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Research Article
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Relationship between attention deficit hyperactivity disorder and highly sensitive person traits during the emotional Go/NoGo task: A near-infrared spectroscopy study

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Abstract: Impaired response inhibition, a core symptom of attention deficit hyperactivity disorder (ADHD), significantly affects an individual's overall quality of life. Nevertheless, the underlying mechanism remains unclear. We conducted the emotional Go/NoGo task among university students to explore the potential correlation between ADHD and highly sensitive person (HSP) traits. Hierarchical multiple regression analysis revealed that the increased commission errors when reacting to angry faces could be better explained by HSP traits rather than by ADHD traits alone. Moreover, we suggest heightened activity in the right prefrontal cortex is associated with these response inhibition difficulties. The results of this study align with those of prior studies, demonstrating that ADHD traits exacerbate response inhibition difficulties in tasks that involve angry faces. However, we emphasize the significant role played by HSP traits compared to ADHD traits alone. This underscores the importance of considering the presence or absence of an ADHD diagnosis and the intensity of ADHD traits and focusing on HSP traits when supporting individuals with pronounced ADHD traits.

Keywords: attention deficit hyperactivity disorder (ADHD), highly sensitive person (HSP), response inhibition, emotional Go/NoGo task, near-infrared spectroscopy (NIRS)

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a developmental disorder that results from impaired brain function and is estimated to affect 5.9% of adolescents and 2.5% of adults (Faraone et al., 2021, p.792). Symptoms of inattention, hyperactivity, and impulsivity primarily characterize it. However, in recent years, researchers have considered the inclusion of additional core symptoms such as emotional dysregulation (Graziano & Garcia, 2016; Shaw et al., 2014; van Stralen, 2016), emotional impulsivity (Barkley & Fischer, 2010, p.512), emotional lability, and sensory sensitivity (DeSerisy et al., 2019, p.324). As a pathological model, ADHD involves executive dysfunction with difficulties in response inhibition at its core (Barkley, 1997, p.51). The number of commission errors and reaction time variability during a cognitive task in which a series of stimuli are presented and the participant is asked to stop responding only when a specific stimulus is presented have been used to indicate response inhibition (Barkley & Murphy, 2010, p.163). A study comparing children with ADHD and typically developing children in a Go/NoGo task showed that children with ADHD had problems with response inhibition and increased commission errors (Benikos & Johnstone, 2009; Johnstone & Clarke, 2009; Monden et al., 2012). Additionally, difficulties in response inhibition (number of commission errors during tasks) in individuals with ADHD have been shown to contribute to self-control difficulties in daily life and occupational difficulties (e.g., number of work experiences; Barkley & Murphy, 2010, p.169), indicating that response inhibition may be a performance indicator that influences the overall quality of life.

Response inhibition in ADHD is affected by facial expression processing. In the emotional Go/NoGo task, which requires a response or response inhibition to specific facial expressions, children with ADHD and individuals with pronounced ADHD traits have been found to have difficulty with response inhibition (Köchel et al., 2014; Manoli et al., 2021). When children with ADHD were asked to press buttons in a Go/NoGo task with neutral, angry, sad, and happy faces as stimuli, the number of errors made by children with ADHD increased significantly compared to typically developing children, from the number of commission errors when neutral faces were presented to commission errors when angry faces were presented (Köchel et al., 2014, p.463). One possible reason for the significant increase in response inhibition difficulties with the addition of an angry facial expression component is that children and adults with ADHD experience difficulty with angry facial expressions during discrimination tasks (Kara et al., 2017; Köchel et al., 2014; Pelc et al., 2006). Conversely, it has been reported that the reward of smiling women and smileys increases the performance of individuals with ADHD in Go/NoGo tasks and other tasks (Kohls et al., 2009; Konrad et al., 2000), and both positive and negative stimuli are factors that influence cognitive and behavioral accuracy in individuals with ADHD (Jensen & Rosén, 2004; Manoli et al., 2021).

