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Associations between P3 Responses and Continuous Performance Test in Children with Attention Deficit Hyperactivity Disorder and Typically Developing Children

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ABSTRACT

Objective: To investigate the associations between P3 responses induced by a Go/NoGo task and behavioral performance measured by the Continuous Performance Test (CPT) in children with attention deficit hyperactivity disorder (ADHD) and typically developing (TD) children. **Methods:** The sample consisted of 21 children with ADHD and 20 TD children. All participants performed two neuropsychological tasks (i.e., Go/NoGo task and CPT), the order of which were randomly assigned. Electrophysiological data were recorded while participants were performing the Go/NoGo task. Behavioral variables (i.e., omission errors, commission errors, reaction time [RT], and reaction time standard errors [RTSE]) measured by the CPT and event-related potentials (i.e., P3 latencies and amplitudes at electrode sites—Fz, Cz, and Pz) evoked by the Go stimuli were collected. Correlations between behavioral variables and P3 responses were calculated. **Results:** Regarding the correlations between P3 responses and CPT performance, different patterns were observed between groups. For children with ADHD, significant associations were found between P3 latencies at Fz and RTs (r = .493, $p < .05$), P3 latencies at Cz and RTs (r = .566, $p < .01$), and P3 latencies at Cz and RTSEs (r = .524, $p < .05$). For TD children, significant associations existed between P3 latencies at Fz and omission errors (r = -.584, $p < .01$), P3 latencies at Fz and RTSEs (r = -.601, $p < .01$), and P3 latencies at Cz and RTSEs (r = -.444, $p < .05$). **Conclusion:** The results indicate that some different mechanisms may be involved when children with ADHD and TD children perform the neuropsychological tasks. However, future studies with larger sample sizes are warranted to validate the current findings.

Keywords: attention deficit hyperactivity disorder, Continuous Performance Test, executive

Function, Go/NoGo task; P3

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探討過動兒和典型發展兒童的 P3 反應與持續性表現作業之關聯

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摘　要

目的：探討注意力不足過動症兒童(過動兒)和典型發展兒童在執行 Go/NoGo 作業時所誘發的 P3 反應與在持續性表現作業(Continuous Performance Test; CPT)上的行為表現之相關性。**方法：**21 位過動兒及 20 位典型發展兒童接受兩個神經心理學作業(即 Go/NoGo 作業和持續性表現作業)的施測，作業的施測次序是隨機安排。當受試者在執行 Go/NoGo 作業時，其電生理的訊號會被記錄。本研究中，我們收集由持續性表現作業所測量的行為變項(即遺漏錯誤、替代性錯誤、反應時間以及反應時間標準誤)和由 Go 刺激所誘發的事件相關電位(即在 Fz、Cz 及 Pz 的 P3 振幅及潛伏期)。進一步地，我們計算 P3 反應和行為變項的相關性。**結果：**P3 反應和由持續性表現作業所量測的行為表現之間的相關在組別間呈現不同的結果。對於過動兒，顯著的相關呈現在 Fz 的 P3 潛伏期和反應時間($r = .493$, $p < .05$)，Cz 的 P3 潛伏期和反應時間($r = .566$, $p < .01$)，Cz 的 P3 潛伏期和反應時間標準誤($r = .524$, $p < .05$)。對於典型發展兒童，顯著的相關存在於 Fz 的 P3 潛伏期和遺漏錯誤($r = -.584$, $p < .01$)，Fz 的 P3 潛伏期和反應時間標準誤($r = -.601$, $p < .01$)，Cz 的 P3 潛伏期和反應時間標準誤($r = -.444$, $p < .05$)。**結論：**結果顯示過動兒和典型發展的兒童在執行神經心理學作業時可能運用不同的機制。然而，未來需要有較大樣本的研究來證實此研究的結果。

