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Sensory Sensory Processing Sensitivity and its Association with Personality Traits and Affect: A Meta-Analysis

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Authors' contribution

FL wrote the paper and performed the literature review

MP performed Bayesian data-analysis and contributed to define the analytic plan

UM contributed to the literature-review and writing

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MP supervised the writing process and was responsible with FL for the study design

Sensory Processing Sensitivity and its Association with Personality Traits and Affect: A Meta-Analysis

Abstract

In two Bayesian meta-analyses, we investigated associations between Sensory Processing Sensitivity (SPS) and the Big Five personality traits (MA1) as well as both Positive and Negative Affect (MA2). Moderators were age and the three SPS subscales. In MA1 (8 papers, 6,790 subjects), SPS in children correlated with Neuroticism (r = .42) but did not with Extraversion, Openness, Agreeableness or Conscientiousness. In adults, SPS correlated with Openness (r = .14) and Neuroticism (r = .40) but did not with Extraversion, Agreeableness or Conscientiousness. In MA2 (19 papers, 5,326 subjects), SPS in children correlated with Negative (r = .29) and Positive Affect (r = .21), but only with Negative Affect (r = .34) in adults. Developmental and measurement aspects are discussed.

Keywords: Sensory Processing Sensitivity; Personality traits; Affect; Highly Sensitive Person scale; Highly Sensitive Child scale; Bayesian meta-analysis

Sensory Processing Sensitivity and its Association with Personality Traits and Affect: A Meta-Analysis

1. Introduction

Sensory Processing Sensitivity (SPS) is described as a basic trait that captures individual differences in sensitivity to internal and external stimuli (Aron & Aron, 1997). It is related to, albeit largely distinct from, other personality constructs (Aron & Aron, 1997; Aron, Aron, & Jagiellowicz, 2012). Individuals who score high on SPS scales, around 30% of the general population (Lionetti et al., 2018; Pluess et al., 2018), are described as having heightened sensory sensitivity and more deeply processing stimuli, with fMRI studies reporting an association between SPS and prominent activation of the brain regions implicated in social processing, empathy and reflective functioning (Acevedo et al., 2014; Acevedo, Jagiellowicz, Aron, Aron, & Marhenke, 2017). Importantly, SPS has also been reported as a marker of behavioural plasticity in response to the environment, with high SPS individuals experiencing fewer behavioural problems and better socio-emotional wellbeing in response to supportive conditions such as positive parenting practices or intervention programs (Nocentini, Menesini, & Pluess, 2018; Pluess et al., 2018; Scrimin, Osler, Pozzoli, & Moscardino, 2018; Slagt, Dubas, van Aken, Ellis, & Dekovic, 2018). Given its ability to capture sensitivity to stimuli and deepen our understanding of inter-individual differences in response to both negative and positive environments, SPS has attracted growing interest from multiple domains of psychology. However, scientific knowledge still lags behind (Greven et al., 2019), thus further investigation into the association of SPS with other established and common traits, building upon existing personality and temperament theories, is of great importance.

In this paper, we aim to identify the extent to which SPS differs from and overlaps with the Big Five personality traits of Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness, as well as both Positive and Negative Affect, by analysing community samples of children and adults. Given the limited number of available studies, we will adopt a Bayesian meta-analytic approach, which performs better in small samples and reduces the likelihood of identifying spurious effects due to the accurate definition of prior information (Lionetti, Pastore, & Barone, 2015; Spiegelhalter, 2004; Spiegelhalter, Abrams, & Myles, 2004) .

1.1. Subscales of Sensory Processing Sensitivity

Based on theoretical reasoning and on the psychometric analysis of the Highly Sensitive Person scale (HSP) for investigating SPS in adults (Aron & Aron, 1997), SPS was originally proposed as a unitary psychological construct describing individuals with greater inhibition when approaching new environments, heightened sensitivity to external stimuli, greater depth of cognitive processing, and higher emotional reactivity (Aron & Aron, 1997; Aron et al., 2012). However, more recent psychometric analysis suggests the existence of three different sensitivity subscales (Smolewska, McCabe, & Woody, 2006): (a) *Ease of Excitation* (EOE), that is, being easily overwhelmed by external and internal stimuli (e.g., experiencing a negative response to "having a lot going on at once" or performing worse at a task when observed); (b) *Aesthetic Sensitivity* (AES), which captures aesthetic awareness (e.g., being deeply moved by the arts and music); and (c) *Low Sensory Threshold* (LST), reflecting unpleasant sensory arousal to external stimuli (e.g., experiencing a negative reaction to bright lights and loud noises). Although this more recent finding could be seen as contradicting the unitary construct, a bifactor structure has consistently been found to be the best-fitting model across children, adolescents, and adults from the US, UK and Belgium, providing support for the existence of a general factor as well as three separate orthogonal factors (Lionetti et al., 2018; Pluess et al., 2018; Weyn et al., 2019). The bifactor solution suggests that, after accounting for the variation explained by a general sensitivity factor, EOE, AES and LST reflect different facets of sensitivity. Thus, different patterns of correlations of the general and subscale factors with different personality traits and affect should be expected.

1.2 Personality traits and affect quality associated with Sensory Processing Sensitivity

Studies on the phenotypical features characterising SPS suggest that, even though SPS overlaps with some personality traits and affect (Lionetti et al., 2018; Pluess et al., 2018) , it is not fully captured by any of these, or indeed by their combined effects. Notably, while SPS as a unitary construct has been found to be a marker of sensitivity toward both negative and positive contexts (Nocentini et al., 2018; Slagt et al., 2018), less is known regarding the three subscales of SPS (EOE, AES and LST), which each correlate in a unique way with personality traits and affect quality. For example, in adult samples, while EOE and LST have often been reported to be positively associated with Negative Affect such as anxiety and depression (Liss, Timmel, Baxley, & Killingsworth, 2005), AES has been frequently found to correlate negatively with such variables (Smolewska, McCabe, & Woody, 2006) and positively with Positive Affect (Sobocko & Zelenski, 2015) and Self-Efficacy (Evers, Rasche, & Schabracq, 2008). Similarly, EOE and LST have been found to be positively correlated with Neuroticism and the Behavioural Inhibition System (Greven et al., 2019), while in some studies, the association between AES and Neuroticism was found to be trivial (Listou Grimen & Diseth, 2016; Pluess et al., 2018) or with low-to medium negative associations (Gerstenberg, 2012). SPS has also been reported to positively correlate with Openness, an association that seems to be mainly driven by the AES factor (Listou Grimen &