Similarly, a Highly Sensitive Person (HSP) is susceptible to positive and negative stimuli (Aron et al., 2012, p.266). Significant positive correlations between the Adult ADHD Self-Report Scale (ASRS) and the Highly Sensitive Person Scale (HSPS) have been reported (Panagiotidi et al., 2020, p.4). HSP is fundamental traits that represent differences in sensitivity and responsiveness to environmental stimuli. Highly sensitive individuals respond to deeper stimuli processing across various situations (Aron & Aron, 1997, p.365). Highly sensitive individuals positively correlate with negative emotions (Benham, 2006; Lionetti et al., 2019; Yano et al., 2021) and show significant amygdala activity in response to negative stimuli (Acevedo et al., 2017, p.368).

Thus, ADHD and HSP exhibit substantial commonalities, particularly in their association with emotional dysregulation and their responsiveness to positive and negative stimuli. Furthermore, the recently demonstrated strong correlation between ASRS and HSPS (Panagiotidi et al., 2020, p.4) sheds light on the increasing convergence between ADHD and HSP. The impairment of response inhibition by angry facial expressions in ADHD, which has been examined in the context of ADHD, may be due to HSP rather than ADHD as a direct cause. The reason is that ADHD is diagnosed by inattention, hyperactivity, and impulsivity without high sensitivity in the diagnostic criteria, while HSP is a concept that includes reactivity to negative stimuli. HSP also comprises three factors: ease of excitation, low sensory threshold, and esthetic sensitivity (Iimura et al., 2023, p.90), and is likely to be a direct factor in the difficulty of response inhibition. Thus, HSP traits, but not ADHD traits, could potentially cause changes in cerebral blood flow in response to negative stimuli, leading to issues with response inhibition.

This study aimed to clarify the causes of response inhibition difficulties in individuals with pronounced ADHD traits concerning HSP traits, and to explore the mechanisms of these difficulties by measuring prefrontal cortex (PFC) activity. This will help examine effective interventions and support methods for psychotherapy. As a performance index, we measured the number of commission errors in the emotional Go/NoGo task. We clarified the neuropsychological basis behind the difficulty in response inhibition by measuring changes in cerebral blood flow using near-infrared spectroscopy (NIRS) during the response inhibition task.

Methods

Participants

A total of 20 undergraduate and graduate students participated in this study. Informed consent was obtained. The study protocol was approved by the Ethics Review Committee of the Faculty of Humanities and Social Sciences, Kumamoto University (reception number: 45).

Questionnaires

CAARS Japanese version (Conners' Adult ADHD Rating Scales [Japanese version]; hereafter CAARS; Conners et al., 1999/2012) is a self-report scale consisting of 66 items on a four-point scale (never: 0, sometimes: 1, often: 2, very often: 3). A cutoff point (t-score of 65 or higher) for the CAARS was used. Among the 18 participants included in the analysis, four participants exceeded the cutoff on the DSM-IV Total ADHD Symptoms subscale, and three on the ADHD Index subscale.

The Japanese version of the HSP scale 10-item version (HSP-J10) (Iimura et al., 2023) is a seven-point self-report scale (1 = not at all applicable to 7 = very applicable) consisting of three factors: excitability, low sensory threshold, and esthetic sensitivity, which measures sensory processing sensitivity in adults. A cutoff point has not been specified, but the mean score for the Japanese is shown to be 42.4 (Iimura et al., 2023, p.90). The mean score of the 18 participants included in the analysis was 47.44 points (SD = 8.65).

Procedure

Participants answered the CAARS and HSP-J10 after performing the emotional Go/NoGo task created in the AIST Facial Expression Database 2017 (Fujimura & Umemura, 2018). Participants were seated such that the distance between the monitor and the participant was approximately 50 cm. They were asked to press a key with the index finger of their dominant hand. Stimuli were presented on a monitor with a 15.6-inch resolution of 1920 × 1080 pixels at a viewing angle of approximately 10°.