關鍵詞：注意力不足過動症、持續作業測驗、執行功能、Go/NoGo 作業、P3

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Introduction

Attention deficit hyperactivity disorder (ADHD) is a common neurodevelopmental disorder characterized by developmentally inappropriate inattention, hyperactivity, and impulsivity (American Psychiatric Association, 2013). The estimated prevalence rates range from 3%-10% among school-age children worldwide (Chen, Shen, & Gau, 2017; Faraone et al., 2015; Gau, Chong, Chen, & Cheng, 2005; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). Children diagnosed with ADHD frequently display difficulty sustaining their attention or regulating their behavior in daily life (Chiang, Chen, Lo, Tseng, & Gau, 2015; Nigg, 2001; Reid, Trout, & Schartz, 2005). For instance, they cannot wait for their turn patiently when playing with others; they tend to interrupt others when they are not supposed to, or they seem not to listen when spoken to (American Psychiatric Association, 2013). Impacts of ADHD core symptoms and neuropsychological functions on social functions may persist into adolescence and adulthood (Chiang & Gau, 2014; Chiang, Huang, Gau, & Shang, 2013; Lin & Gau, 2017, 2018; Lin, Lo, Yang, & Gau, 2015).

Relative to typically developing (TD) children, children with ADHD show more inferior performance on tasks tapping attention and inhibition such as the Go/NoGo task (Paul-Jordanov, Bechtold, & Gawrilow, 2010; Paul et al., 2007) and Continuous Performance Task (CPT) (Chiang et al., 2015; Groom et al., 2010; Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009). For example, compared to TD children, children with ADHD have been observed to display slower and more variable reaction times (RTs) (Epstein et al., 2011; Lin et al., 2014; Lin, Hwang-Gu, & Gau, 2015; Uebel et al., 2010) and exhibit more omission (an index of inattention) and commission (an index of impulsivity or dis-inhibition) errors (Broyd et al., 2005; H. Y. Lin et al., 2015; Paul-Jordanov et al., 2010). Apart from assessing executive functions at the behavioral level, researchers have implemented studies to obtain electrophysiological data while participants with or without ADHD are performing neuropsychological tasks in order to explore the neural mechanisms underlying ADHD (e.g., Johnstone et al., 2007; Senderecka, Grabowska, Szewczyk, Gerc, & Chmylak, 2012; Shen, Tsai, & Duann, 2011).

In event-related potential (ERP) studies, the P3(00), an ERP component, is typically elicited in the Go/NoGo task or CPT (Broyd et al., 2005; Fallgatter et al., 2005; Paul-Jordanov et al., 2010; Paul et al., 2007). It deflects positively peaking at around 300 ms after stimulus onset. The P3 is closely related to selective attention and allocation of efforts (Kok, 2001; Picton, 1992). Abnormal P3 activity has been observed in ADHD (Prox, Dietrich, Zhang, Emrich, & Ohlmeier, 2007). For example, Strandburg et al. (1996) found reduced and delayed visual P3 in children with ADHD. Jonkman et al. (1997) reported that children with ADHD were more likely than healthy children to exhibit smaller P3 amplitudes in selective attention tasks, indicating that the activation of P3 process was impaired in ADHD. Similarly, Overtoom et al. (1998) reported that significantly reduced P3 amplitudes to targets were observed in the ADHD group during a visual continuous performance task as compared to healthy individuals. Moreover, P3 is reported to be associated with behavioral indicators related to attention and inhibition (e.g., RT, reaction time variability, commission, and commission errors) (Cheung et al., 2017; Nieuwenhuis, Aston-Jones, & Cohen, 2005; Shen, Lee, & Chen, 2014).

