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Original Article

**Increased resting-state activity in the cerebellum with mothers having less
adaptive sensory processing and trait anxiety**

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24 **Abstract**

25 Child-rearing mothers with high levels of trait anxiety have a tendency for less adaptive
26 sensory processing, which causes parenting stress. However, the neural mechanisms underlying
27 this sensory processing and trait anxiety remain unclear. We aimed to determine the whole-
28 brain spontaneous neural activity and sensory processing characteristics in mothers with
29 varying parenting stress levels. Using resting-state functional magnetic resonance imaging, we
30 assessed mothers caring for more than one preschool aged (2–5 years) child and presenting
31 with varying levels of sensory processing, trait anxiety, and parenting stress. Spontaneous
32 neural activities in select brain regions were evaluated by whole-brain correlation analyses
33 based on the fractional amplitude of low-frequency fluctuations (fALFF). We found significant
34 positive correlations between levels of sensory processing with trait anxiety and parenting
35 stress. Mothers having less adaptive sensory processing had significantly increased resting-state
36 network activities in the left lobule VI of the cerebellum. Increased fALFF values in the left
37 lobule VI confirmed the mediation effect on the relationship between trait anxiety and sensory
38 processing. A tendency for less adaptive sensory processing involving increased brain activity
39 in lobule VI could be an indicator of maternal trait anxiety and the risk of parenting stress.

40

41 **Keywords:** amplitude of low-frequency fluctuations, cerebellum, parenting stress, resting-state fMRI,
42 less adaptive sensory processing, trait anxiety

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46

47 1 **Introduction**

48 Everyday life is full of various sensory stimuli. Sensory processing refers to the ability to regulate and
49 organize reactions to sensory stimuli in a graded and adaptive manner (1-3). In other words, sensory
50 processing refers to the ability of the brain to correctly respond to the surrounding environmental
51 stimuli and remain at the correct responsiveness level. Sensory processing has been explained based
52 on neurological threshold and behavioral response; the neurological thresholds refer to the intensity of
53 stimuli needed for the central nervous system (CNS) to notice or react to stimuli, while the behavioral
54 responses refer to the manner of response in relation to the thresholds (2).

55 Although most people present with balanced sensory processing abilities, approximately 15%
56 of the population present with a tendency for less adaptive sensory processing patterns (4). The brains
57 of individuals with a tendency for less adaptive sensory processing, who present hyper-responsive or
58 hypo-responsive behaviors, are thought to be unable to receive stimuli or filter out irrelevant stimuli
59 (5, 6); for example, "they startle easily from unexpected or loud noises," "they don't notice when
60 other people come in the room," "they don't seem to notice when their hands or faces are dirty," "they
61 are unaware of odors that others notice," " they keep the shades down," "they touch others when
62 they're talking" (2, 4). The response process is not as automatic as that in most individuals and
63 requires more effort for those with less adaptive tendency for sensory processing. This may interfere
64 with engagement in daily activities such as eating, grooming, and socializing (6).

65 Healthy individuals with a tendency for less adaptive sensory processing, such as those with
66 low sensory input registration or sensory hypersensitivity, have been shown to have high trait anxiety
67 (7, 8). Trait anxiety predisposes individuals to daily evasive behavior as well as excessive and volatile
68 emotions (9, 10). In adults with autistic traits, abnormal sensory processing is positively associated
69 with trait anxiety (8). Sensory processing ability has been studied in adults with mental health issues
70 (11, 12), including anxiety and social-emotional issues, and can predict psychological distress (13).
71 Particularly, there is a strong association between trait anxiety and sensory processing difficulties,
72 which can cause stress in routine situations.

73 Significantly, anxiety in child-rearing mothers is associated with depressive symptoms and
74 care stress (14, 15). Increased trait anxiety in mothers has been shown to induce parenting stress (16).
75 Moreover, a high level of trait anxiety in mothers is a risk factor for child maltreatment (17). A study
76 of mother–child mutual play reported that mothers with increased trait anxiety were less sensitive to
77 their child's behaviors (18). In addition, maternal anxiety is associated with less adaptive sensory
78 processing even in healthy adults (19). Mothers with a tendency for less adaptive sensory processing
79 were reluctant to respond promptly to their children's signs, including crying (20). Low threshold
80 prenatal sensory patterns correlated with maternal–infant postnatal attachment (21).

81 In a study of the rearing brain, a mother's brain becomes sensitive to baby stimuli during the
82 first months of life (22). In other words, child-rearing mothers are constantly exposed to the stimulus
83 of their baby, in addition to other daily sensory stimuli. Mothers have a response bias to infant's facial
84 stimuli, which is generally perceived as adaptive (23). As environment stimuli are also typically
85 present, a process is envisioned in which unrelated stimuli are suppressed, and the target infant's
86 facial stimulus unconsciously and consciously pops up. If there is a tendency for less adaptive sensory
87 processing, such processing cannot be performed. In this case, the infant's facial expression input may
88 be complex for the mother, leading to child-rearing stress. Taken together, these previous findings
89 suggest that trait anxiety in mothers can influence a tendency for less adaptive sensory processing,
90 which can lead to difficulties in parenting.