One block consisted of a Go block and a Go/NoGo block. The instruction was 3 s, stimulus presentation was 0.8 s, and the inter-stimulus interval was 0.2 s. The block set with the same conditions was repeated six times with a break before moving on to the next condition. The Go block consisted of 24 neutral trials in which the participants

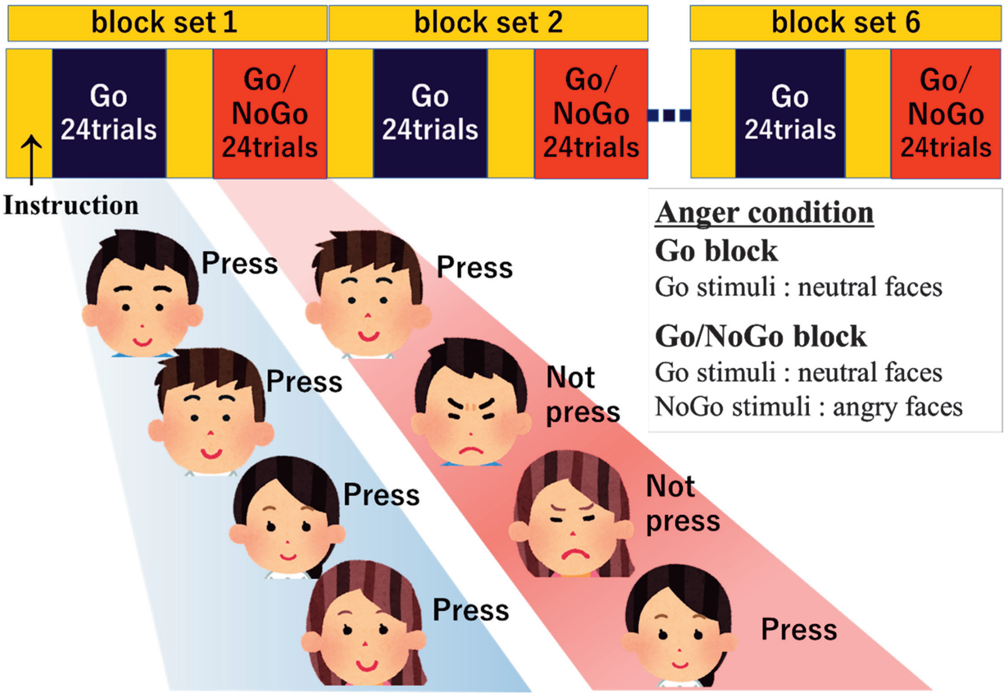

Figure1. Emotional Go/NoGo task
Note. Dummy illustrations were used.

pressed the key for all presented faces. The Go/NoGo block comprised 24 trials, 12 Go trials, and 12 NoGo trials, in which they pressed the key for Go trials and did not press the key for NoGo trials. There were five conditions: three emotional conditions (Go: neutral and NoGo: anger) (Go: neutral and NoGo: sadness) (Go: neutral and NoGo: happiness) and two non-emotional conditions (Go: woman and NoGo: man) (Go: man and NoGo: woman), in which all stimuli were neutral (Fig 1). The order of stimulus presentation was random, such that the same stimulus was not followed more than once, and the order in which the five conditions were performed was counterbalanced across the participants. Before the measurement, a practice block was performed to check whether the participants could identify facial expressions and understand the content of the task. The number of commission errors during the NoGo block was recorded for each condition. The average number of commission errors in each emotional condition minus the average number of non-emotional conditions was used as Δcommission errors data to capture changes due to the addition of emotion. We use the symbol Δ (delta), which represents the difference or the amount of change, to denote the change in the number of commission errors.

Near-infrared spectroscopy measurement

Changes in oxygenated hemoglobin (oxy-Hb) concentrations in the PFC during task execution were recorded using a multichannel NIRS system (OEG-16; Spectratech Inc., Tokyo, Japan). The sensor band of the OEG-16 comprised 16 channel measurement points, of which six emitting points and six detecting points were alternately arranged at intervals of 30 mm. The temporal resolution is 0.65 s, and the sensor measures the change in oxy-Hb concentration at a depth of approximately 3 cm from the scalp. The center of the sensor band was placed at the participant's Fpz according to the international 10-20 method. Channels 1-6 were additionally averaged for right PFC, channels 7-10 for middle PFC, and channels 11-16 for left PFC concentration change. Based on a previous study (Yasumura et al., 2019, p.580), to increase the signal-to-noise ratio, each recording was converted to a z-score. The z-score was calculated using the mean and standard deviation of changes in the oxy-Hb concentrations during the last 6 s of the Go block. The average signal for each channel during the NoGo blocks was used as the data for analysis. Statistical software R version 4.0.0. was used to calculate z-values.