To our best knowledge, previous research on ADHD has documented P3 responses and their associations with other behavioral performance or cognitive processes using one neuropsychological task (e.g., Kok, 2001; Overtoom et al., 1998; Prox et al., 2007; Senderecka et al., 2012). However, studies with investigation into the associations of P3 responses elicited by one task with behavioral performance measured by another task with similar cognitive construct would help us not only to extend the application of P3 but also to understand the utility of P3 responses as a measure relating to other performance in research and clinical settings in the future. Moreover, there has been no study to demonstrate the differential correlation patterns between the P3 response to Go/NoGo tests and the behavioral performance assessed by the CPT between children with ADHD and those without ADHD. Therefore, based upon the literature, our present study aimed (1) to compare the behavioral performance measured by the CPT (i.e., RTs, reaction time variability, commission errors, and omission errors) and P3 responses (i.e., P3 amplitudes and latencies) evoked by the Go/NoGo task in children with ADHD and TD children, and (2) to investigate the associations between the CPT performance and Go/NoGo task-evoked P3 responses in the two groups. We hypothesized that compared to TD children, children with ADHD showed more deficient behavioral performance on the CPT (i.e., longer RTs, larger reaction time variability, and more commission and omission errors) and exhibited diminished and delayed P3 responses on the Go/NoGo task. No specific expectations were made with respect to the associations between P3 and CPT behavioral performance in children with ADHD and TD children as this is, to date, the first study to explore the P3-CPT associations using this Go/NoGo task (Paul-Jordanov et al., 2010; Paul et al., 2007). Accordingly, the analyses for this research question were more exploratory.

Methods

Participants

The sample consisted of 21 children with ADHD (17 boys) and 20 typically developing (TD) children (18 boys), aged 8 to 12 years (ADHD group: M ± SD = 9.84 ±1.27 years vs. TD group: M ± SD = 10.49 ± 1.12 years). The sample in this study overlapped with that in the previous research (Hung, Gawrilow, Hsieh, & Gau, 2017). Children with ADHD were recruited from the Children's Mental Health Center of Department of Psychiatry, National Taiwan University Hospital, if they met the inclusion criteria. The ADHD group was recruited and clinically diagnosed based on the *DSM-IV-TR* criteria (American Psychiatric Association, 2000) while non-ADHD children were recruited from local schools without having clinically relevant diagnoses based on clinical evaluation and psychiatric interview. Excluded from participating in the study were those who had a serious medical illness, such as a cardiovascular disease; who had a Full-Scale IQ score less than 80; who had a history of bipolar disorder, psychosis, any substance abuse, pervasive developmental disorder, depression or anxiety disorders; who had a history of any neurological disorder, or who had ever used any psychotropic medications before the study. This study protocol was approved by the institutional review board of the National Taiwan University Hospital. All children and their parents signed the consent forms before they participated in this study.

Procedure and Electrophysiological Recording

After clinical evaluation, children and parents (mainly mothers) were invited to the lab. All children then completed the intelligence test and were instructed to perform two neuropsychological tasks (i.e., Go/NoGo task and continuous performance test). The order of neuropsychological tasks was randomly assigned to children.

While children were performing the Go/NoGo task, their electrophysiological data were simultaneously recorded using a cap chosen to fit optimally each child's head. Electrodes were used at up to 40 recording sites (according to International 10-20 system) utilizing an electrode cap. Electrodes at the tip of the nose and at Fpz served as the reference and ground, respectively. Four additional electrodes placed above and below the left eye and at the outer canthi of both eyes were used for monitoring blinks and eye movements. All impedances were below 5 kΩ. Signals were digitized at a rate of 1 kHz with system acquisition filter settings of 0.5 to 100 Hz, with no 60-Hz notch filter. Electroencephalography and stimulus markers were recorded continuously, while participants were instructed to minimize eye movements and muscle artifact during the recording.

Children on medication for ADHD were required to be free of medication 48 hours before the task session with their attending physicians' approval. Mothers of children with and without ADHD were instructed to complete copies of the questionnaire relevant to their children's behaviors while their children were performing the tasks.

Measures

Swanson, Nolan, and Pelham IV Scale (SNAP-IV) – Parent Form. The SNAP-IV, a 26-item rating scale, is used to assess ADHD and oppositional defiant disorder (ODD) symptoms of children aged 4-18 years old (Swanson et al., 2001). Items in the scale are to address both criteria of ADHD (including inattention and hyperactivity/impulsivity), and ODD. The SNAP-IV is based on a 4-point rating scale to describe the degree to which the behavior is abnormally frequent and severe as compared to the same-age typically developing children. The psychometric property of the Chinese version of the SNAP-IV has been established (Liu et al., 2006), and it has been widely used in ADHD research in Taiwan (e.g., Gau et al., 2007).