91 Trait and state anxiety are two psychological concepts essential to understanding how
92 individuals respond emotionally and cognitively in different situations (24, 25). Trait anxiety is a
93 stable and lasting tendency that defines a person's overall anxiety level across time and situations and
94 is defined more as a personality feature (10). It is often seen as a fundamental part of someone's
95 personality. People with high trait anxiety consistently feel uneasy, worried, and on edge in various
96 circumstances, even without immediate stressors. This enduring trait can impact how individuals
97 perceive threats, cope, and navigate their environment. The State-Trait Anxiety Inventory (STAI)
98 assesses trait anxiety, helping to measure this relatively constant disposition.

99 In contrast, state anxiety is a temporary emotional state marked by a temporary increase in
100 feelings of apprehension, tension, and nervousness, which is a temporary reaction to adverse events

101 (10). It arises in response to specific situations or stressors an individual encounters. Unlike trait
102 anxiety, state anxiety varies depending on the perceived threat or challenge in the immediate context.
103 This anxiety type is often linked to the 'fight or flight' response and is a natural adaptive reaction to
104 perceived dangers. State anxiety is typically evaluated through self-report measures like the State
105 portion of the State-Trait Anxiety Inventory (STAI-State), which captures a person's current
106 emotional experience.

107 Thus, trait anxiety reflects a stable individual trait related to experiencing anxiety, while state
108 anxiety captures the fluctuating emotional response to particular situations. A recent fMRI study has
109 shown differences in resting-state functional connectivity (rs-FC) for healthy human trait anxiety and
110 state anxiety. Furthermore, concerning structural gray matter (GM), trait anxiety was related to
111 volume alterations in anterior cingulate, limbic regions such as the amygdala with and cingulate
112 gyrus, precuneus, cuneus, and inferior frontal gyrus, and cerebellar involvement; the cerebellum was
113 particularly strongly related (26). Additionally, previous studies show that sensory processing
114 capacity (AASP) predicts psychological distress in adults with mental health problems (12, 27) and
115 that lower sensory processing capacity is associated with higher trait anxiety (7, 8). Hence, the present
116 study addressed only trait anxiety in parenting mothers to identify the neural basis of sensory
117 processing with trait anxiety in a whole-brain search to show the relationship between trait anxiety,
118 sensory processing capacity, and its neural basis.

119 Fractional amplitude of low-frequency fluctuations (fALFF) can reflect individual
120 characteristics in healthy adults, including the "Big Five" personality traits (28), trait extroversion
121 (29), trait empathy (30), trait grit (31), subjective well-being (32), trait hopefulness (33), and
122 perceived stress (34). However, there are no studies on the characteristics of spontaneous neural
123 activity in child-rearing mothers with a tendency for less adaptive sensory processing and trait anxiety
124 using measurements of fALFF by resting-state functional MRI (rs-fMRI).

125 The tendency toward nonadaptive sensory processing induced by trait anxiety may be a
126 stressor. Thus, it is unclear whether the effects of trait anxiety observed in mothers' parenting in
127 everyday situations are mediated. Although neurobiology can elucidate the role of sensory processing
128 in trait anxiety, relevant studies on the neural mechanism have been limited by their reliance on

129 clinical samples with specific forms of psychopathology such as general anxiety disorder (35) and
130 post-traumatic stress disorder (36).

131 Regarding the neural basis of sensory processing characteristics in healthy adults, studies
132 have reported positive correlations of modality-specific (e.g., visual, auditory, or tactile) sensory
133 scores with the gray matter volume in the related primary sensory areas (37). Moreover, the neural
134 basis of sensory processing has been suggested to involve the neocortex, basal ganglia, and cerebellar
135 activities (38). The neocortex is a sensory processor and elegant motor programmer. The basal ganglia
136 and the cerebellum interact with the neocortex and have been involved in the adaptation and behavior
137 of sensory information. In a recent study, connectome-based predictive modeling (CPM) suggested
138 predicting maternal anxiety toward their infant between cerebellum and motor-sensory-auditory
139 network and between frontoparietal and motor–sensory–auditory networks (39). Finally, the
140 cerebellum has been suggested to be involved in emotion (e.g., anxiety) and motor control (36, 40).
141 Accordingly, we hypothesized that the cerebellum is involved in trait anxiety, which involves less
142 adaptive processing of sensory input in mothers.

143 Whole-brain exploration of fALFF analysis is suitable for exploring potential biomarkers
144 through whole-brain investigation for the following reasons. First, fALFF assesses the amplitude of
145 low-frequency oscillations across the entire brain, providing a comprehensive examination of regional
146 neural activity and connectivity patterns. This approach allows researchers to investigate brain-wide
147 alterations and identify potential biomarkers that might not be evident through region-specific
148 analyses. Second, unlike region-of-interest (ROI) based analyses, whole-brain fALFF analysis does
149 not rely on predefined brain regions or specific hypotheses (41). It allows for an unbiased exploration
150 of the entire brain, enabling the identification of novel biomarkers and potential associations between
151 brain alterations and clinical outcomes (42). Third, many neurofunctional disorders are characterized
152 by widespread brain dysfunction rather than isolated abnormalities in specific regions. Whole-brain
153 fALFF analysis captures such distributed alterations, which may be crucial in identifying reliable
154 biomarkers with diagnostic or prognostic significance. In addition, some neurological or functional
155 conditions might involve subtle changes in brain activity that are not readily apparent in conventional
156 ROI-based studies. Whole-brain fALFF analysis can detect such subtle alterations, contributing to a

157 deeper understanding of complex brain disorders (43). Lastly, the data-driven nature of whole-brain
158 fALFF analysis allows for exploratory investigations without a priori assumptions. It enables
159 researchers to discover unexpected associations and patterns, leading to new hypotheses and avenues
160 for future research. Thus, whole-brain fALFF analysis is valuable for exploring potential biomarkers
161 for neurological and functional disorders. Its unbiased and comprehensive nature makes it well-suited
162 for identifying brain-wide alterations and their associations with clinical or subclinical phenotypes.