Diseth, 2016; Smolewska et al., 2006). In most studies, none of the SPS subscale factors were found to correlate with Agreeableness and Conscientiousness, with only a few exceptions (for a recent review, see also Greven et al, 2019). In other words, LST, EOE and AES combined appear to reflect different aspects of general sensitivity to both negative and positive environmental stimuli, thereby supporting the existence of a general SPS trait in children, adolescents, and adults. Yet, there is some research evidence suggesting that each of these subscales may correlate in a unique way with other individual traits, thus potentially reflecting independent components of SPS. A better understanding of the degree to which EOE, AES and LST are differentially associated with specific personality traits and affect, and the extent to which these associations are stable across the life course, could inform subsequent research studies on the relevance of considering SPS at a summary and/or facet level.

1.3. The current paper

In this paper, we aim to investigate the SPS phenotype by assessing the association of personality traits (MA1) and affect (MA2) with SPS and its subscales. The study will provide deeper insight into the extent to which SPS overlaps with, or differs from, the Big Five personality traits and both Positive and Negative Affect. Investigating SPS as a unitary construct while also considering its facets will further contribute to a better definition of SPS and its three components (i.e., EOE, AES and LST) that have been identified previously but whose relevance and specificity are largely unknown.

When looking at personality traits (MA1), we will consider Neuroticism and the Behavioural Inhibition System (BIS) together, and Extraversion and the Behavioural Activation System (BAS) together, based on research reporting strong associations between the pairs (Smits & Boeck, 2006). SPS, as well as BIS and BAS, have been reported to capture basic distinctions among individuals (Heimpel, Elliot, & Wood, 2006; Smits & Boeck, 2006) and individual differences in terms of responsivity to environmental stimuli (Heimpel et al., 2006; Pluess, 2015). SPS has also been reported to correlate with Neuroticism (for a review see Greven et al., 2019). Thus, the association between SPS and these traits is particularly worth investigating. The association between SPS and Openness will also be explored as empirical studies suggest that some components of SPS correlate with Openness (Listou Grimen & Diseth, 2016). Furthermore, although significant associations with Agreeableness and Conscientiousness are rarely reported (with a few exceptions, see Greven et al., 2019), we will include these two personality traits in the analysis for completeness of the Big Five. When investigating affect (MA2), we will distinguish between Negative and Positive Affect based on the theory that SPS captures sensitivity to both negative and positive stimuli, and supported by empirical evidence that different components of SPS show different patterns of correlation with negative and positive emotions and affective states (Bridges & Schendan, 2018; Liss, Mailloux, & Erchull, 2008).

Across both meta-analyses, we will investigate whether associations of SPS with personality and affect differ according to the type of personality trait and affect quality, and whether age and SPS subscales moderate this association. Personality will be considered as a factor variable with five levels (each corresponding to the Big Five personality dimension investigated), and affect as a factor variable with two levels (one for Positive and one for Negative Affect).

We posit that SPS would strongly and positively correlate with Neuroticism/Behavioural Inhibition and Negative Affect, moderately with Openness and Positive Affect, and that the association with Extraversion/Behavioural Activation would be trivial. We also expect to find no associations with Agreeableness or Conscientiousness. However, we hypothesise that different patterns of associations would emerge when taking the subscales of sensitivity into account. Specifically, we predict that AES would positively correlate with Positive Affect, Extraversion/Behavioural Activation and Openness. Regarding Neuroticism/Behavioural Inhibition and Negative Affect, we expected negative and moderate or weak associations. Furthermore, we expect EOE and LST to correlate positively with Neuroticism/Behavioural Inhibition and Negative Affect, and to correlate negatively or trivially with Extraversion/Behavioural Activation and Positive Affect, with no relevant association with Openness. Finally, we theorise that these associations would be consistent across child and adult samples (i.e., there would be no moderation due to a participant's age).

2. Method

The meta-analyses were conducted in accordance with PRISMA guidelines for systematic reviews and meta-analysis (Moher, Liberati, Tetzlaff, Altman, & Group, 2009), following a three-step approach: identification, screening, and coding, as described below.

2.1. Identification

We identified potentially relevant articles by searching in SCOPUS and Web of Science databases. The search was conducted on January 31st, 2018. In order to be included, articles had to contain the words "Highly Sensitive Person" OR "Highly Sensitive Child" OR "Sensory Processing Sensitivity" in the title, abstract, or keywords (for SCOPUS) or in the topic (for Web of Science), and had to have been published after the Aron and Aron's (1997) seminal article in which the psychological construct of SPS was first introduced. We limited the search to English-written articles. After removing double entries, the final list included 76 contributions.

2.2. Screening

After the selection phase, we screened papers based on the abstract and, when necessary to disentangle ambiguities, by reading the paper text. This screening phase was done in accordance with the following inclusion criteria: (1) focus on SPS as defined by Aron and Aron (1997); (2) research papers reporting empirical data; (3) use of the self-report HSP or HSC scale for the assessment of SPS; (4) availability of information on the association between SPS and personality and/or Negative/Positive Affect ; and (5) community/non-clinical samples. The screening was conducted by two independent coders. Based on the first criterion, 26 papers were excluded because they focused on non-relevant types of "sensitivity" (e.g., allergies) or sensitivity-related temperament traits (e.g., perceptual sensitivity). Based on the second criterion, 10 contributions were excluded because they were review/commentary papers. Under criterion three, 4 papers were excluded because one used a parent-report HSC scale (Slagt et al., 2018), another used a parent-report questionnaire that had not been tested for construct validity (Boterberg & Warreyn, 2016), a third concerned the assessment of SPS in dogs (Braem et al., 2017) and the fourth used a unique HSP factorial structure (Şengül-İnal & Sümer, 2017). Based on the fourth criterion, 10 papers were excluded because they lacked the necessary associations of interest. Finally, in line with criterion five, 3 papers were excluded because they involved at-risk, non-normative populations. After the screening process, 22 eligible papers were identified, with an inter-rater agreement of 100%. After consulting experts in the field about contributions presented at conferences or submitted/under review but not yet indexed in scientific databases , we added 2 more contributions (Nocentini, Menesini, Lionetti, & Pluess, 2017; Weyn et al., in press), resulting in a total of 24 articles for inclusion in the current paper. In total, we obtained a sample of 6,790 subjects for MA1 and 5,326 subjects for MA2, as described in more detail below.