Go/NoGo Task. The Go/NoGo task (Paul-Jordanov et al., 2010; Paul et al., 2007) was used in the study. This task consisting of 360 stimuli (50% colored drawings of transportation vehicles and 50% colored drawings of animals) were presented on a computer screen. The stimuli lasted 1,000 ms and were presented with an inter-stimulus interval (ISI) of 1,500 ms. A fixation cross was shown 500 ms before each stimulus, in the middle of the screen. We asked children to respond to animals and vehicles by pressing one of two colored buttons, respectively. The correspondence of stimulus type and response-button was reversed after the first half of the experiment, to prevent the task from becoming too easy. We introduced a practice session of 16 trials in each half of the experiment to ensure that children understood the task. In 33% of the trials, a stop sign—a spread-out white hand on a purple circular background—was presented 150 ms before the stimulus. The stop sign indicated that no response was to be given on the following trial. The trials using stop signs were treated as NoGo trials; all other trials were Go trials.

Conners' Continuous Performance Test (CPT). The CPT is a computerized task for individuals above 6 years of age. In the CPT, participants are instructed to press the spacebar when a letter except "X" appears on the computer screen but to stop pressing the spacebar when "X" is shown. The CPT consists of 6 blocks, including 3 sub-blocks that each contains 20 letter presentations, for a total of 360 trials. The sub-blocks vary in inter-stimulus intervals (ISI) of 1, 2, and 4 s, and the sequence of ISI conditions is presented randomly. For the purpose of the current study, several indexes in the CPT are selected for data analysis, including omission errors (the number of times not responding to a target), commission errors (the number of times responding to a non-target), RT (the period of time between the presentation of the stimulus and the response), and hit RT standard errors (consistency of RT). These four indexes may be included in 2 dimensions: focused attention (hit RT standard errors, and omission errors), hyperactivity/impulsivity (commission errors, and RT) according to the factor analysis by Egeland and Kovalik-Gran (2010).

Data Analysis

For behavioral data, omission errors, commission errors, reaction time (RT), and reaction time standard errors (RTSE) were collected from the CPT.

For electrophysiological data, electroencephalogram (EEG) data were recorded while children were performing the Go/NoGo task. Data analysis was performed using Neuroscan. EEG data epochs (-100 to 800 ms in relation to stimulus onset) for correct Go trials (trials followed by a correct button press) were averaged per participant, excluding epochs containing other artifacts (signal amplitudes > ±250 μV). Following blink correction, data were band-pass filtered at 0.5-30 Hz. Grand average waveforms were computed by averaging Go epochs across participants within group. Peak latencies and amplitudes of the P3(00) based on a defined latency range (270-500 ms) for each trial type at Fz, Cz and Pz were collected.

Behavioral data and event-related potentials (i.e., P3 latencies and amplitudes at electrode sites—Fz, Cz, and Pz) evoked by the Go stimuli were compared between the ADHD and control groups using Student's independent *t*-tests. Correlations between behavioral data and P3 responses were calculated with Pearson's correlation coefficient. The strength of correlations was defined as excellent (> 0.75), good (0.50-0.75), fair (0.25-0.50), and low (≤ 0.25). In addition, we calculated Cohen's *d* for effect size (the standardized difference between the two means) for the group comparisons with small, medium, and large effect sizes as Cohen's *d* 0.2 to 0.5, 0.5 to 0.8, and ≥ 0.8, respectively. Significance of all statistical analyses was set at $p < 0.05$. We used Statistical Package for Social Science software version 19 for Windows (IBM Corp., Armonk, New York, USA) for data analysis.