Analysis methods

Before statistical analysis, considering their attitude toward the task, we excluded those who made more than three standard deviations (*SD*) in the number of commission errors during the Go/NoGo blocks. A total of 18 participants (Nine men and Nine women, 26.5 ± 8.9 [*SD*] years old) were included in the analysis. One-way ANOVA with Bonferroni post hoc analysis was performed on the commission errors in the Go/NoGo task. To examine the relationship between CAARS, HSP-J10, PFC activity (right PFC, middle PFC, and left PFC), and Δcommission errors in each emotional condition were analyzed using Spearman's rank correlation coefficient to examine associations. Subsequently, a hierarchical multiple regression analysis (stepwise method) was conducted to examine the difference in the influence of ADHD and HSP. Further, the amount of change in the coefficient of determination when PFC activities were added using CAARS, HSP-J10, and PFC activity as explanatory variables and anger Δcommission errors as the dependent variable in each emotion condition. Hierarchical multiple regression analysis was employed as the analytical method. The data were analyzed using SPSS Windows software version 26, with a significance level of 5%.

Results

Based on the results of the one-factor repeated measures ANOVA for several commission errors, a significant main effect was observed (F (3, 17) = 5.868, $p < 0.01$, ηp^2=.257). Based on Bonferroni post hoc comparisons, anger and sadness were significantly higher than in the non-emotional group (Fig 2).

Correlation analysis

Spearman's correlation coefficient between CAARS and HSP-J10 was determined and had a significant positive correlation (ρ = .613, p = .007). There was a positive correlation between HSP-J10 and Δcommission errors (ρ = .506, p =.032) and between right PFC and Δcommission errors (ρ =.489, p =.040) in the anger condition (Table 1). No significant correlations existed between each questionnaire, Δcommission errors, and PFC activity in the sadness and happiness conditions.

Hierarchical multiple regression analysis

In Step 1, we examined the effect of the CAARS scores on anger Δcommission errors. Subsequently, in Step 2, the HSP-J10

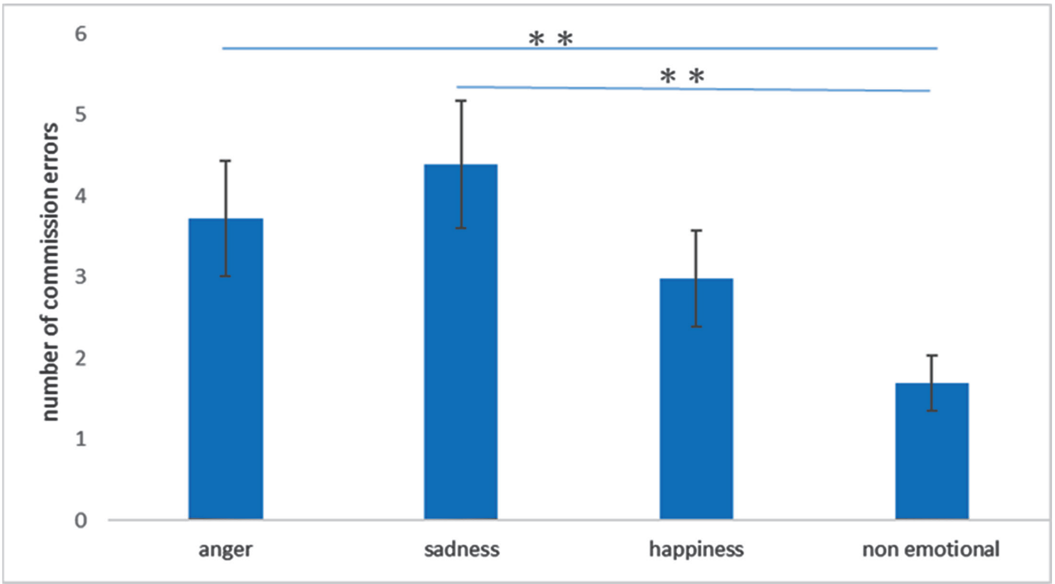

Figure 2. Mean number of commission errors in the Go/NoGo task; Error bars indicate standard error
Note. **p <.01, *p <.05.