2.3. Coding

All eligible studies were coded for sample size and age of participants (children/adolescents up to 16 years of age vs. adults/college/university students), and for the association between SPS (assessed using the HSP and the HSC scales) and the Big Five personality traits (MA1), and Negative and Positive Affect (MA2). In MA1, personality was considered as a variable with five levels, each corresponding to one of the investigated personality traits. Given empirical data providing evidence for strong overlap between constructs, data on Neuroticism and Behavioural Inhibition were merged, as well as between Extraversion and Behavioural Activation (Smits & Boeck, 2006). In MA2, affect was considered as a variable with two levels: Positive and Negative. Anxiety, depression, stress, complaints and negative affect/negative emotions were merged into a unique Negative Affect category. Positive emotionality, sense of coherence, optimism, happiness, and life satisfaction were merged into a unique Positive Affect category. We investigated associations with the general SPS factor, as well as the interaction effects with each of the three SPS subscales of EOE, AES and LST. A list of all of the studies included in the two meta-analyses, together with Pearson correlation coefficients for the relevant associations, is reported in Table 1 for MA1 and Table 2 for MA2. Inter-rater agreement on Pearson correlations was conducted on 25% of the values reported in Tables 1 and 2, and complete agreement amongst raters was achieved.

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TABLE 1 AND 2 APPROXIMATELY HERE

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2.4 Plan of analysis

We adopted a fully Bayesian approach for both MA1 and MA2 (Kruschke & Liddell, 2017). Specifically, we considered the Pearson correlation coefficients between SPS (and SPS subscales) and the relevant outcome variable(s) as reported in the identified papers, as well as the effect size, by transforming the correlation values into Fisher z-scores (hereafter labelled Z). Following a model-selection approach (Burnham & Anderson, 2003; Fox, 2015), we compared a series of mixed-effect models in order to test the contribution of moderators that could be relevant. A list of all of the models considered, along with descriptions of the mixed-model approach and Bayesian estimation method used for the analysis, can be found below.

2.4.1 Model selection

Firstly, we considered and compared the following models:

1. Model 0 (M0), a baseline model which estimates the overall effect size for the association between SPS and personality (MA1) and Affect (MA2), irrespective of the level.
2. Model 1 (M1), a model testing whether the effect size is moderated by the type of personality trait (MA1) or type of Affect (MA2).
3. Model 2 (M2), a model testing whether the type of SPS facet (i.e., EOE, AES, LST or summary score) moderates the effect size (MA1 and MA2).
4. Model 3 (M3), an additive effect model which includes the type of personality trait, Affect and SPS facets as moderators (MA1 and MA2).
5. Model 4 (M4), an interaction model, with the interaction term between the above listed moderators (MA1 and MA2),
6. Model 5 (M5), a model exploring whether the best identified model (among those listed above) improved when a participant's age group (children/adolescents vs. adults) was included as a moderating factor.

In order to select the model that fit the data best, we considered the Watanabe-Akaike Information Criterion (Watanabe, 2010) , where lower values suggest a better fit to the data, and Akaike Weights, which represent an estimate of the probability that the model will make the best prediction in new data conditional upon the set of models considered (Burnham & Anderson, 2003; McElreath, 2016; Wagenmakers & Farrell, 2004). By adopting a model comparison approach, we were able to estimate meta-analytic values, as well as explore whether consideration of the different SPS facets (in addition to SPS as a unique construct) would provide a better explanation for the data.

2.4.2. Mixed-effects meta-analysis

The models described above were run using a mixed-effects approach, by which the eligible studies were assumed to be a random sample of the relevant distribution of effects, and correlational values representing the association between SPS and each target variable were nested within each study (Borenstein, Hedges, Higgins, & Rothstein, 2010). A graphical representation of the baseline model (M0) is depicted in Figure 1. Grey circles represent observed variables z_{ij}, i.e., the correlation values transformed into Z (z_{ij}) and $\hat{\sigma}_{ij}^2$ estimated sampling variances. White circles represent the model parameters, i.e., the estimated effect size θ and its associated variance τ^2. Estimated effects of each study are represented by δ_i. The STAN code for this model is reported in the appendix.

The baseline model (M0) can be described by the following equation:

$$z_{ij} = \theta + \lambda_i + \epsilon_{ij}$$

where: z_{ij} is the j-th effect size in the i-th study, $i = 1, \dots, I$ (study), $j = 1, \dots, J_i$, λ_i are the best linear unbiased predictors (BLUPS) (Pinheiro & Bates, 2000) with $\theta + \lambda_i = \delta_i$, $\lambda_i \sim N(0, \tau^2)$, and $\epsilon_{ij} \sim N(0, \sigma_\epsilon^2)$. All other listed models are derived from this base formula.

2.4.3 *Bayesian estimation*

The parameters θ and τ^2 were estimated within a Bayesian data-analysis framework. The Bayesian components of data analyses are the following: (1) the prior distribution, i.e., a probability distribution representing the knowledge derived from previous studies and proposed by the researcher; (2) the observed evidence, i.e., the data itself; and (3) the posterior distribution, derived from combining observed data with the prior distribution and which represents what we would usually define as the result of the analysis.

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FIGURE 1 ABOUT HERE

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In our study, the prior distribution of the target effect size (θ) was skeptical, assuming that there was no relevant effect to be observed. A skeptical prior allowed us to reduce the chances of identifying a spurious effect and is therefore considered to be more conclusive in refuting an association; conversely, it provided us with more certainty when an effect was detected (Lionetti et al., 2015; Spiegelhalter, 2004; Spiegelhalter et al., 2004). Specifically, our prior was a Cauchy distribution with location 0 and scale 1 for the effect size of θ, and a half-Cauchy with location 0 and scale 5 for the standard error τ (see Figure 1, right side) (Gelman et al., 2014; Gelman, Jakulin, Pittau, & Su, 2008). Each model was fitted using the Bayesian Markov Chain Monte Carlo estimation method based on 4000 iterations in four chains considering 8000 post-warmup draws. Convergence was assessed by examining the potential scale reduction factor (PSRF) (Gelman & Rubin, 1992). Once the best model was identified, we analysed parameter posterior distributions and summarised these distributions using posterior means and 89% Highest Posterior Density Intervals (HPDI) (Box & Tiao, 1973; Kruschke, 2011; McElreath, 2016). HPDI can be considered similar to Confidence Intervals in the frequentist approach. More specifically, they provide a direct representation of the most credible values of the estimated parameter (Pearson's r, in the current study) after accounting for prior believes. 89% HPDI represents the narrowest interval containing 89% of posterior samples. When HPDI does not include 0 (or it only contains a small proportion of values that are close to zero), it is reasonable to conclude that 0 is not a credible value and thus that an effect and/or an association can be reasonably supported (for a comparable application in the psychology field, see also Fawcett, Lawrence, and Taylor (2016)).

