online 21 December 2021

is a prerequisite for reflective behavior. As such, we assume that individual differences in the integrity of those inhibitory functions modulate the responsive behavioral patterns related to environmental sensitivity and SPS. Even though inhibitory control plays a key role in the conceptualization of SPS, to date no study has investigated the relationship between them. Indeed, these individual differences in behavioral inhibition might clarify the difference between SPS and a pathological hypersensitivity occurring in seemingly related disorders. Thus, the goal of our research is to (a) investigate whether SPS is related to better information processing during an inhibitory control paradigm, and (b) apply an antisaccade eye-tracking task to investigate SPS. There are distinct forms of inhibition e.g., inhibition of intrusive stimuli, cognitive, motor and oculomotor inhibition (Nigg, 2000). The antisaccade task is mainly concerned with oculomotor inhibition, while the application of emotional faces in this task further allows evaluating interference control of specific emotions.

SPS has been linked to several psychological disorders e.g., anxiety and major depression (Liss, Mailloux, & Erchull, 2008). These disorders are found to be related to impaired inhibition. In fact, patients show impaired performance in a very common task to investigate inhibition of reflexive behavior, namely the antisaccade task. In general, anxiety and depression are associated with diminished performance in antisaccade tasks, even though these relationships may vary, based on the emotional content of stimuli (Chen, Clarke, Watson, MacLeod, & Guastella, 2014; Derakshan, Ansari, Hansard, Shoker, & Eysenck, 2009; Reinholdt-Dunne et al., 2012). Reinholdt-Dunne et al. (2012) found greater antisaccade costs for angry than neutral faces in highly anxious participants compared with low-anxious individuals. Others found that highly anxious subjects demonstrated higher latencies as compared to low anxious participants regardless of emotional valence (Basanovic et al., 2018). Anxiety was further associated with the aberrant processing of positive stimuli, and greater compensatory efforts in the inhibition of threat (Chen et al., 2014.). Attentional control theory proposed that especially trait worry impairs efficiency more than performance effectiveness and that anxious individuals allocate attentional resources to threat-related stimuli (Eysenck et al., 2007). Depressed subjects exhibit higher error rates in a classic antisaccade task (Hoffmann, Ettinger, Montoro, Reyes del Paso, & Duschek, 2019). In a recent study of healthy individuals (Hoffmann, Büsel, Ritter, & Sachse, 2021), emotional faces were found to improve inhibitory control performance in comparison to neutral geometrical and scrambled face stimuli in the antisaccade task. SPS was associated with increased activation of brain regions involved in awareness, integration of sensory information, and empathy (i.e., insula, inferior frontal gyrus, and middle temporal gyrus) during processing of emotional faces (Acevedo et al., 2014). An emotional antisaccade task has never been applied to investigate the influence of SPS on inhibitory control during emotional face processing, though.

Existing evidence suggests that higher-SPS individuals are more thorough in searching for subtle cues and perform better in visual attention tasks. SPS is usually applied as a continuous predictor variable. One fMRI study examined whether SPS was associated with neural responses to gross versus subtle changes in visual stimuli (Jagiellowicz et al., 2011). Higher SPS was associated with longer response latencies to minor versus major changes; activation was greater in brain areas associated with high-order visual processing and attention (i.e., right claustrum, left occipitotemporal, bilateral temporal and medial and posterior parietal regions), when detecting minor versus major changes in stimuli. These results persisted even after controlling for introversion and neuroticism, indicating they are specific to SPS. Gerstenberg (2012) found that higher SPS was associated with faster reaction times and lower error rates in a visual detection task; higher SPS was associated with more stress, though. Finally, in another fMRI study, Asians and Americans performed either context-independent (typically easier for Americans) or context-dependent (typically easier for Asians) visuospatial tasks (Aron et al., 2010). High-SPS compared to low-SPS participants showed less culture-related differences in task performance. While low-SPS subjects showed increased activation of the frontal and parietal cortex when performing the more difficult task for their respective cultural background, this was not present in high-SPS subjects. While in easier tasks high-SPS individuals show faster responses (Gerstenberg, 2012), they inhibit their responses and pay more attention to stimuli in cognitively demanding tasks (Jagiellowicz et al., 2011).

The antisaccade paradigm allows to test whether high-SPS individuals are able to control their reflexive reaction towards different target cues better than low-SPS individuals are. As there is previous research regarding the relation between SPS-subscales and performance on a visual detection task (Gerstenberg, 2012), we hypothesized that higher SPS would be related to faster processing speed and higher accuracy on the antisaccade task (Hypothesis 1). As higher SPS is associated with increased activation of brain regions involved in integration of sensory information, and empathy during processing of emotional faces (Acevedo et al., 2014), we assume better performance in the emotional antisaccade task (Hypothesis 2). For the different emotional stimuli, we would investigate whether SPS interacts with emotional valence on an exploratory basis. As Acevedo et al. (2014) found significant differences in brain activation for happy and sad faces compared to neutral ones, SPS most likely interacts with emotional valence in the emotional antisaccade task. As there are strong associations between SPS and depression (Liss et al., 2008), we decided to add depression and mood as control variables. We hypothesized that SPS would have incremental validity beyond individual mood and depression (Hypothesis 3).