163 No previous brain MR imaging study has used rs-fMRI and sensory characteristics as a clue
164 in studying women, especially mothers raising children. We here aimed to identify the neural
165 correlates of sensory processing and trait anxiety using rs-fMRI exploratory fALFF analysis through a
166 whole-brain search instead of the standard network analysis (ROI-ROI correlation analysis) to explore
167 a potential biomarker. We also aimed to enroll child-rearing mothers for testing our hypothesis that
168 subclinical anxiety reflects the atypical neural activity of brain regions involved in regulating sensory
169 perception, sensory processing, and emotional behavior. Furthermore, we determined whether there
170 was a correlation of alterations in regional brain activities with parenting stress.

171

172 **2 Methods**

173 **2.1 Participants**

174 Between 2015 and 2016, we enrolled 33 mothers (age range = 27–46 years, mean age = 35.9 years,
175 standard deviation [SD] = 4.5 years) through advertisements targeted to female caregivers caring for
176 more than one preschool, typically developing child, as previously described (44). The ethnicity of all
177 participants was Japanese.

178 The study protocol was approved by the Ethics Committee of the University of Fukui, Japan
179 (Approval # FU-20150109), and all procedures were conducted in accordance with the Declaration of
180 Helsinki and the Ethical Guidelines for Clinical Studies of the Ministry of Health, Labor, and Welfare
181 of Japan. The participants received explanations regarding the purpose and meaning of the study, and
182 written informed consent was obtained from all subjects.

183 All participants had completed ≥ 12 years of education and were living above the relative poverty line,
184 which is set at 50% of the median household income in Japan (Organization for Economic

185 Cooperation and Development, 2016). Based on self-report questionnaires, none of the participants
186 had a history of brain injury, neurological or major psychiatric illness, current medication use,
187 excessive alcohol intake, or cigarette smoking. Moreover, none of the participants were pregnant or
188 had been diagnosed with or treated for depression or anxiety disorder. According to the Japanese
189 version of the Flinders Handedness Survey (FLANDERS)(45), all the participants were classified as
190 either right or left-handed.

191 All the participants met the safety requirements for undergoing rs-fMRI (exclusion of ferromagnetic
192 implants, claustrophobia, pregnancy, and other factors). The standardized questionnaire was collected
193 by mail after the brain imaging.

194

195 **2.2 Psychological Questionnaires**

196 **Anxiety.** We used the trait subscale of the State-Trait Anxiety Inventory (STAI), a 20-item self-
197 reported questionnaire (10), to measure the participants' current anxiety mood. The STAI-Trait
198 assesses how respondents "generally feel" (e.g., "I am a steady person" or "I lack self-confidence").
199 Each STAI-Trait item has a weighted score of 1–4. A rating of 4 indicates the presence of a high trait
200 anxiety level.

201

202 **Depression.** The Beck Depression Inventory-II (BDI-II) (46) was used to measure the participants'
203 current depressed mood. The BDI-II scores range from 0 to 63 with the cut-off points 14, 20, and 29
204 indicating mild, moderate, and severe depression levels, respectively.

205

206 **Sensory processing.** The Adult/Adolescent Sensory Profile (AASP) (47) was used to measure the
207 participants' sensory processing degree. The AASP is a 60-item questionnaire designed as a trait
208 measure of six sensory modalities involved in everyday sensory stimuli: visual (e.g., prefers
209 darkness), auditory (e.g., holds hands over ears to protect them from sound), touch, taste/smell,
210 movement (vestibular/proprioceptive), and activity level. It assesses how often the respondent
211 performs a particular behavior using a 5-point scale (1, almost never; 2, seldom; 3, occasionally; 4,
212 frequently; and 5, almost always; range of possible scores, 60–300). In contrast, the 60-item

213 questionnaire is classified into four quadrants based on the Dunn's model (5). The four quadrants are
214 defined by a "neurological threshold continuum axis" (i.e., behaviors hyper-responsive versus hypo-
215 responsive to sensory stimuli) and a "passive-active behavior axis" (i.e., the person does/does not try
216 to compensate behaviorally for an abnormal threshold). The AASP is the most widely used sensory
217 processing scale in the world (48).

218 In a recent study, sensory processing problems were suggested to include sensory over-responsivity
219 (SOR), under-responsivity (SUR), and seeking symptoms (1, 3). The SOR score used the sum of the
220 avoidance quadrant and the sensitivity quadrant of the sensory profile score (1). Similarly, some or all
221 four-quadrant scores are sometimes summed up (8, 49-52). The short sensory profile (SSP) version
222 for children initially has a total score, and the higher the total score, the more atypical sensory
223 processing (49, 53). However, in previous studies, the four-quadrant scores were often analyzed
224 individually (7, 54).