All analyses were performed with *R* software and programming language (R Core Team, 2016). Pearson's correlations were transformed into Fisher's *z* using the metafor package (Viechtbauer, 2010). Bayesian estimates were performed using the rstan (Stan Development Team, 2017) and brms (Bürkner, 2016) packages. The STAN code is reported in the appendix.

3. Results

3.1. MA1: Association between SPS (and SPS subscales) with the Big Five personality traits

3.1.1. Descriptive statistics

Of the 8 papers (10 samples, *n* = 6,790 subjects, Table 1) that examined the association between SPS and Neuroticism/Behavioural Inhibition, 6 papers (8 samples) also included Extraversion/Behavioural Activation, 5 papers (6 samples) considered Openness, and 4 papers (5 samples) examined all of the Big Five personality traits. In total, 153 effect sizes were identified (Pearson's *r*, M = 0.10, *SD* = 0.23). As can be seen in Figure 2, Panel A depicts the observed correlation values as a function of the eligible studies. Panel B reports Pearson correlation values and the relative sampling standard deviation.

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FIGURE 2 APPROXIMATELY HERE

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3.1.3. Model selection

Table 3 (upper part of the table) reports the goodness of fit indices of the six models tested. The model that provided the best fit was Model 5 (M5), which included the interaction term containing all of the moderators (SPS facet, type of Affect and age). This model had the lowest WAIC and the highest Akaike Weight.

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TABLE 3 APPROXIMATELY HERE

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3.1.4. Effect size posterior distributions

To interpret the interaction between SPS facet, personality trait and age, we used the posterior distribution of effect sizes (i.e., posterior distributions of *Z* converted back into Pearson's *r*, hereafter known simply as *r*). 89% HDPI intervals are included in square brackets. Figure 3 represents posterior distributions of *r* for each level of the SPS facet (column) and personality variable (row). In each Panel, the dark grey density curve refers to data on children, while the light grey curve refers to data on adults. Effect size posterior distributions mean values are reported in Table 4 (upper part of the table).

In children, AES correlated positively with both Extraversion/Behavioural Activation (r = .21 [-.02; .44]) and Openness (r = .27 [.05; .49]), but not with Neuroticism/Behavioural Inhibition (r = .10 [-.14; .33]), Agreeableness (r = .14 [-.09; .37]) or Conscientiousness (r = .11 = [-.12; .35]). A different pattern of associations emerged for EOE and LST, whereby both correlated with Neuroticism/Behavioural Inhibition, although the relationship was strongest with EOE (*r* = .46 [.28; .65] for EOE and *r* =.27 [.06; .50] for LST). Both EOE and LST correlated negatively with Extraversion/Behavioural Activation at *r* = -.23 [-.46; .01] and *r* = -.16 [-.40; .06] for EOE and LST respectively. No association was identified with Openness (*r* = .01 [-.23; .24] for EOE and *r* = .10 [-.14; .33] for LST), Agreeableness (*r* = -.04 [-.28; .20] for EOE and *r* = -.03 [-.26; .21] for LST) or Conscientiousness (*r* = -.08 [-.32; .15] for EOE and *r* = .10 [-.14; .33] for LST). There was also no correlation between the total SPS score and Extraversion/Behavioural Activation (*r* = -.13 [-.37; .09]), Openness (*r* = .13 [-.11; .36]), Agreeableness (*r* = .05 [-.19; .28]) or Conscientiousness (*r* = -.03 [-.21; .27]), but a positive correlation with Neuroticism/Behavioural Inhibition emerged (*r* = .42 [.24; .63]).

In contrast, in adults, AES was found to be positively associated with Neuroticism/Behavioural Inhibition (*r* = .17 [.02; .32]), whilst no relevant association was identified with Extraversion/Behavioural Activation (*r* = .08 [-.07; .23]). As was the case in children, AES correlated with Openness, although the effect size was larger in adults (*r* = .36 [.22; .49]). There was no correlation between AES and Agreeableness (*r* = .03 [-.13; .18]) or Conscientiousness (*r* = .02 [-.12; .19]). As in children, EOE and LST positively correlated with Neuroticism/Behavioural Inhibition (*r* = .44 [.32; .57] for EOE and *r* = .27 [.12; .41] for LST). However, in contrast to children, no significant negative association with Extraversion/Behavioural Activation emerged in adults (*r* = -.05 [-.21; .09] for EOE and *r* = -.07 [-.22; .08] for LST). Furthermore, no association between EOE or LST were found with Openness (*r* = .03 [-.12; .19] for EOE and *r* = .05 [-.13; .21] for LST), Agreeableness (*r* = .04 [-.11; .20] for EOE and *r* = -.02 [-.17; .15] for LST) or Conscientiousness (*r* = .01 [-.14; .17] for EOE and *r* = .02 [-.14; .18] for LST). Similar to findings with children, the total SPS score in adults was not associated with Extraversion/Behavioural Activation (*r* = -.02 [-.18; .12]), Agreeableness (*r* = .03 [-.11; .19]) or Conscientiousness (*r* = .03 [-.13; .18]), but a positive correlation was found with Neuroticism/Behavioural Inhibition (*r* =.40 [.27; .53]). A small association between SPS and Openness was identified (*r* = .14 [-.01; .29]).