2. Method

2.1. Participants and procedure

Forty-four volunteers (M_{age} = 23.11, SD_{age} = 4.98; 35 female) participated with informed consent in the present study, which was approved by the Ethics Committee of the University of the first author. Subjects participated in the experiment as party of an empirical seminar within their bachelor program in psychology. Exclusion criteria were visual impairment corrected with glasses or any current psychological problem. To rule out the presence of mental disorders in our sample, we applied the screening questionnaire from the Diagnostic Expert System for Mental Disorders (DIA-X-SSQ; Wittchen & Perkonigg, 1996). After outlier analysis, 38 subjects (M_{age} = 23.26, SD_{age} = 5.38; 31 female) were entered into the final analyses. To identify outliers within each condition, we applied the absolute deviation around the median technique (Leys et al., 2013). Therefore, we calculated the absolute deviation around the median for each condition and removed any subject that deviated more than three absolute deviations from the median in one or more conditions. In sum, we excluded six subjects and computed all analyses without those outliers. Note that the experiment was very long and tiring, so that processing speed most likely declined in some participants over the course of the 3 h experimental session.

Sensitivity power analysis with G * Power (Faul et al., 2009) showed that a sample size of $N = 26$ would be sufficient to detect a medium-sized effect of $r = 0.50$ with a statistical power of 1-β = 0.80 and α = 0.05 for all the computed correlations. Effect sizes for correlations between SPS-subscales and RTs in a visual search task are ranging from $r = -0.39$ to -0.65 (Gerstenberg, 2012). Sample size was determined before data analysis. Furthermore, we assume that 2625 replications per participant and 38 participants yield sufficiently precise estimates and good confidence interval coverage.

2.2. Measures

2.2.1. Antisaccade tasks

Binocular eye-movement registration was carried out using an infrared-based eye-tracking system (Tobii TX-300, Tobii AB, Danderyd, Sweden), which allows for quantification of horizontal eye-movements up to ±25° (sampling-rate: 300 Hz). Before data acquisition, we calibrated and validated the eye-tracker with a 5-point calibration procedure. We performed artifact correction and calculation of saccade parameters with a custom-developed interactive analysis software. This software allowed evaluating RTs based on a linear regression and eye-movement interval classification.

In the classic antisaccade paradigm, a neutral cue (white circle, 1° diameter, line thickness 0.3°) was presented in the center of the display for a variable interval of 1000–2000 ms (Tobii TX-300 screen-unit; resolution: 1920 × 1080; refresh rate: 60 Hz; viewing distance: 60 cm; Dell Precision T-5610). Viewing distance was kept stable via chinrest. After the variable interval, this cue moved either 12° left or right from the center. After another 1000 ms, it moved back to the center (no gap or overlap, see Fig. 1). Each position appeared equally often (randomized order). First, subjects fixated on the central cue. As soon as it appeared on another location, they had to fixate on the mirror position of the respective target. Moreover, subjects performed prosaccades, where they simply followed the cue. Pro- and antisaccades were presented block-wise. In addition, we applied the same paradigm with emotional faces (happy, fearful, sad, and neutral; FACES database from Ebner et al., 2010). We removed non-facial features (e.g., hair, neck) from those faces and resized them to 6°x8°. Stimuli were balanced for gender (50% male faces); faces were Caucasian. Emotions were presented randomized within blocks. All blocks were preceded by 10 practice trials, the data from which were discarded. After each 75 trials, subjects got the possibility to take a break. We randomized the order of blocks across participants. The experimental session took 2.5 to 3 h per participant, depending on individual breaks between blocks.

- *Block 1* (classic prosaccades): 150 trials
- *Block 2* (classic antisaccades): 375 trials
- *Block 3–4* (emotional faces prosaccades): 600 trials (150 per emotion)
- *Block 5–8* (emotional faces antisaccades): 1500 trials (375 per emotion)

Central performance indicators were (1) saccade reaction times (RTs) and (2) error rates (ERs). Eye-movements were defined by criteria of amplitude ≥1.5°, velocity ≥ 30°/s and latency between 100 and 900 ms (Ettinger et al., 2003). We excluded trials with RTs faster than 100 ms from analyses to avoid the inclusion of potentially premature or artifact-bearing responses. This threshold was set to ensure that the response was in fact a reaction to the stimulus as well as a saccadic eye-movement (Ettinger et al., 2003). For calculating RTs, the beginning of a saccade was used. Artifact-affected trials and direction errors were removed from analyses (2.5% of trials in the classic paradigm; 2.4% of trials in the emotional paradigm). Thus, RTs were calculated only on correct responses.

2.2.2. Questionnaires

For measuring SPS, we applied the German version of the Highly Sensitive Person Scale (HSPS-G, Konrad & Herzberg, 2017), which consists of 26 items that are rated from "1" (strongly disagree) to "5" (strongly agree) e.g., "Changes in my life shake me up", and "I am easily overwhelmed by things like bright lights, strong smells, coarse fabric, or sirens close by". Cronbach's Alpha was 0.92 within our sample.

Moreover, participants were presented with the German version of the Beck Depression Inventory (BDI-II; Hautzinger et al., 2006). Higher scores indicate an increased burden of depressive symptoms. Additionally, we applied the mood scale (von Zerssen & Petermann, 2011) for quantification of current affective state. This 28-item scale includes positive and negative adjectives related to general aspects of well-being (e.g., cheerful, relaxed), as well as to more specific emotions (e.g., depressed, insecure). Higher values on the scale indicate a more adversely affected emotional state. Last, the state-trait anxiety scale (Spielberger, 1983) was applied to measure both state and trait anxiety. Items are rated from "1" (never) to "8" (always) e.g., "Unimportant thoughts run through my head and weigh me down." for trait anxiety and "I am tense" for state anxiety. Cronbach's Alpha was 0.79 for state and 0.86 for trait anxiety within our sample (see Fig. 3 for the distribution of SPS, BDI-II, and trait anxiety scores within our sample).