225 Thus, the four quadrants of Dunn's model may overlap within an individual, as described in "At least
226 one sensory quadrant of four quadrants" (55, 56). Initially, the four-quadrant scores of Dunn's model
227 are closely related theoretically and statistically (7, 54). In particular, the "neurological threshold
228 axis," which constitutes the four quadrants, has been confirmed to be continuous by skin conductance
229 measurements and Electroencephalography (EEG), but the other "passive-active axis" has not been
230 confirmed (4, 52). Therefore, we adopted the AASP total scores to confirm the neurological
231 characteristics underlying individual differences in sensory processing (57).

232

233 **Parenting stress.** We used the Japanese version of the Parental Stress Index (PSI-J) (58) adapting the
234 PSI (59) for measuring maternal parenting stress. The PSI-J is a 78-item self-report questionnaire,
235 which is divided into child and parent rating items on a five-point scale that ranges from 1
236 (completely disagree) to 5 (completely agree). The child domain of stressors includes the child's
237 adaptability and behavioral characteristics (e.g., degree to please parents, child's mood, degree to
238 annoy parents, distractibility, and hyperactivity). The parent domain of stressors includes parental
239 characteristics and feelings of social childcare support in the family (e.g., parental role restriction,

240 social isolation, relationship with spouse, parental competence, depression/guilt, attachment, health).
241 Higher scores indicate higher levels of parenting stress.

242

243 **2.3 fMRI data acquisition**

244 Scanning took place on the GE Discovery MR 750 3.0 Tesla scanner (General Electric, Milwaukee,
245 WI, USA) using a 32-channel head coil. Functional images were acquired using a T2*-weighted
246 gradient-echo echo-planar imaging sequence to produce 40 continuous transaxial slices with a
247 thickness of 3.5 mm and 0.5 mm gap, respectively, covering the entire cerebrum and cerebellum
248 (repetition time [TR] = 2300 ms; echo time [TE] = 30 ms; flip angle [FA] = 81°; field of view [FOV]
249 = 192 mm; 64 × 64 matrix; voxel dimension = 3.0 × 3.0 mm; 201 acquisitions). During the scan, the
250 participants were instructed to close their eyes, remain awake, and think of nothing in particular.
251 We acquired high-resolution structural whole-brain images using a 3D T1-weighted fast spoiled-
252 gradient recalled imaging sequence (TR = 6.38 ms; TE = 1.99 ms; FA = 11°; FOV = 256 mm; 256 ×
253 256 matrix; 172 slices; voxel dimension = 1.0 × 1.0 × 1.0 mm).

254

255 **2.4 fMRI data analysis**

256 **Preprocessing.** To account for the time required for MRI signal equilibration and subject adaptation
257 to the scanning environment, the first 10 volumes were discarded. The remaining 191 images were
258 corrected for slice timing, followed by spatial realignment to correct for head motion.

259 We adjusted for head motion effects by computing the mean frame-wise displacement (FD) (60). All
260 participants' data were within the motion thresholds for inclusion in the analysis, defined as
261 translational parameters <3 mm, rotational parameters <3°, and FD < 0.5. Subsequently, high-
262 resolution T1 images were co-registered with the functional images using a nonlinear image
263 registration approach. Next, images were segmented using a recently published diffeomorphic
264 anatomical registration algorithm that employs an exponentiated Lie algebra technique (61).
265 Subsequently, functional images were spatially normalized to the Montreal Neurological Institute
266 template, resampled to a spatial resolution of 3 × 3 × 3 mm³, and spatially smoothed with a 6-mm full
267 width at half-maximum Gaussian kernel. Next, nuisance signals in 24 head-motion parameters (62),

268 the global signal, the time series of the cerebrospinal fluid and white matter, and any linear trends
269 were regressed out of each voxel's time course. Finally, we performed temporal band-pass filtering
270 (0.01–0.8 Hz) of the residual time series to reduce the effect of low- and high-frequency drifts and
271 noise, respectively (63).

272

273 **Fractional amplitude of low-frequency fluctuations analysis.** To investigate the spontaneous
274 neural activity, we calculated the fALFF rather than the original ALFF because the former is
275 considered less sensitive to physiological noise and artifacts that could weaken low-frequency
276 oscillation approaches (60). To perform the fALFF calculation, the time course of each voxel signal
277 was transformed into the corresponding power spectrum by fast Fourier transform (FFT).
278 Subsequently, the power spectrum obtained by FFT was square-root-transformed and averaged across
279 0.01–0.08 Hz at each voxel, according to a previous study (64). The obtained averaged square root
280 was divided by the global mean value, providing fALFF maps (65). Finally, for standardization,
281 individual fALFF maps were divided by the grand average of the fALFF value. In order to perform a
282 path analysis, we calculated the average value for each voxel in the cluster as a representative fALFF
283 value for each subject.

284 Imaging data were preprocessed and analyzed using the Statistical Parametric Mapping
285 software (SPM12; Wellcome Trust Centre for Neuroimaging, London, UK) and the Data Processing
286 Assistant for rs-fMRI (DPARSF) (66) running on MATLAB R2016 (MathWorks, Natick, MA).