In other words, AES was found to be correlated with Extraversion/Behavioural Activation in children only and with Neuroticism/Behavioural Inhibition in adults only. Whilst EOE and LST were found to negatively correlate with Extraversion/Behavioural Activation in children, no such association was found in adults. In both adults and children, EOE and LST were found to be positively associated with Neuroticism/Behavioural Inhibition but not with Openness. In both children and adults, Openness correlated with AES, but the relationship was stronger in adults. At a summary score level, SPS was found to be moderately associated with Neuroticism/Behavioural Inhibition in both adults and children, whilst no association with Extraversion/Behavioural Activation emerged. In adults, SPS showed a small but positive association with Openness, whereas no association was seen in children. No relevant associations were identified between SPS and Agreeableness or Conscientiousness.

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TABLE 4 ABOUT HERE

FIGURE 3 ABOUT HERE

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3.2. MA2: Association between SPS (and SPS subscales) with Negative and Positive Affect

3.2.1. Descriptive statistics

Of the 19 papers (21 samples, *n* = 5,326 subjects, Table 2) that examined the association between SPS (and SPS subscales) and Affect, a total of 123 effect sizes were identified (Pearson's *r*, *M* = 0.19, *SD* = 0.22). As can be seen in Figure 4, Panel A depicts the observed correlation distribution as a function of the eligible studies. Panel B reports Pearson correlation values and the relative sampling standard deviation. At a first glance, the graphical representation of effect size values, varying from negative to positive, provides evidence for the analysis of candidate moderators.

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FIGURE 4 ABOUT HERE
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3.2.2. Model selection

Table 3 (lower part of the table) reports the goodness of fit indices of the models tested. The model that provided the best fit was Model 5 (M5), which included the interaction term containing all of the moderators (SPS facet, type of Affect and age). This model had the lowest WAIC and the highest Akaike Weight.

3.2.3 Effect size posterior distributions.

In order to interpret the three-way interaction effect between SPS facet, the type of Affect and age, we computed the posterior distribution of the effect size transformed in Pearson's *r* for a smooth interpretation of effects. Figure 5 represents posterior distributions for each level of type of Affect (row) and SPS facet (column). In each panel, the dark grey density curve refers to child data and the light grey density curve to adult data. Effect size posterior distributions mean values are reported in Table 4 (lower part of the table).

In children, AES was positively associated with Positive Affect (*r* =.29 [.14; .45]) but not with Negative Affect (*r* = .05 [-.11; .24]). EOE and LST were positively associated with Negative Affect (*r* = .26 [.09; .42] for EOE and *r* = .21 [.06; .38] for LST) but not with Positive Affect (*r* = .06 [-.11; .24] for EOE and *r* = .07 [-.11; .24] for LST). At a summary score level, SPS was positively associated with both Negative (*r* = .29 [.13; .44]) and Positive (*r* = .21 [.04; .38]) Affect to a similar degree. However, the positive association between SPS and Positive Affect was mainly driven by the association of AES to Positive Affect.

In adults, AES was also positively associated with Positive Affect (*r* = .16 [.06; .26]), although to a lower extent than was found for children. A small association was identified with Negative Affect (*r* = .12 [.02; .21]), although this was stronger than the effect found in children. For EOE and LST, the same pattern found for children emerged in adults, with no significant association with Positive Affect (*r* = -.15 [-.26, -.06] for EOE and *r* = -.07 [-.18; .03] for LST), and positive associations with Negative Affect (*r* = .36 [.28; .44] for EOE and *r* = .29 [.20; .38] for LST). In contrast to children, the association between the summary SPS score and Positive Affect was close to zero (*r* = -.05 [-.15; .06]). SPS moderately correlated with Negative Affect (*r* = .34 [.27; .42]).

To summarise, in children, AES correlated positively only with Positive Affect (with a close-to-zero effect size for the association with Negative Affect), while EOE and LST were only associated with Negative Affect (with a close-to-zero effect size for the association with Positive Affect). In adults, AES showed a weak positive correlation with both Negative and Positive Affect, while EOE and LST correlated positively with Negative Affect (with stronger effect sizes for EOE compared to LST) but showed no significant association with Positive Affect. At a summary score level, SPS in children was positively associated with both Negative and Positive Affect to largely the same extent, while in adults, SPS was positively associated with Negative Affect only.

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FIGURE 5 ABOUT HERE
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4. Discussion

SPS has been identified a measurable individual trait characterised by heightened sensitivity to external stimuli, greater depth in cognitive processing and high emotional reactivity (Aron & Aron, 1997; Aron et al., 2012). Available empirical evidence suggests that

SPS is, to an extent, related to other individual traits that reflect sensitivity to the environment, such as Introversion, Neuroticism, Openness, Behavioural Inhibition and Negative Affect (Aron & Aron, 1997; Liss et al., 2008; Liss et al., 2005) . However, data has not always been consistent when different subscales of SPS were considered (Greven et al., 2019).

The meta-analyses performed in this study explored the associations of SPS and its subscales with the Big Five personality traits (MA1), and with Negative and Positive Affect (MA2), with the aim of better understanding the characteristics of highly sensitive individuals and exploring the degree to which SPS differs from other individual traits. Results across both meta-analyses converge on the notion that SPS is indeed a trait that is relatively distinct from other common personality traits and Affect across both child and adult samples. Yet, contrary to our expectations, there were some differences and specificities across the age groups.

As hypothesised, results from the first meta-analysis (MA1) showed that SPS strongly and positively correlates with Neuroticism/Behavioural Inhibition in both adults and children, whilst no association was found with Extraversion/Behavioural Activation. However, a small positive association was identified with Openness in adults but not in children. As predicted, no significant association was identified between SPS and Agreeableness or Conscientiousness in both children and adults. Overall, these results suggest that SPS correlates with those personality traits that have been extensively studied in relation to SPS (Aron & Aron, 1997). With the exception of Openness, this was true irrespective of the age at assessment. However, many differences between adult and child samples emerged when SPS subscales were considered. Specifically, AES correlated positively with Neuroticism/Behavioural Inhibition in adults, but not in children, whilst AES correlated positively with Extraversion/Behavioural Activation in children, but not in adults. Similarly, EOE and LST correlated negatively with Extraversion/Behavioural Activation in children, but not in adults. Whilst AES correlated with Openness in both adults and children, the association was stronger for the latter group, hence resulting in a correlation between the summary SPS score and Openness only in the adult sample.