Trait anxiety, neuroticism, negative affectivity, or other related traits are highly correlated with SPS, mainly due to the negative tone of items measuring response to overstimulation (Aron et al., 2012). Therefore, SPS is usually calculated as a residual score between SPS and neuroticism, because SPS is highly correlated with neuroticism, as both traits share a great overlap. As we did not measure neuroticism, we decided to use trait anxiety instead, which is highly correlated with neuroticism (Zunhammer, Eberle, Eichhammer, & Busch, 2013).

2.3. Statistical analyses

In our sample, SPS correlated significantly with trait anxiety (r = 0.45, $p < 0.01$) and depression ($r = 0.39$, $p < 0.01$). Following standard procedures using the HSP-scale (e.g., Acevedo et al., 2014; Acevedo, Jagiellowicz, Aron, Marhenke, & Aron, 2017), trait anxiety was partialized out of the SPS-scores. Thus, results reported herein are not confounded with trait anxiety.

First, we applied a repeated measures ANOVA model to test whether performance indices (RTs and ERs) differed between different emotions (neutral, happy, sad, and fearful). We further added SPS as a covariate, to test whether SPS interacted with emotional processing. For the first and second hypothesis, we computed Pearson correlations between SPS as well as RTs, and ERs of the antisaccade paradigms. For the third hypothesis, we performed a hierarchical regression analysis with SPS as a predictor and RT as dependent variable. We added age and gender in a first step, depression, and mood scores in a second step, and SPS in a third step. To reduce the influence of heteroskedasticity, robust standard errors were calculated using the heteroskedasticity consistent estimator 3 (HC3; Davidson & MacKinnon, 1993) in the RLM macro for SPSS by Darlington and Hayes (2017). Standardized coefficients are reported. All statistical analyses were conducted in SPSS 26.

3. Results

The repeated measures ANOVA for RTs showed no significant effect of emotion ($F[3, 108] = 0.07$, $p = 0.978$). RTs were similar for all emotions (all M = 263 ms). When including SPS as a covariate, we found a significant emotion by SPS interaction ($F[3, 108] = 3.5$, $p = 0.018$, $\eta_p^2 = 0.089$). Simple contrasts showed significant differences between the sad and neutral face ($F[1, 36] = 6.72$, $p = 0.014$, $\eta_p^2 = 0.157$). For ERs, there was neither a main effect of emotion ($F[3, 108] = 0.008$, p = 0.999) nor an emotion by SPS interaction ($F[3, 108] = 0.543$, p =

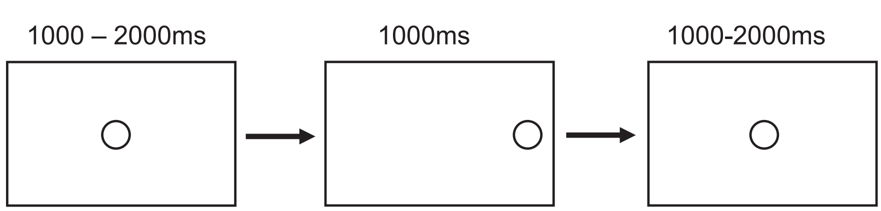

Fig. 1. Trial sequence as applied in the antisaccade paradigms.

0.654). Correlation analysis showed a significant relation between SPS and RT in the emotional, but not in the classic antisaccade task (see Table 1). There was no relation between SPS and prosaccade performance. Processing speed was faster for each of the displayed emotions individually (see Table 2); accuracy in terms of ERs was not related to SPS. To test whether SPS predicted RTs in the emotional antisaccade paradigm beyond mood and depressiveness, we performed a multiple linear regression model with age, gender, as well as mood and depressiveness as control variables. For this first regression model, we calculated the mean RT across all emotions, as mean RTs did not differ between emotions.

In a first step our model showed that neither age nor gender could predict mean RTs in the emotional antisaccade paradigm ($\Delta R^2 = 0.00$, $F(2,35) = 0.03$, $SE = 1.03$, $p = 0.97$) within our sample, thus indicating that age and gender could not account for individual differences in antisaccade processing speed. Furthermore, we added individual mood and depression scores in a second step, which increased the explained variance from 0% to 4%; results indicated that neither depressiveness nor mood predicted emotional antisaccade performance ($\Delta R^2 = 0.04$, $F(2,33) = 0.61$, $SE = 1.04$, $p = 0.55$). Finally, SPS was the only variable that successfully predicted emotional antisaccade performance within this sample ($\Delta R^2 = 0.21$, $F(1,32) = 7.19$, $SE = 0.95$, $p = 0.01$) and further increased the explained variance from 4% to 21%. In a second model, we focused on the sad faces separately. Again, age and gender did not predict RTs for sad faces ($\Delta R^2 = 0.00$, $F(2,35) = 0.06$, $SE = 1.03$, $p = 0.94$). Furthermore, we added individual mood and depression scores in a second step, which increased the explained variance from 0% to 5%; results indicated that neither depressiveness nor mood predicted RTs for sad face stimuli ($\Delta R^2 = 0.05$, $F(2,33) = 0.79$, $SE = 1.03$, $p = 0.46$). Finally, SPS was the only variable that successfully predicted ($\Delta R^2 = 0.26$, $F(1,32) = 8.96$, $SE = 0.93$, $p = 0.01$), with even more variance explained than for the mean RT across all stimuli. Thus, our cleaned data set shows that SPS has a strong influence on inhibitory control performance beyond mood and depression, especially in sad face stimuli (see Fig. 2).