287

288 **2.5 Statistical analysis**

289 Statistical analyses were performed using SPSS Version 24 (IBM Corp., Armonk, NY). Data were
290 expressed as mean \pm SD. Using the datasets mentioned above, we performed a correlation analysis to
291 investigate the relationships among trait anxiety, sensory processing characteristics, and parenting
292 stress. Next, we performed a whole-brain correlation analysis of STAI and AASP total scores with
293 fALFF values to determine the relationship between the degree of sensory processing and resting-
294 state brain activities. The model included age, BDI-II scores, and mean FD as nuisance covariates. In
295 addition, the mean FD, which was derived from individual analysis, was included to further exclude

296 residual head-motion effects. The statistical threshold was set at $P < 0.005$ uncorrected at the peak
297 level and $P < 0.05$ at the cluster level, with family-wise error (FWE) corrected over the whole brain.
298 Further, we analyzed the correlation of the fALFF values with the STAI trait scores and the PSI total
299 scores.

300 A path analysis mediated using the bootstrapping technique to obtain a 95% bias-corrected confidence
301 interval (CI) of indirect effect was utilized to determine whether the fALFF value significantly
302 mediated the association between trait anxiety and the degree of sensory processing. The bootstrap
303 test was conducted using the R 3.1.2 Test package (<http://www.R-project.org/>).

304

305 **3. Results**

306 **3.1 Descriptive statistics**

307 Among the 33 participants, six were excluded (three did not fill out the questionnaire and three had a
308 history of depression). Among the six excluded participants, one was not living above the relative
309 poverty line and another was not married. All participants were unmedicated.

310 Artifact-free images suitable for rs-fMRI analyses were obtained from 27 female caregivers
311 (age = 35.6 ± 4.3 years; AASP total scores = 141 ± 23.8 ; STAI trait scores = 42.6 ± 9.5 ; BDI-II scores
312 = 11.3 ± 6.1 ; PSI total scores = 193.5 ± 40.7) who were caring for more than one preschool aged (2–5
313 years) child, including seven first-time mothers (**Table 1**). Of the 27 subjects, 25 were right-handed,
314 and two were left-handed. None of the subjects exhibited severe anxiety, depression, abnormal
315 sensory profiles, excessive parenting stress, or difficulties in child-rearing. The participants included
316 four mothers with AASP total scores >1 SD (>164.8) from the mean.

317

318 Insert Table 1 here

319

320 There were significant positive correlations of sensory processing levels (AASP total scores)
321 with the trait anxiety and with the PSI total (STAI, $r = 0.537$, $P = 0.004$; PSI, $r = 0.434$, $P = 0.024$,
322 respectively) in mothers with various levels of sensory processing and parenting stress (**Figure 1A**,

323 **B).** There was no significant association between the AASP total scores and the BDI-II scores ($r =$
324 $0.176, P = 0.381$).

325 Questionnaire data are summarized in **Table 2**.

326

327 Insert Table 2 here

328

329 Insert Figure 1 (A), (B) here

330

331 **3.2 Imaging results**

332 We observed that individuals with higher AASP total scores had increased resting-state network
333 activities in the left cerebellum, the region including lobule VI (Talairach's coordinates $x = -30, y = -$
334 $60, z = -24$; cluster size = 80 voxels) ($P = 0.008$, FWE-corrected cluster level), as shown in **Figure 2**.

335

336 Insert Figure 2 here

337

338 None of the other values, such as the STAI trait and the PSI total scores showed a corrected
339 cluster probability approaching significance. Without multiple comparison corrections, however, we
340 found the result as an activity ($P < .005$, uncorrected at peak level, and $P < 0.05$, uncorrected at
341 cluster level). Examination of voxels with decreased fALFF revealed no clusters anywhere in the
342 brain. In lobule VI, fALFF values were significantly associated with the STAI scores ($r = 0.466, P =$
343 0.014). However, we observed no significant associations between the lobule-VI fALFF values and
344 the PSI total scores ($r = 0.306, P = 0.120$).

345 We conducted a mediation analysis to assess the mediation effect of fALFF values in the left
346 lobule VI. **Figure 3** shows the mediation model used for predicting AASP total scores. In this model,
347 trait anxiety levels, left lobule VI fALFF, and AASP total scores were included as the independent
348 variable, mediator, and dependent variable, respectively. Trait anxiety levels significantly predicted
349 AASP total scores as indicated by previous multilevel regression analyses ($\beta = 0.537, P < 0.01$).

350 Further, trait anxiety levels predicted fALFF values in the left lobule VI ($\beta = 0.466, P < 0.05$). When
351 trait anxiety levels and fALFF values in the left lobule VI were entered into the prediction model of
352 the AASP total scores, there was a reduced effect of trait anxiety levels ($\beta = 0.232, P = 0.114$) while
353 fALFF values in the left lobule VI remained significant ($\beta = 0.655, P < 0.01$). A bootstrapping
354 procedure tested the mediating effect of fALFF values in the left lobule VI using 5,000 resamples.
355 This technique yielded a 95% bootstrap CI without zero [0.010 to 1.883], which suggested that fALFF
356 values in the left lobule VI significantly mediated the effect of trait anxiety on AASP total scores. We
357 also developed a reverse causality model in which AASP predicts trait anxiety via the left lobule VI
358 and examined its mediating effects. The results showed no significant indirect effect of AASP on
359 STAI via left lobule VI (95% bootstrap CI [-0.15 to 0.22]).