In our second meta-analysis (MA2), which focused on the association between SPS and Affect, findings showed that the association between SPS and Negative Affect was moderate and similar in effect size in both children and adults, whereas the association with Positive Affect was evident only in children, driven mainly by the AES subscale. Because we selected only studies with community samples in our meta-analyses, it is unlikely that the absence of an association between SPS and Positive Affect in adults was due to the presence of sensitive at-risk individuals (e.g., with clinical depression or anxiety). An alternative explanation may come from methodological differences between the construction of the HSP and HSC scales. While the 27-item HSP scale for adults was originally designed to capture a unitary construct of sensitivity, with the three subscales of EOE, AES, and LST only being identified in subsequent studies, the 12-item HSC scale for children was designed specifically to reflect the three-factor structure and reduce the bias of the adult scale towards negative aspects of sensitivity (Pluess et al., 2018). Related to this, a clear difference is observable in the phrasing of items belonging to the AES factor in the two scales. In the adult version, AES-related items reflect a general appreciation of aesthetic features in the environment in a more neutral way (e.g., *"I am deeply moved by the arts or music"*) and there are several AES-related items that explicitly refer to an increased depth of processing (e.g., *"I seem to be aware of subtleties in my environment", "I have a rich, complex inner life"*), suggesting that the adult AES scale may be capturing depth of processing rather than sensitivity to positive environmental influences. In the child version, AES-related items more directly capture sensitivity to positive stimuli associated with a positive response (e.g., *"Nice music makes me* *happy"*) with only one item capturing depth of processing (e.g., *"I notice when small things have changed in my environment"*). With regard to the other two factors, EOE and LST, similar associations were identified in both children and adults, although EOE was found to be more strongly correlated with negative emotions than LST.

In summary, our meta-analytic findings have identified associations between SPS and Negative and Positive Affect in children, Negative Affect only in adults, Neuroticism/Behavioural Inhibition in both children and adults, and Openness in adults. Importantly, associations are small to moderate, suggesting that SPS does not fully overlap with any of these traits, or with their combination. In addition, our meta-analyses found that SPS presented a consistent pattern of association with Neuroticism/Behavioural Inhibition, which is coherent with the notion that individuals that score high on SPS (i.e., those who are more reactive to the environment) present a more inhibited approach in response to novel and unfamiliar situations (Aron & Aron, 1997). Given that findings were stable across the child and adult samples, this result may have important implications for studies exploring SPS and reactivity to the environment from a developmental perspective. At a facet level, EOE and LST showed a comparable trend in children and adults on all associations (with the exception of Extraversion/Behavioural Activation), but the AES subscale indicated different associations between children and adults in terms of effect size (e.g., the positive association with Positive Affect was twice as high in children) and in terms of associations found in children and not in adults, and vice versa.

Limitations and future directions

Findings from our meta-analyses lend support to the hypothesis that SPS is relatively distinct from other common personality traits and that SPS subscales need to be considered, especially with child samples. However, results should be considered with caution given the limited number of studies that have investigated the association of SPS with personality traits (although they entail reasonably large samples). Furthermore, an analysis of personality variables associated with SPS at a personality facet level has not been carried out yet. Multiple directions for future research are possible. The first pertains to investigating the degree to which the 12-item child version and 27-item adult version of the HSP questionnaire are comparable and capture sensitivity towards both negative and positive stimuli. Currently, research adopting the HSC scale has provided support that the scale reflects general Environmental Sensitivity to negative and positive experiences in intervention and longitudinal studies (Nocentini et al., 2018; Pluess & Boniwell, 2015; Slagt et al., 2018). Similar results have been reported in studies adopting the HSP in laboratory contexts (Acevedo et al., 2017; Lionetti et al., 2018). Still, our results indicated that the HSP scale for adults does not correlate with self-reported Positive Affect when no manipulation of the environment occurs, whilst the HSC scale does. Only longitudinal studies could clarify whether different effect sizes reported for the association between SPS and affect in children and adults are driven by developmental aspects or by differences in how the construct is measured across the two scales.

A second direction for future research involves investigation into the interaction between SPS and the environment regarding the development of personality and affect over time. In the current study, we have not been able to explore the interaction between SPS and the environment in predicting Affect due to the relatively low number of studies that included the quality of the environment in their analysis framework and the extensive variability among environmental indicators (Acevedo et al., 2017; Booth, Standage, & Fox, 2015; Lionetti et al., 2018; Liss et al., 2008; Nocentini et al., 2018; Pluess & Boniwell, 2015).

A third direction of future studies pertains to the ability for researchers to generalise the findings of studies on SPS, which mainly involve participants from Western countries, to different cultures. This has to be investigated in more detail (Weyn et al., in press).

Furthermore, our findings suggest that the differences found between EOE and LST were mainly quantitative rather than qualitative in nature. However, items included in the two subscales seem to semantically tap into different aspects of sensitivity. For a more in-depth understanding, analysis at the facet level of personality traits should be considered.

Finally, the original theory of SPS proposed a more in-depth process of environmental stimuli as a core aspect of increased sensitivity to the environment (Aron & Aron, 1997; Aron et al., 2012). However, a 'depth of processing' facet is not captured by items currently included in the HSP and HSC scales, thus limiting the opportunity for exploring this construct and its association with other personality traits further.

Conclusion

In conclusion, Sensory Processing Sensitivity (SPS) and its three facets measured with the Highly Sensitive Person (HSP) and Highly Sensitive Child (HSC) scales, are moderately associated with some of the Big Five personality traits and Affect. The strongest and most consistent associations emerged for Neuroticism/Behaviour Inhibition and Negative Affect with SPS and all three facets for both adults and children. While Agreeableness and Conscientiousness were not related to SPS and its facets, some significant associations emerged for Extraversion/Behavioural Activation, Openness, and Positive Affect. However, detected associations were small and varied as a function of SPS subscales and age of the samples. In summary, our series of meta-analyses provides important evidence that SPS is largely distinct from established common personality and affect, although a consistent moderate association with Neuroticism/Behavioural Inhibition and Negative Affect emerged, which may reflect heightened sensitivity to negative aspects of the environment, possibly due to an inherent negative bias of the scales.

References

Acevedo, B. P., Aron, E. N., Aron, A., Sangster, M. D., Collins, N., & Brown, 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, doi: 10.1002/brb3.242

Acevedo, B. P., Jagiellowicz, J., Aron, E. N., Aron, A., & Marhenke, R. (2017). Sensory processing sensitivity and childhood quality's effects on neural responses to emotional stimuli. *Neuropsychiatry, 14*(5).