4. Discussion

Our study aimed to investigate whether the stable temperament trait SPS influences inhibitory control performance in the antisaccade task. We put a special focus on the processing of emotional face stimuli in comparison to neutral, geometrical ones. In line with earlier studies (e.g., Aron et al., 2010; Jagiellowicz et al., 2011; Gerstenberg, 2012), SPS predicted performance on an emotional antisaccade task in terms of RTs, thus partially supporting earlier results and our first hypothesis. This result was solely valid for the emotional version of the paradigm, but not the classic one containing smaller, circular stimuli. Nevertheless, it is in accordance with studies that found a relation between SPS and higher-order visual processing (Aron et al., 2010; Jagiellowicz et al., 2011) as well as increased activation of brain regions involved in the integration of sensory information, and empathy during the processing of emotional faces (Acevedo et al., 2014). In line with results by Gerstenberg (2012), we found that SPS was related to shorter RTs, which supports that notion of faster cognitive processing due to SPS.

As SPS was related to faster RTs in the emotional, but not in the classic antisaccade paradigm, one could argue that SPS is indeed related to better processing capacity (Aron et al., 2010). What we found complements earlier results, as higher SPS was related to faster inhibitory control with emotional face stimuli. In line with our second hypothesis, this was not true for non-emotional stimuli. Jagiellowicz et al. (2011) found that the higher an individual was on SPS, the longer it took them to respond to minor changes (relative to time spent on major changes). Their task was to compare two pictures with major vs. minor changes in it. As we also applied the antisaccade task with small, circular stimuli, but found no relation to SPS there, we can confirm this result. In general, subjects took longer to respond to smaller, circular than to bigger facial stimuli (see Table 2). We further conducted an analysis to test whether different emotions are processed differently and found no difference concerning RTs or ERs between the four emotions. When entering SPS as a covariate to the ANOVA model, we found a significant SPS by emotion interaction, where the sad face differed significantly from the neutral emotion concerning RTs. This result stands in line with another study that found significant positive associations for greater SPS scores with brain activations in response to sad versus neutral faces (Acevedo et al., 2014).

As for our third hypothesis, SPS predicted antisaccade performance beyond individual mood and depressiveness. We proposed this as SPS is usually related to higher depression scores (Liss et al., 2008), which was also true for our sample. When controlling for anxiety, the residual SPS-score was not related to depressiveness anymore. Nevertheless, only SPS was able to predict performance in the emotional antisaccade task, which suggests that SPS has a greater influence on processing speed than individual mood. As our results show, depression scores are clinically not relevant for a major depression diagnosis (see figure xx). Earlier studies showing a relation between SPS and depression (e.g. Liss et al., 2008) did not report descriptive statistics for their samples. Therefore, we do not know if this result is sample specific. In earlier studies, SPS has also been linked to other psychological disorders, e.g. ADHD (Panagiotidi, Overton, & Stafford, 2020), and schizophrenia (Brown, Cromwell, Filion, Dunn, & Tollefson, 2002), which are characterized by pathological emotional and sensory processing (Acevedo, Aron, Pospos, & Jessen, 2018). Subjects suffering from ADHD or schizophrenia display severe deficits in the antisaccade paradigm, e.g. longer RTs and higher ERs (Aichert et al., 2013; Hakvoort Schwerdtfeger et al., 2012; Hutton & Ettinger, 2006; O'Driscoll et al., 2005). Although AHDH and schizophrenia share some overlap with SPS, our results promote the notion

Table 1
Means, standard deviations, and Pearson product-moment correlations between the SPS residual score (controlling for anxiety), and pro- as well as antisaccade performance indices in both the classic and emotional version of the paradigm.

	M(SD)	1.	2.	3.	4.	5.	6.	7.	8.
1. SPS_RES	0.00 (0.58)								
2. Anti-classic RT	309.14 (28.58)	−0.274							
3. Anti-classic ER	14.92 (10.29)	−0.150	0.108						
4. Anti-emotional RT	270.16 (24.49)	**−0.429****	**0.709****	0.277					
5. Anti-emotional ER	8.96 (7.00)	−0.291	0.108	**0.574****	**0.343***				
6. Pro-classic RT	228.53 (20.28)	0.023	**0.336***	**−0.343***	0.116	**−0.359***			
7. Pro-classic ER	1.28 (2.31)	0.023	0.143	0.196	0.273	**0.356***	0.047		
8. Pro-emotional RT	202.73 (15.08)	−0.162	−0.015	**−0.343***	0.077	**−0.448****	0.262	0.000	
9. Pro-emotional ER	3.24 (3.90)	0.141	−0.178	−0.003	−0.017	0.222	−0.242	**0.234***	−0.159

Note. $N = 38$.
Significant values are bold.
* $p < 0.05$.
** $p < 0.01$.