360

361 Insert Figure 3 here

362

363 4. Discussion

364 To our knowledge, no previous brain MR imaging study has used rs-fMRI and sensory characteristics
365 as a clue in studying women, especially mothers raising children. Thus, we performed a whole-brain
366 exploratory fALFF analysis instead of the standard network analysis (ROI-ROI correlation analysis)
367 to explore a potential biomarker through a whole-brain search. Our findings revealed an association
368 between the degree of sensory processing evaluated using the AASP total scores and the resting-state
369 brain activity in the left lobule VI (**Figure 2**). Individuals with higher AASP total scores had higher
370 levels of both trait anxiety and parenting stress, as assessed by STAI and PSI scores, respectively
371 (**Figure 1**). Additionally, path analysis showed that fALFF values in the left cerebellar lobule VI
372 mediated the effect of trait anxiety levels on AASP total scores (**Figure 3**). This study elucidates the
373 neural mechanism of the involvement of this region in sensory processing in mothers.

374 Notably, we observed a strong association between fALFF values in the left lobule VI of the
375 cerebellum and the degree of sensory processing as measured by the AASP total scores. The reason
376 for the association of functional brain activity alterations in left lobule VI with a less adaptive sensory

377 processing phenotype remains unclear. Nonetheless, our findings are consistent with previous rs-
378 fMRI studies using independent component analysis, which reported a functional connection between
379 this region (lobule VI) and a salience network (67, 68). The salience network is involved in the
380 detection and integration of emotional and sensory stimuli and the coordination of switching between
381 internal and external cognition of the default mode network (69). The sensory processing scores,
382 based on the Dunn model, suggest the ability to monitor and adjust information such that the CNS
383 may generate appropriate responses to specific stimuli (2). Our finding that sensory processing scores
384 were associated with left lobe VI supports that the salience network, including left lobe VI, is the
385 neural basis of sensory processing. A previous study that assessed continuous cognitive processes and
386 resting network switching in adults suggested lobule VI involvement (70). Importantly, lobule VI is
387 the only region in the cerebellum that has been identified as crucially involved in switching from non-
388 motor to motor functions (71). Thus, the mechanism of the association of the left lobule VI with a
389 tendency for less adaptive sensory processing, including hypersensitivity and/or low registration of
390 sensory stimuli, could play an important role in triggering correct responses to environmental stimuli.

391 Additionally, the lobule VI is associated with negative emotions such as fear, anger, and
392 disgust (72). Individuals with higher sensory processing scores presented with higher trait
393 anxiety scores (7, 8), and greater parenting stress (13, 16), which is consistent with the present
394 report. A recent meta-analysis study on anxiety-related brain networks reported an association
395 of high anxiety levels with attenuated connectivity within the salience and sensorimotor
396 network (73). For example, adults with general anxiety disorder had low connectivity between
397 the amygdala and the cerebellum. Therefore, our findings suggest that trait anxiety could
398 induce less adaptive sensory processing at the subclinical level.

399 Although this finding has been discussed from the perspective of a potential cause-and-effect
400 mechanism, our evidence only supports an association between sensory processing and the resting-
401 state brain activity of lobule VI. The cerebellum is considered a general-purpose co-processor, with its
402 effects being dependent on various brain centers connected to individual modules (67, 74) and a

403 cerebellar timing process that contributes to sensory perception (75, 76). Conversely, participants with
404 high lobule VI activation in the resting state could show subclinical but atypical levels of co-processor
405 function, as well as atypical cerebellar timing processes in the sensory domain. Further, the
406 cerebellum could be crucially involved in the pathogenesis of anxiety; cerebellar stimulation could
407 potentially be used to treat psychiatric disorders by enhancing the cerebellar modulation of cognition
408 and emotion (77, 78).

409 Notably, mediation analysis here revealed that trait anxiety symptoms in mothers affected the
410 spontaneous neural activity of the left lobule VI. The tendency for less adaptive sensory processing in
411 these individuals could be induced by subclinical trait anxiety levels, which may activate the resting-
412 state network dynamics of the left lobule VI and prevent general-purpose processor function.

413 Therefore, mothers who poorly register sensory input could present a continuous error signal to the
414 cerebellum that does not habituate (79, 80). Subsequently, perception becomes disordered and the
415 mother's action toward the child seems illogical. Our findings are consistent with previous findings
416 that mothers with high trait anxiety show poor responsiveness to the behavior of their child (18).

417 Specifically, we observed a correlation between the degree of sensory processing and both
418 trait anxiety and levels of parenting stress. Moreover, the left-lobule-VI mediated between the degree
419 of sensory processing and trait anxiety; however, cerebellar fALFF values were not correlated with
420 parenting stress. Previous studies on parents have shown that human mothers adapt to parenting by
421 means of reward-related motivational brain networks. In contrast, mothers with high levels of trait
422 anxiety and invasive care tendencies employ different brain networks, including the stress-related
423 occipital cortex and cerebellum (81, 82). Taken together, these findings suggest that was observed for
424 less adaptive sensory processing, possibly induced by subclinical trait anxiety, could result in a
425 compensatory increase in the resting-state brain activity of the cerebellum, which could be a risk
426 indicator for parenting stress.