Table 1. Correlation of each questionnaire with prefrontal cortex activity and Δcommission errors in anger condition

	CAARS	HSP-J10	Right PFC	Middle PFC	Left PFC	Δcommission errors
CAARS	—	.613**	.019	.217	.046	.309
HSP-J10		—	.236	.018	-.045	.506*
Right PFC			—	.280	.220	.489*
Middle PFC				—	.785**	.054
Left PFC					—	.054
Δcommission errors						—

Note. CAARS, Conners' Adult ADHD Rating Scales [Japanese version]; HSP-J10, The Japanese version of the Highly Sensitive Person scale 10-item version; Right PFC, right prefrontal cortex; Middle PFC, middle prefrontal cortex; Left PFC, left prefrontal cortex.
***p* <.01, **p* <.05.

score was entered. In Step 3, PFC activity (right, middle, and left PFC) was added to the variables in Step 2. The results showed that the model in Step 1 was not significant, and the CAARS scores did not significantly contribute to anger Δcommission errors. However, a significant model was obtained in Step 2, and the change in the coefficient of determination from Step 1 was also significant, indicating that the HSP-J10 score significantly predicted anger Δcommission errors. A significant model was also obtained in Step 3, and the change in the coefficient of determination from

Table 2. Results of hierarchical multiple regression analysis in the anger condition

	Standard Partial Regression Coefficient (β)		
	Step 1	Step 2	Step 3
CAARS	.131	-.318	-.204
HSP-J10		.724**	.528**
Right PFC			.467**
Coefficient of determination (adjusted R^2)	-.044	.251*	.434*
Change in coefficient of determination (ΔR^2)		.322**	.195**

Note. CAARS, Conners' Adult ADHD Rating Scales [Japanese version]; HSP-J10, The Japanese version of the Highly Sensitive Person scale 10-item version; Right PFC, right prefrontal cortex.
***p* <.01, **p* <.05.

Step 2 was also significant, indicating a significant effect of HSP-J10 scores and right PFC. The standard partial regression coefficients (β) and the change in the coefficient of determination (ΔR^2) when the variables were entered at each step are shown in Table 2. The residuals followed a normal distribution, and no significant multicollinearity was found based on the VIF values and other factors.

Discussion

This study showed a correlation between ADHD traits measured by the CAARS and HSP traits measured by the HSP-J10. This study confirms the results of a previous study (Panagiotidi et al., 2020, p.4) that showed a correlation between ADHD and HSP, in a Japanese population of university students. The HSP-J10 included the following questions: "Do other people's moods affect you?", "Are you made uncomfortable by loud noise?", and "Are you deeply moved by the arts or music?". It comprises three factors: ease of excitation, low sensory threshold, and esthetic sensitivity (Iimura et al., 2023, p.90). The emotional dysregulation noted in ADHD (Barkley & Fischer, 2010; DeSerisy et al., 2019; Graziano & Garcia, 2016; Shaw et al., 2014; van Stralen, 2016) encompasses the ease of excitation and low sensory thresholds on the HSP scale. Emotional dysregulation in ADHD, increasingly highlighted in recent years, can be viewed as a comorbidity of HSP. The need for psychological support focused on HSPs has been suggested for individuals with ADHD traits and ADHD.

Additionally, the decrease in reaction accuracy due to emotional arousal upon seeing a negative facial expression is a phenomenon that is generally observed in Japanese university students, while the ADHD trait itself was not correlated with anger Δcommission errors, the HSP trait, which was correlated with ADHD, was positively correlated with anger Δcommission errors. Individuals with pronounced HSP traits responded to angry faces because of their emotional reactions when they detected angry faces, unable to inhibit their behavioral reactions. In the present case, activation of the right prefrontal cortex was observed. This suggests that the factor that makes it difficult for individuals to inhibit their reactions to angry faces is not the strength of ADHD traits, but rather the HSP traits that are likely to coexist with ADHD and the activation of the right PFC.