Table 2
Means, standard deviations, and Pearson product-moment correlations between the SPS residual score (controlling for anxiety), and emotional antisaccade performance indices, split up for the four different emotions.

	M (SD)	1.	2.	3.	4.	5.	6.	7.	8.
1. SPS_RES	−0.01 (0.59)								
2. Anti-neutral RT	263.56 (19.50)	**−0.364***							
3. Anti-happy RT	263.54 (18.54)	**−0.441****	**0.969****						
4. Anti-sad RT	263.46 (19.09)	**−0.478****	**0.965****	**0.987****					
5. Anti-fearful RT	263.74 (18.57)	**−0.421****	**0.978****	**0.985****	**0.987****				
6. Anti-neutral ER	8.16 (6.17)	−0.261	**0.370***	**0.344***	**0.332***	**0.326***			
7. Anti-happy ER	8.14 (6.39)	−0.313	**0.374****	**0.390***	**0.374***	**0.363****	**0.940****		
8. Anti-sad ER	8.19 (6.52)	−0.264	0.308	0.297	0.299	0.271	**0.941****	**0.944****	
9. Anti-fearful ER	8.15 (6.40)	−0.302	**0.330***	**0.334***	**0.323***	0.309	**0.946****	**0.951****	**0.953****

Note. $N = 38$.
Significant values are bold.
* $p < 0.05$.
** $p < 0.01$.

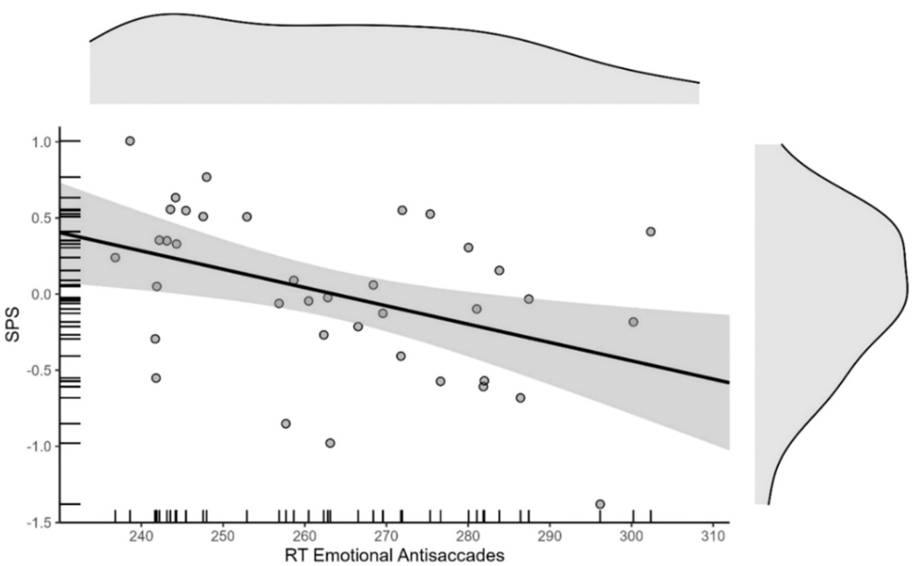

Fig. 2. SPS and its association with mean RTs in the emotional antisaccade task. Standardized values ($N = 38$) are displayed with linear regression and a 95% confidence interval. Histograms on either side of the graph denote relative frequency distributions.

that SPS is different from those disorders, as cognitive processing and inhibitory control are not impaired.

One major limitation of the present study pertains to the predominantly young sample; performance in the antisaccade task was shown to be better in younger adults (Munoz, Broughton, Goldring, & Armstrong, 1998; Nieuwenhuis, Ridderinkhof, De Jong, Kok, & Van Der Molen, 2000). However, even with this possible restriction of range of age, our results support the assumption about the relation between SPS and performance on the emotional antisaccade task and thus speak for its potential replicability. Furthermore, regression analysis indicated that performance on the emotional antisaccade task was fully independent of age and gender as we controlled for those variables within our multiple linear regression model. Another limitation is that the experimental session was very long (2.5 to 3 h), which surely had an influence on individuals' processing speed over time. Fatigue indeed might have played a role for those subjects we excluded from our analyses, as they were probably more tired than the rest of the sample. Moreover, wearing contact lenses can cause your eyes to dry out more quickly, which definitively happened to some of these subjects. Nonetheless, by randomizing the experimental blocks and making breaks, data quality was very good e.g., only 2.5% of data comprised of blinks or direction errors. Unfortunately, we did not measure the Big Five personality dimensions within our sample. Usually, SPS is calculated as a residual score between SPS and neuroticism, because SPS is highly correlated with neuroticism, as both traits share a great overlap. As we did not measure personality, we decided to use trait anxiety instead, which is highly correlated with neuroticism (Zunhammer et al., 2013). The relationship between SPS and depressiveness is consistent with other studies (Hofmann & Bitran, 2007; Meyer et al., 2005; Neal et al., 2002). Gerstenberg (2012) found that mainly low sensory threshold predicted performance on their visual detection task. In contrast, we found no relations between SPS-subscales and performance in the antisaccade tasks. Therefore, it is likely that different tasks lead to different outcomes, and that depending on the cognitive components involved, different sub-dimensions of SPS might be involved. For future research, it would be interesting to investigate on which occasions SPS leads to slower or faster cognitive processing and whether differences between SPS-subscales or the global SPS-scale are able to predict performance outcomes. Therefore, one could vary the intensity of stimuli in the antisaccade task and then compare performance between those two kinds of stimuli.