427 For mothers who have a tendency for less adaptive sensory processing, it is important to
428 formulate an environmental setting and a support mechanism that is tailored to the situation of each
429 individual mother in order to supplement sensory processing. In particular, mothers with increased
430 fALFF values in cerebellar lobules VI who are more likely to respond to general daily sensory stimuli

431 such as “hold your hand over your ear to protect your ear from sound,” and “I don't notice when
432 people come in,” which makes it easy to feel parenting stress and anxiety. Clinicians may detect them
433 early and intervene early, and provide specific advice of the form, "If you feel stressed about your
434 baby's noisy crying, put your baby to sleep in a safe place, leave the place, and relax," "You may
435 attach a bell on your child to make it easier to notice any movement," which will help reduce the
436 stress and anxiety of rearing a child.

437 As shown in Table 2, the BDI-II scores strongly correlated with parenting stress. The
438 relationship between parenting stress and depressive state has been extensively studied in
439 psychological and parenting research (83, 84). Parenting stress and depressive state can influence
440 each other in a bidirectional manner. High levels of parenting stress can contribute to developing or
441 exacerbating depressive symptoms in parents. On the other hand, experiencing depressive symptoms
442 can reduce a parent's ability to cope with parenting challenges, leading to increased parenting stress.
443 Various factors can contribute to parenting stress, including the child's behavior, developmental
444 challenges, financial pressures, lack of social support, and the parent's coping abilities. Thus,
445 parenting stress and depressive state are closely related and can have significant implications for both
446 parents' mental well-being and the parent-child relationship. Recognizing and addressing parenting
447 stress through supportive interventions can be essential in preventing or alleviating depressive
448 symptoms in parents and promoting overall family well-being (83). Adequate social support, coping
449 skills, and self-care practices can act as protective factors against parenting stress and depressive
450 symptoms. Enabling caregivers to seek help by engaging supporters in proactive coping strategies is
451 essential to mitigate the adverse effects of parenting stress on mental health.

452 This study has several limitations. First, the study design and lack of a control group
453 comprised of patients with anxiety disorders or neurodevelopmental disorders limit the validity of our
454 findings. We could not enroll such a patient group because we aimed to employ rs-fMRI as an
455 unbiased whole-brain approach for identifying the neural correlates of sensory processing and trait
456 anxiety in child-rearing mothers without other severe psychopathology or at high risk for anxiety
457 disorder. However, given the paucity of findings on this topic, we believe that our contribution is
458 important. Second, the method of assessing sensory processing using a self-reported questionnaire

459 runs the risk of missing problem screening that the caregiver is having. For example, they may not be
460 aware of their hypersensitivity or insensitivity, or they may not recognize the questionnaire items
461 accurately and respond appropriately. In addition, because all the psychometric assessments were self-
462 reported, we ran the risk of including participants with sensory processing disorders. Conversely,
463 professional evaluation of healthy individuals without sensory processing disorder is as difficult as
464 evaluating participants with a specific diagnosis. Consequently, without self-reporting, there is a risk
465 of confounding neuroimaging differences associated with sensory processing and trait anxiety with
466 those involved in enhanced resilience. Taken together, the evidence indicates that the imaging
467 differences observed in our participants can be generalized to the general population because they are
468 outcome independent.

469 Third, this study was performed in a naturalistic setting with some participants having
470 missing data, and consequently being excluded. Therefore, we cannot rule out the possibility of
471 positive selection bias. Positive selection bias occurs when missing values are not randomly
472 distributed in a dataset, but instead, specific values are more likely to be missing than others. In a
473 naturalistic setting, this bias could occur if participants with specific characteristics or conditions are
474 likelier to drop out or be unavailable for data collection (85). Also, positive selection bias can distort
475 the results by introducing a non-random pattern of missing data, which may not represent the entire
476 population under study. This bias can lead to overestimating or underestimating associations between
477 variables. Thus, we should carefully analyze missing data patterns to mitigate positive selection bias
478 and explore potential reasons for the missingness.

479 Fourth, this study had a cross-sectional design that precluded the identification of causal links
480 between trait anxiety, sensory processing, and its impact on the brain functions of mothers beyond
481 statistical causal inference based on cross-sectional data. Longitudinal studies are required to
482 elucidate these associations fully. Fifth, although the present study was conducted with mothers
483 raising children typically, future studies will need to consider more essential control groups, such as
484 adult men and women not in the child-rearing years. Sixth, in the present study with multiple
485 comparison corrections, no salience/default mode network-related regions other than the cerebellum
486 may be due to sample size or sample characteristics such as childrearing mothers. Lastly, we used the

487 PSI scale in the present study. Additional studies are needed to measure brain activity further while a
488 mother interacts with her child (i.e., mother and child play tasks analyzed through an MRI scanner) to
489 evaluate the influence of sensory processing on mother–child interaction. Sixth, state anxiety was not
490 measured in the present study. In order to further study the subject/mother's anxiety tendency and
491 sensory processing from various perspectives, it may be necessary to examine state anxiety as well.