Ahadi, B., & Basharpoor, S. (2010). Relationship between sensory processing sensitivity, personality dimensions and mental health. *Journal of Applied Sciences*, *10*(7), doi: 570-574. 10.3923/jas.2010.570.574

Andresen, M., Goldmann, P., & Volodina, A. (2018). Do overwhelmed expatriates intend to leave? The effects of sensory processing sensitivity, stress, and social capital on expatriates' turnover intention. European Management Review, 15(3), 315-328, doi/full/10.1111/emre.12120

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.

Aron, A., Ketay, S., Hedden, T., Aron, E. N., Rose Markus, H., & Gabrieli, J. D. (2010). Temperament trait of sensory processing sensitivity moderates cultural differences in neural response. *Social Cognitive and Affective Neuroscience*, 5(2-3), 219-226. doi: 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. doi:10.1177/1088868311434213

Bakker, K., & Moulding, R. (2012). Sensory-processing sensitivity, dispositional mindfulness and negative psychological symptoms. *Personality and Individual Differences*, *53*(3), 341-346, doi.org/10.1016/j.paid.2012.04.006

Benham, G. (2006). The highly sensitive person: Stress and physical symptom reports. *Personality and Individual Differences*, 40(7), 1433-1440.

Booth, C., Standage, H., & Fox, E. (2015). Sensory-processing sensitivity moderates the association between childhood experiences and adult life satisfaction. *Personality and Individual Differences, 87*, 24-29. doi:10.1016/j.paid.2015.07.020

Borenstein, M., Hedges, L. V., Higgins, J., & Rothstein, H. R. (2010). A basic introduction to fixed-effect and random-effects models for meta-analysis. *Research synthesis methods, 1*(2), 97-111. doi: 10.1002/jrsm.12

Boterberg, S., & Warreyn, P. (2016). Making sense of it all: The impact of sensory processing sensitivity on daily functioning of children. *Personality and Individual Differences, 92*, 80-86. doi:http://dx.doi.org/10.1016/j.paid.2015.12.022

Box, G., & Tiao, G. (1973). Bayesian inference in statistical inference. *Adison-Wesley, Reading, Mass*.

Braem, M., Asher, L., Furrer, S., Lechner, I., Würbel, H., & Melotti, L. (2017). Development of the "Highly Sensitive Dog" questionnaire to evaluate the personality dimension "Sensory Processing Sensitivity" in dogs. *PloS one, 12*(5), e0177616. https://doi.org/10.1371/journal.pone.0177616

Bridges, D., & Schendan, H. E. (2018). Sensitive individuals are more creative. *Personality and Individual Differences*. http://dx.doi.org/10.1016/j.paid.2018.09.015

Brindle, K., Moulding, R., Bakker, K., & Nedeljkovic, M. (2015). Is the relationship between sensory-processing sensitivity and negative affect mediated by emotional regulation? *Australian Journal of Psychology*, 67(4), 214-221. https://doi.org/10.1111/ajpy.12084

Bürkner, P.-C. (2016). brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software, 80*(1), 1-28. doi: 10.18637/jss.v080.i01

Burnham, K. P., & Anderson, D. R. (2003). *Model selection and multimodel inference: a practical information-theoretic approach*: Springer Science & Business Media.

Evers, A., Rasche, J., & Schabracq, M. J. (2008). High Sensory Processing Sensitivity at Work. *International Journal of Stress Management, 15*(2), 189 - 198. doi: 10.1037/1072-5245.15.2.18

Fawcett, J. M., Lawrence, M. A., & Taylor, T. L. (2016). The representational consequences of intentional forgetting: Impairments to both the probability and fidelity of long-term memory. *Journal of Experimental Psychology: General, 145*(1), 56. doi: 10.1037/xge0000128

Fox, J. (2015). *Applied regression analysis and generalized linear models*: Sage Publications.

Gearhart, C. C. (2014). Sensory-processing sensitivity and nonverbal decoding: The effect on listening ability and accuracy. *International Journal of Listening*, *28*(2), 98-111.

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., & Rubin, D. B. (2014). *Bayesian data analysis* (Vol. 2): CRC press Boca Raton, FL.

Gelman, A., Jakulin, A., Pittau, M. G., & Su, Y.-S. (2008). A weakly informative default prior distribution for logistic and other regression models. *The Annals of Applied Statistics*, 1360-1383.

Gelman, A., & Rubin, D. B. (1992). Inference from iterative simulation using multiple sequences. *Statistical Science*, 457-472.

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. doi:10.1016/j.paid.2012.04.019

Greven, C. U., Lionetti, F., Booth, C., Aron, E., Fox, E., Schendan, H. E., . . . Bijttebier, P. (2019). Sensory Processing Sensitivity in the context of Environmental Sensitivity: a critical review and development of research agenda. *Neuroscience & Biobehavioral Reviews, 98*, 287-305. doi: https://doi.org/10.1016/j.neubiorev.2019.01.009

Heimpel, S. A., Elliot, A. J., & Wood, J. V. (2006). Basic personality dispositions, self-esteem, and personal goals: An approach-avoidance analysis. *Journal of Personality, 74*(5), 1293-1320.

Kjellgren, A., Lindahl, A., & Norlander, T. (2009). Altered states of consciousness and mystical experiences during sensory isolation in flotation tank: Is the highly sensitive personality variable of importance? *Imagination, Cognition and Personality*, 29(2), 135-146

Kruschke, J. K. (2011). Bayesian assessment of null values via parameter estimation and model comparison. *Perspectives on Psychological Science, 6*(3), 299-312. doi: 10.1177/1745691611406925

Kruschke, J. K., & Liddell, T. M. (2017). The Bayesian New Statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. *Psychonomic Bulletin & Review*, 1-29. doi: 10.3758/s13423-016-1221-4

Lionetti, F., Aron, A., Aron, E. N., Burns, G. L., Jagiellowicz, J., & Pluess, M. (2018). Dandelions, tulips and orchids: evidence for the existence of low-sensitive, medium-sensitive and high-sensitive individuals. *Translational Psychiatry, 8*(1), 24. doi:10.1038/s41398-017-0090-6

Lionetti, F., Pastore, M., & Barone, L. (2015). Attachment in institutionalized children: A review and meta-analysis. *Child Abuse & Neglect, 42*, 135-145. doi: 10.1016/j.chiabu.2015.02.013

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.