Finally, the results reported from our study as well as from other studies show that SPS predicts performance on executive performance tasks beyond individual states such as mood and depressiveness. Therefore, SPS has positive implications for better and faster processing of visual information, especially emotional faces. On the other hand, several studies have shown that SPS is also related to higher perceived stress. Thus, for the clinical as well as for the organizational and work

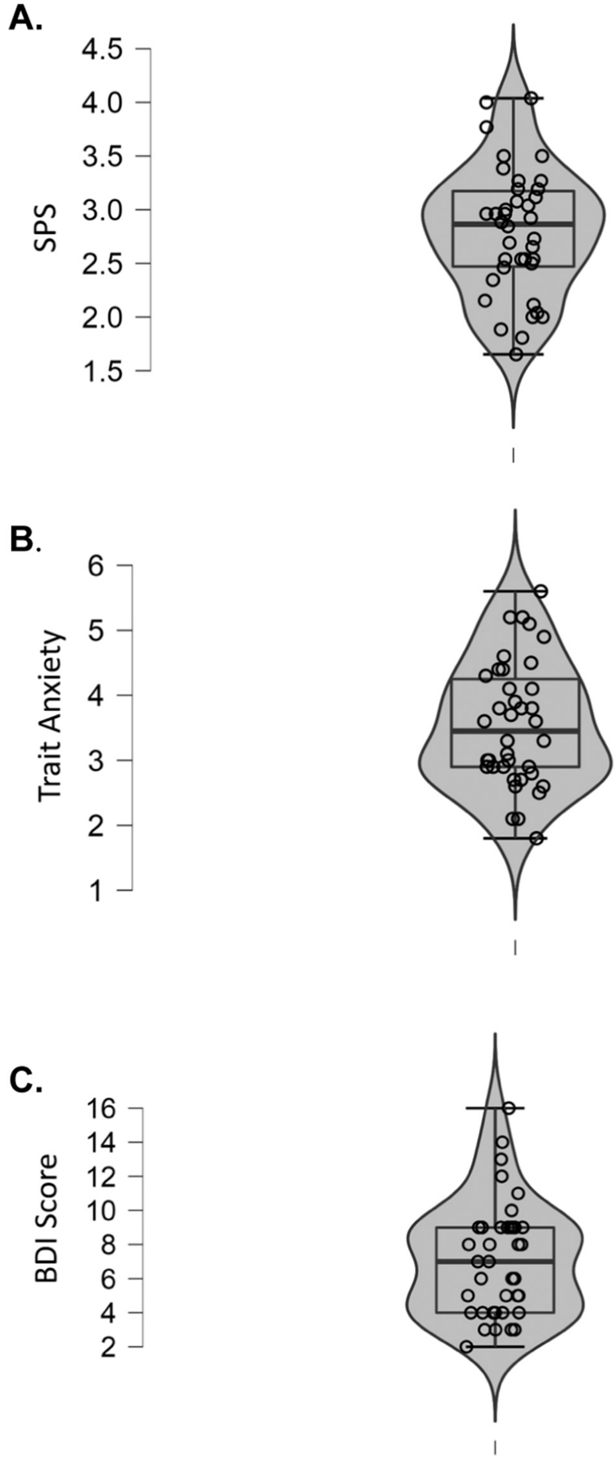

Fig. 3. Boxplots showing the distribution of SPS (A), trait anxiety (B) and BDI-II scores (C) within our study sample.

psychology domains, future research should have a closer look at the positive and negative consequences of this trait and investigate how to strengthen the positive behavioral outcomes while intervening when negative consequences occur.

Data availability

Data is available on Open Science Framework (https://osf.io/xyqvj/).

Declaration of competing interest

The authors declare that they have no conflict of interest.

Acknowledgements

We would like to thank Stella Ilg and Tobias Holzinger for carrying out data collection in our eye-tracking lab.

References

Acevedo, B. P., Aron, E. N., Aron, A., Sangster, M. D., Collins, N., & Brown, L. L. (2014). The highly sensitive brain: An fMRI study of sensory processing sensitivity and response to others' emotions. *Brain and Behavior, 4*(4), 580–594. https://doi.org/10.1002/brb3.242

Acevedo, B., Aron, E., Pospos, S., & Jessen, D. (2018). The functional highly sensitive brain: A review of the brain circuits underlying sensory processing sensitivity and seemingly related disorders. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 373*(1744). https://doi.org/10.1098/rstb.2017.0161

Acevedo, B. P., Jagiellowicz, J., Aron, E., Marhenke, R., & Aron, A. (2017). Sensory processing sensitivity and childhood quality's effects on neural responses to emotional stimuli. *Clinical Neuropsychiatry: Journal of Treatment Evaluation, 14*(6), 359–373.