492 In summary, this study demonstrates evidence for a neurofunctional indicator underlying
493 various levels of trait anxiety and less adaptive sensory processing by the fALFF values in the left
494 cerebellar lobule VI in a sample of child-rearing mothers. Further, the discussed findings indicate that
495 fALFF could be a clinically meaningful measure for detecting maternal trait anxiety as a factor for
496 parenting stress. Determination of this measure for daily sensory stimulation could be used to screen
497 for parents at risk of maltreating their child for delivery of early guidance interventions, and to further
498 elucidate individual differences within various levels of trait anxiety and parenting stress. These
499 results of our study are promising results for clinical application. The fALFF value offers several
500 advantages over self-reported questionnaires like STAI and PSI-J. Such MRI assessment provides an
501 objective and direct measurement of brain function, whereas self-reported questionnaires rely on
502 subjective responses from individuals. MRI allows researchers to visualize and quantify brain regions
503 and their activities directly, providing more concrete and accurate data. Thus, it can assess brain
504 activity related to anxiety or stress, even when participants are unaware of these processes. On the
505 other hand, self-reported questionnaires rely on participants' conscious awareness and may not capture
506 unconscious or subtle emotional experiences.

507 Despite these advantages, it is essential to acknowledge that MRI assessments have some
508 limitations, including cost, technical expertise requirements, and potential claustrophobia or
509 discomfort for specific individuals during the scanning process. Therefore, combining MRI and self-
510 reported questionnaires can provide a more comprehensive understanding of psychological and
511 neurobiological factors.

512 One strength of this study is that it allows for future longitudinal and comparative rs-fMRI
513 studies on different levels of sensory processing in mothers to assess parenting stress. To accumulate
514 such research findings, it will be possible in the future to establish treatments (psychoeducations)

515 tailored to individuals who have various sensory processing patterns, which will adequately mitigate
516 parenting stress and anxiety. Taken together, we believe that these approaches, including early
517 screening and psychoeducation, are critical for assisting mothers to cope with a tendency for less
518 adaptive sensory processing during their parenting period and to form a stable attachment with their
519 child, which could help prevent child maltreatment.

520

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523 N.S. R.K. and A.T. wrote the manuscript. All authors have read and approved the final manuscript.

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535

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540

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543

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546

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552

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757
758

759 **Table 1.** Participants' demographic characteristics and psychological questionnaires score ($n = 27$).

	Mean	SD	Range	%
Age (years)	35.6	4.3	27-43	
Right-handed				84.8
Completed at least 12 years of education				100
Married (non-divorced, non-widowed)				100
Number of family members	4.6	1.1	3-7	
Number of children	2	0.8	1-4	
Months since last childbirth	31	1.7	1-69	
Living above the relative poverty line				100
State-Trait Anxiety Inventory: Trait Score	42.6	9.5	25-63	
Beck Depression Inventory-II Score	11.3	6.1	2-23	
Adult/Adolescent Sensory Profile Score (total)	141	23.8	95-214	
Quadrant scores Low Registration	31.4	6.8	22-55	
Sensation Seeking	40.2	5.7	32-55	
Sensory Sensitivity	36.6	9.1	18-61	
Sensation Avoiding	32.9	8.8	20-53	
Modality-specific subscales Visual	24.6	4.8	17-33	
Auditory	24.6	6.3	15-43	
Touch	31.2	7.2	20-55	
Taste/smell	17.5	3.9	10-24	
Movement (vestibular/proprioceptive)	17.4	3.4	11-27	
Activity level	25.8	4.6	17-37	
Parenting Stress Index Score (total)	193.5	40.7	118-302	
Child Domain Score	86.3	18.7	51-122	
Parent Domain Score	107.3	25.6	64-180	

Table 2. The correlations between psychological questionnaires score

Psychological Questionnaires	Correlation									
	1	2	3	4	5	6	7	8	9	10
1 State-Trait Anxiety Inventory: Trait Score										
2 Beck Depression Inventory- II Score	.608**									
3 Adult/Adolescent Sensory Profile score(total)	.537**	.176								
4 Low Registration	.478*	.152	.760**							
5 Sensation Seeking	-.016	-.105	.512**	.394*						
6 Sensory Sensitivity	.563**	.223	.902**	.597**	.213					
7 Sensory Avoiding	.507**	.194	.844**	.406*	.207	.799**				
8 Parenting Stress Index Score(total)	.681**	.748**	.434*	.514**	.155	.316	.345			
9 Child Domain Score	.484*	.674**	.375	.351	.153	.257	.373	.888**		
10 Parent Domain Score	.729**	.698**	.416*	.560**	.135	.314	.276	.942**	.681**	

** $P < .01$, * $P < .05$

Figure Legend

Figure 1 (A) Scatterplot showing the relation between trait scores from the STAI and AASP total scores. (B) Scatterplots showing the relation between PSI scores and AASP total scores. STAI, State-Trait Anxiety Inventory; AASP, Adult/Adolescent Sensory Profile; PSI, Parenting Stress Index.

Figure 2 Brain regions with *significantly increased resting-state network activities*, measured as fractional amplitude of low-frequency fluctuations (fALFF) using a fast Fourier transform. The main cluster is in the left cerebellum, lobule VI; Talairach's coordinates $x = -30, y = -60, z = -24$; cluster size = 80 voxels; $Z = 4.06$, family-wise error-corrected cluster level. Color scale represents t -values in the range 0–5.

Figure 3 Path model of the mediation effect of resting-state activity (fALFF values) in the left cerebellum, lobule VI, on the relationship between degree of trait anxiety, measured as the trait scores of the State-Trait Anxiety Inventory (STAI), and sensory modulation (AASP total scores). fALFF, fractional amplitude of low-frequency fluctuations; AASP, Adult/Adolescent Sensory Profile, SE, standard error; β , Standardized partial regression coefficient; *, $P < .05$; **, $P < .01$; n.s., not significant.