Liss, M., Timmel, L., Baxley, K., & Killingsworth, P. (2005). Sensory processing sensitivity and its relation to parental bonding, anxiety, and depression. *Personality and Individual Differences, 39*(8), 1429-1439.

Listou Grimen, H., & Diseth, Å. (2016). Sensory Processing Sensitivity: Factors of the Highly Sensitive Person Scale and Their relationships to Personality and Subjective Health Complaints. *Perceptual and Motor Skills, 123*(3), 637-653. doi: 10.1177/0031512516666114

McElreath, R. (2016). *Statistical rethinking: A bayesian course with examples in R and Stan*: CRC Press: Boca Raton FL.

Meredith, P. J., Bailey, K. J., Strong, J., & Rappel, G. (2016). Adult attachment, sensory processing, and distress in healthy adults. *American Journal of Occupational Therapy*, *70*(1), doi: 7001250010p1-7001250010p8.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Group, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Plos medicine, 6*(7), e1000097.

Nocentini, A., Menesini, E., Lionetti, F., & Pluess, M. (2017). *Highly Sensitive Child scale: Investigation of Construct Validity in a Sample of Italian Children*. Paper presented at the European Conference of Developmental Psychology, Utrecht.

Nocentini, A., Menesini, E., & Pluess, M. (2018). The Personality Trait of Environmental Sensitivity Predicts Children's Positive Response to School-Based Anti-Bullying Intervention. *Clinical Psychological Science*. doi: 10.1177/2167702618782194

Pluess, M. (2015). Individual differences in Environmental Sensitivity. *Child Development Perspectives, 9*(3), 138-143. doi:10.1111/cdep.12120

Pluess, M., Assary, E., Lionetti, F., Lester, K. J., Krapohl, E., Aron, E. N., & Aron, A. (2018). Environmental Sensitivity in Children: Development of the Highly Sensitive Child Scale and Identification of Sensitivity Groups. *Developmental Psychology, 54*(1), 51-70. doi:10.1037/dev0000406

Pluess, M., & Boniwell, I. (2015). Sensory-Processing Sensitivity predicts treatment response to a school-based depression prevention program: Evidence of Vantage Sensitivity. *Personality and Individual Differences, 82*(0), 40-45. doi:http://dx.doi.org/10.1016/j.paid.2015.03.011

Scrimin, S., Osler, G., Pozzoli, T., & Moscardino, U. (2018). Early adversities, family support, and child well-being: The moderating role of environmental sensitivity. *Child: Care, Health and Development, 44*(6), 885-891. https://doi.org/10.1111/cch.12596

Şengül-İnal, G., & Sümer, N. (2017). Exploring the Multidimensional Structure of Sensory Processing Sensitivity in Turkish Samples. *Current Psychology*, 1-13. https://doi.org/10.1007/s12144-017-9751-0

Slagt, M., Dubas, J. S., van Aken, M. A., Ellis, B. J., & Dekovic, M. (2018). Sensory Processing Sensitivity as a Marker of Differential Susceptibility to Parenting. *Developmental Psychology, 54*(3), 543-558. doi: http://dx.doi.org/10.1037/dev00004

Smits, D. J., & Boeck, P. (2006). From BIS/BAS to the big five. *European Journal of Personality, 20*(4), 255-270.

Smolewska, K. A., McCabe, S. B., & Woody, E. Z. (2006). A psychometric evaluation of the Highly Sensitive Person Scale: The components of sensory-processing sensitivity and their relation to the BIS/BAS and "Big Five". *Personality and Individual Differences, 40*(6), 1269-1279. doi:10.1016/j.paid.2005.09.022

Sobocko, K., & Zelenski, J. M. (2015). Trait Sensory-Processing Sensitivity and subjective well-being: Distinctive associations for different aspects of sensitivity. *Personality and Individual Differences, 83*, 44-49. https://doi.org/10.1016/j.paid.2015.03.045

Spiegelhalter, D. J. (2004). Incorporating Bayesian ideas into health-care evaluation. *Statistical Science*, 156-174.

Spiegelhalter, D. J., Abrams, K. R., & Myles, J. P. (2004). *Bayesian approaches to clinical trials and health-care evaluation* (Vol. 13): John Wiley & Sons.

Stan Development Team. (2017). Stan Modeling Language Users Guide and Reference Manual, Version 2.17.0.

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software, 36*(3), 1-48. 10.18637/jss.v036.i03

Wachs, T. D. (2013). Relation of maternal personality to perceptions of environmental chaos in the home. *Journal of Environmental Psychology*, *34*, 1-9. https://doi.org/10.1016/j.jenvp.2012.11.003

Wagenmakers, E.-J., & Farrell, S. (2004). AIC model selection using Akaike weights. *Psychonomic Bulletin & Review, 11*(1), 192-196.

Watanabe, S. (2010). Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory. *Journal of Machine Learning Research, 11*(Dec), 3571-3594.

Weyn, S., Van Leeuwen, K., Pluess, M., Lionetti, F., Greven, C., Goosens, L., . . . Bijttebier, P. (2019). Psychometric Properties of the Highly Sensitive Child Scale Across Developmental Stage, gender, and Country. *Current Psychology*. https://doi.org/10.1007/s12144-019-00254-5

Appendix

```
data {
  int<lower=0> N; // number of effect sizes
  int<lower=1> paperID[N]; // paper ID
  int<lower=1> npaper; // number of papers
  vector[N] z; // observed effect sizes
  vector[N] sigma2; // estimated sampling variances
}
transformed data {
  vector[N] sigma;
  for (n in 1:N) {
    sigma[n] = sqrt(sigma2[n]);
  }
}
parameters {
  real theta; // effect size
  vector[npaper] lambda; // BLUPS
  real<lower=0,upper=5> tau; // standard deviation of effect size estimate
```

```
}
transformed parameters {
  real tau2;
  vector[npaper] delta;
  tau2 = tau^2;
  for (n in 1:N)
    delta[paperID[n]] = theta+lambda[paper[n]];
}
model {
  tau ~ cauchy(0,5); // prior of standard deviation
  theta ~ cauchy(0,1); // skeptical prior of effect size
  lambda ~ normal(0,tau);
  for (n in 1:N)
    z[n] ~ normal(delta[paperID[n]], sigma[n]);
}
```