Aichert, D. S., Derntl, B., Wöstmann, N. M., Groß, J. K., Dehning, S., Cerovecki, A., Möller, H.-J., Habel, U., Riedel, M., & Ettinger, U. (2013). Intact emotion–cognition interaction in schizophrenia patients and first-degree relatives: Evidence from an emotional antisaccade task. *Brain and Cognition, 82*(3), 329–336. https://doi.org/10.1016/j.bandc.2013.05.007

Aron, E. N., & Aron, A. (1997). Sensory-processing sensitivity and its relation to introversion and emotionality. *Journal of Personality and Social Psychology, 73*(2), 345–368. https://doi.org/10.1037/0022-3514.73.2.345

Aron, A., Ketay, S., Hedden, T., Aron, E. N., Rose Markus, H., & Gabrieli, J. D. E. (2010). Temperament trait of sensory processing sensitivity moderates cultural differences in neural response. *Social Cognitive and Affective Neuroscience, 5*(2–3), 219–226. https://doi.org/10.1093/scan/nsq028

Aron, E. N., Aron, A., & Jagiellowicz, J. (2012). Sensory processing sensitivity: A review in the light of the evolution of biological responsivity. *Personality and Social Psychology Review, 16*(3), 262–282. https://doi.org/10.1177/1088868311434213

Basanovic, J., Notebaert, L., Clarke, P. J. F., MacLeod, C., Jawinski, P., & Chen, N. T. M. (2018). Inhibitory attentional control in anxiety: Manipulating cognitive load in an antisaccade task. *PloS One, 13*(10), Article e0205720. https://doi.org/10.1371/journal.pone.0205720

Boyce, W. T., & Ellis, B. J. (2005). Biological sensitivity to context: I. An evolutionary-developmental theory of the origins and functions of stress reactivity. *Development and Psychopathology, 17*(2), 271–301. https://doi.org/10.1017/S0954579405050145

Brown, C., Cromwell, R. L., Filion, D., Dunn, W., & Tollefson, N. (2002). Sensory processing in schizophrenia: Missing and avoiding information. *Schizophrenia Research, 55*(1–2), 187–195. https://doi.org/10.1016/S0920-9964(01)00255-9

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology, 67*(2), 319–333.

Chen, N. T. M., Clarke, P. J. F., Watson, T. L., MacLeod, C., & Guastella, A. J. (2014). Biased saccadic responses to emotional stimuli in anxiety: An antisaccade study. *PloS One, 9*(2), Article e86474. https://doi.org/10.1371/journal.pone.0086474

Darlington, R. B., & Hayes, A. F. (2017). *Regression analysis and linear models*. New York: The Guilford Press.

Davidson, R., & MacKinnon, J. G. (1993). *Estimation and inference in econometrics*. Oxford University Press.

Derakshan, N., Ansari, T. L., Hansard, M., Shoker, L., & Eysenck, M. W. (2009). Anxiety, inhibition, efficiency, and effectiveness. An investigation using antisaccade task. *Experimental Psychology, 56*(1), 48–55. https://doi.org/10.1027/1618-3169.56.1.48

Ebner, N. C., Riediger, M., & Lindenberger, U. (2010). FACES—A database of facial expressions in young, middle-aged, and older women and men: Development and validation. *Behavior Research Methods, 42*(1), 351–362. https://doi.org/10.3758/BRM.42.1.351

Ettinger, U., Kumari, V., Crawford, T. J., Davis, R. E., Sharma, T., & Corr, P. J. (2003). Reliability of smooth pursuit, fixation, and saccadic eye movements. *Psychophysiology, 40*(4), 620–628. https://doi.org/10.1111/1469-8986.00063

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*(2), 336–353. https://doi.org/10.1037/1528-3542.7.2.336

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Gerstenberg, F. X. R. (2012). Sensory-processing sensitivity predicts performance on a visual search task followed by an increase in perceived stress. *Personality and Individual Differences, 53*(4), 496–500. https://doi.org/10.1016/j.paid.2012.04.019

Gray, J. A. (1981). A critique of Eysenck's theory of personality. In H. J. Eysenck (Ed.), *A model for personality* (pp. 246–276). Springer.

Greven, C. U., Lionetti, F., Booth, C., Aron, E. N., Fox, E., Schendan, H. E., Pluess, M., Bruining, H., Acevedo, B., Bijttebier, P., & Homberg, J. (2019). Sensory processing sensitivity in the context of environmental sensitivity: A critical review and development of research agenda. *Neuroscience and Biobehavioral Reviews, 98*, 287–305. https://doi.org/10.1016/j.neubiorev.2019.01.009

Hakvoort Schwerdtfeger, R. M., Alahyane, N., Brien, D. C., Coe, B. C., Stroman, P. W., & Munoz, D. P. (2012). Preparatory neural networks are impaired in adults with attention-deficit/hyperactivity disorder during the antisaccade task. *NeuroImage. Clinical, 2*, 63–78. https://doi.org/10.1016/j.nicl.2012.10.006

Hautzinger, M., Kühner, C., & Keller, F. (2006). *Beck Depression Inventar II (BDI 2)*. Frankfurt a. M.: Pearson Assessment & Information.