Regarding brain localization, brain activity in ADHD mainly involves the right frontal and parietal hemispheres (Köchel et al., 2014, p.465). The low activation of the right lateral prefrontal cortex in children with ADHD, as shown by NIRS measurements during the reverse Stroop task (Yasumura et al., 2014, p.104) and the normalization of right inferior and middle prefrontal gyri activity during Go/NoGo tasks brought about by medication (Monden et al., 2012; Nagashima et al., 2014) and absence of increased right PFC activation during angry face observation (Ichikawa et al., 2014, p.56), it is widely believed that the brain basis of response inhibition difficulties in ADHD lies in reduced activity in the right prefrontal cortex.

What are the implications of the increase in commission errors and the accompanying increase in activity in the right PFC caused by detecting angry faces? If we follow the idea that PFC activity represents an increase in emotional responses (Posner et al., 2011, p.159), the increased activation of the right PFC observed in this study may be due to increased emotional reactivity elicited by angry facial expressions. In essence, a reasonable interpretation might be that HSP traits amplified the emotional response to angry faces, leading to an excessive activation of right PFC activity and this heightened activation could have impaired performance in response inhibition.

Similar to this study, an emotional Go/NoGo task with eye movements in healthy participants with pronounced ADHD traits showed increased commission errors when presented with an angry face and difficulty moving their gaze away from the angry facial expression (Manoli et al., 2021, p.1926). The difficulty in disengaging gaze from angry faces indicates that individuals with ADHD overinvest in processing resources when encountering angry expressions, which may make it difficult to inhibit their responses. This study's results also explain, from the HSP perspective, the background of the high sensitivity of children with ADHD to punishment (Furukawa et al., 2021; Luman et al., 2012) and the performance reduction due to punishment (Baumann et al., 2021; Furukawa et al., 2021) , which is a concern in the context of nurturing and education.

Conclusion

The decrease in reaction accuracy due to emotional arousal upon seeing a negative facial expression is also generally observed in Japanese university students. We hypothesized that HSP factors amplify the decreased response accuracy, and our hypothesis was proven. We also suggest that high HSP may coexist among clients with high ADHD traits. Among the clients with pronounced ADHD traits who receive psychotherapy and psychological support, there is a high probability of individuals with high HSP traits. As HSP traits influence response inhibition, which determines the quality of daily life, there is a need to show empathy for the difficulties caused by HSP traits and address the theme of coping with HSP traits.

This study supports the claim that individual differences in HSPs should be considered in psychotherapeutic interventions and approaches to improving mental health (Aron & Aron, 1997; DeSerisy et al., 2019; Greven et al., 2019; Yano et al., 2021). HSP should not be disregarded because it is not a diagnostic name but should be viewed as an important trait that affects performance. However, the positive aspects of HSP, such as communication skills (e.g., responsiveness to others' moods and conscientiousness) and creativity (Aron et al., 2012; Bridges & Schendan, 2019; Pluess & Belsky, 2013), should be encouraged.

Limitations

This study has some limitations that should be considered. First, our findings were based on self-reports, which means that some individuals may have very strong inattention, hyperactivity, and impulsivity but weak awareness. This may have resulted in a low impact of ADHD traits on response inhibition and brain activity. Second, the sample size in this study is small, so the generalizability of the results may not be high. Further research is needed to increase the sample size and strengthen the conclusions drawn. Third, the participants in this study were all non-clinical, which raises the question of whether the results can be easily generalized to the clinical populations. In the future, it is necessary to clarify the quantitative and qualitative differences between the clinical and non-clinical groups. Finally, this study did not consider depression, anxiety, or autistic tendencies, likely to be comorbid with ADHD. In the future, it will be necessary to more rigorously distinguish between specific brain activities due to HSP traits while controlling for other traits.

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