Hoffmann, A., Ettinger, U., Montoro, C., Reyes del Paso, G. A., & Duschek, S. (2019). Cerebral blood flow responses during prosaccade and antisaccade preparation in major depression. *European Archives of Psychiatry and Clinical Neuroscience, 269*(7), 813–822. https://doi.org/10.1007/s00406-018-0956-5

Hoffmann, A., Büsel, C., Ritter, M., & Sachse, P. (2021). Do emotional stimuli interfere with response inhibition? Evidence from the antisaccade paradigm. *Cognition & Emotion, 1–8*. https://doi.org/10.1080/02699931.2021.1979475

Hofmann, S. G., & Bitran, S. (2007). Sensory-processing sensitivity in social anxiety disorder: relationship to harm avoidance and diagnostic subtypes. *Journal of Anxiety Disorders, 21*(7), 944–954. https://doi.org/10.1016/j.janxdis.2006.12.003

Hutton, S. B., & Ettinger, U. (2006). The antisaccade task as a research tool in psychopathology: A critical review. *Psychophysiology, 43*(3), 302–313. https://doi.org/10.1111/j.1469-8986.2006.00403.x

Jagiellowicz, J., Xu, X., Aron, A., Aron, E., Cao, G., Feng, T., & Weng, X. (2011). The trait of sensory processing sensitivity and neural responses to changes in visual scenes. *Social Cognitive and Affective Neuroscience, 6*(1), 38–47. https://doi.org/10.1093/scan/nsq001

Kagan, J. (1994). *Galen's prophecy: Temperament in human nature*. Routledge.

Konrad, S., & Herzberg, P. Y. (2017). Psychometric properties and validation of a german high sensitive person scale (HSPS-G). *European Journal of Psychological Assement, 35*(3), 364–378. https://doi.org/10.1027/1015-5759/a000411

Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology, 49*(4), 764–766. https://doi.org/10.1016/j.jesp.2013.03.013

Liss, M., Mailloux, J., & Erchull, M. J. (2008). The relationships between sensory processing sensitivity, alexithymia, autism, depression, and anxiety. *Personality and Individual Differences, 45*(3), 255–259. https://doi.org/10.1016/j.paid.2008.04.009

McNaughton, N., & Gray, J. A. (2000). Anxiolytic action on the behavioural inhibition system implies multiple types of arousal contribute to anxiety. *Journal of Affective Disorders, 61*(3), 161–176. https://doi.org/10.1016/S0165-0327(00)00344-X

Meyer, B., Ajchenbrenner, M., & Bowles, D. P. (2005). Sensory sensitivity, attachment experiences, and rejection responses among adults with borderline and avoidant features. *Journal of Personality Disorders, 19*(6), 641–658. https://doi.org/10.1521/pedi.2005.19.6.641

Munoz, D. P., Broughton, J. R., Goldring, J. E., & Armstrong, I. T. (1998). Age-related performance of human subjects on saccadic eye movement tasks. *Experimental Brain Research, 121*(4), 391–400.

Neal, J. A., Edelmann, R. J., & Glachan, M. (2002). Behavioural inhibition and symptoms of anxiety and depression: Is there a specific relationship with social phobia? *British Journal of Clinical Psychology, 41*(4), 361–374. https://doi.org/10.1348/014466502760387489

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*(2), 220–246. https://doi.org/10.1037/0033-2909.126.2.220

Nieuwenhuis, S., Ridderinkhof, K. R., De Jong, R., Kok, A., & Van Der Molen, M. W. (2000). Inhibitory inefficiency and failures of intention activation: Age-related decline in the control of saccadic eye movements. *Psychology and Aging, 15*(4), 635–647. https://doi.org/10.1037/0882-7974.15.4.635

O'Driscoll, G. A., Dépatie, L., Holahan, A.-L. V., Savion-Lemieux, T., Barr, R. G., Jolicoeur, C., & Douglas, V. I. (2005). Executive functions and methylphenidate response in subtypes of attention-deficit/hyperactivity disorder. *Biological Psychiatry, 57*(11), 1452–1460. https://doi.org/10.1016/j.biopsych.2005.02.029

Panagiotidi, M., Overton, P. G., & Stafford, T. (2020). The relationship between sensory processing sensitivity and attention deficit hyperactivity disorder traits: A spectrum approach. *Psychiatry Research, 293*, Article 113477. https://doi.org/10.1016/j.psychres.2020.113477

Pluess, M. (2015). Individual differences in environmental sensitivity. *Child Development Perspectives, 9*(3), 138–143. https://doi.org/10.1111/cdep.12120

Reinholdt-Dunne, M. L., Mogg, K., Benson, V., Bradley, B. P., Hardin, M. G., Liversedge, S. P., Pine, D. S., & Ernst, M. (2012). Anxiety and selective attention to angry faces: An antisaccade study. *Journal of Cognitive Psychology, 24*(1), 54–65. https://doi.org/10.1080/20445911.2011.560111

Spielberger, C. D. (1983). State-trait anxiety inventory for adults (STAI-AD) [Database record]. *APA PsycTests*. https://doi.org/10.1037/t06496-000

von Zerssen, D., & Petermann, F. (2011). *Bf-SR. Befindlichkeits-Skala. Revidierte Fassung [Mood Scale. Revised version]*. Göttingen, Germany: Hogrefe.

Wittchen, H. U., & Perkonigg, A. (1996). *DIA-X SSQ. Swetz und zeitlinger*. Frankfurt, Germany: Swetz Test Services.

Wolf, M., van Doorn, G. S., & Weissing, F. J. (2008). Evolutionary emergence of responsive and unresponsive personalities. *Proceedings of the National Academy of Sciences, 105*(41), 15825–15830. https://doi.org/10.1073/pnas.0805473105

Zunhammer, M., Eberle, H., Eichhammer, P., & Busch, V. (2013). Somatic symptoms evoked by exam stress in university students: The role of alexithymia, neuroticism, anxiety and depression. *PloS one, 8*(12), Article e84911. https://doi.org/10.1371/journal.pone.0084911