Results

Demographic and clinical characteristics of participants are presented in Table 1. Children with ADHD scored pronouncedly higher than TD children on all the subscales of the SNAP-IV (Inattention: ADHD: 54.62 ± 8.75 vs. TD: 44.33 ± 5.59, $p < .001$; Hyperactivity/Impulsivity: ADHD: 51.65 ± 5.22 vs. TD: 44.73 ± 3.45, $p < .001$; and ODD symptoms: ADHD: 50.03 ± 9.51 vs. TD: 41.61 ± 5.38, $p < .001$).

As shown in Table 2, no significant differences were found between children with ADHD and non-ADHD children on the behavioral performance measured by the CPT (i.e., omission errors, commission errors, RT, and RTSE). A medium effect size of 0.53 was observed between groups in terms of the commission error. Similarly, in terms of electrophysiological performance, significant differences were not observed between ADHD and TD children (see Table 3).

Regarding the correlations between P3 responses and CPT performance in Table 4, different patterns were observed in the two groups. For children with ADHD, significances were found between P3 latencies at Fz and RTs (r = .493, p < .05), P3 latencies at Cz and RTs (r = .566, p < .01), and P3 latencies at Cz and RTSEs (r = .524, p < .05). In the TD group, pronounced associations existed between P3 latencies at Fz and omission errors (r = -.584, p < .01), P3 latencies at Fz and RTSEs (r = -.601, p < .01), and P3 latencies at Cz and RTSEs (r = -.444, p < .05).

Discussion

To the best of our knowledge, this is the first study to investigate the correlations between Go/NoGo task-elicited P3 responses and CPT-measured behavioral performance in children with ADHD and TD children. This study showed that differential correlational patterns existed across the two groups, indicating that some similar and some different mechanisms may be involved when children with ADHD and TD children are performing the neuropsychological tasks.

In the current study, no significant differences were observed between children with ADHD and TD children regarding the CPT-measured variables (i.e., omission errors, commission errors, reaction time, and reaction time standard error). As previous studies focusing on the CPT-measured performance in ADHD have shown inconsistent findings, these non-significances in our study are not without precedent. For instance, regarding CPT errors, some studies demonstrated that children with ADHD committed more omission and commission errors relative to their typically developing peers whereas some studies showed no significant group differences (see Losier, McGrath, and Klein (1996) for a meta-analytic review). The mixed findings may be attributable to several factors, including the existence of comorbid disorders (ADHD with or without comorbid disorders), different comparison groups (ADHD compared with TD children or with other clinical groups), and small sample size (Losier et al., 1996). Moreover, medication has been shown to exert beneficial effects on the behavioral performance measured by the CPT in ADHD (Lawrence et al., 2005). As six children in the ADHD group (28.57%) have taken medication for a period of time before participating in this study, their performance on the CPT could be ameliorated to some extent, which would mask/decrease between-group differences. Although the CPT-measured behavioral performance showed no significant group differences, the effect size for commission errors reached medium level (d = 0.53). Therefore, the current findings are possibly limited by the small sample size. Future studies with a larger sample size and with investigation into the effects of other factors on CPT performance are warranted to confirm the present findings.

Regarding the Go/NoGo task-evoked P3 responses, we did not find any pronounced group differences on all variables (i.e., P3 latencies and amplitude at Fz, Cz, and Pz), which is inconsistent with previous findings (Overtoom et al., 1998; Paul et al., 2007; Strandburg et al., 1996). This inconsistency may be accounted for by two possibilities. First, abnormal electrophysiological components characterizing children with ADHD are more evident while they are performing difficult and demanding tasks (Klorman, 1991). And P3 is reported to be influenced by task difficulty in a study using visual oddball task (Kim, Kim, Yoon, & Jung, 2008). Based on these earlier reports, it is possible that the Go/NoGo task used in the present study is not demanding for the sample. Future Go/NoGo studies exploring the effect of a variety of task difficulty levels on P3 in ADHD would be helpful to clarify this speculation. Second, medication has been reported to affect P3 performance in ADHD (Lawrence et al., 2005; Paul-Jordanov et al., 2010). As mentioned before, six children with AHDH (28.57%) in this study are not drug-naïve. As a result, similar to the behavioral performance observed on the CPT, the electrophysiological performance of children with ADHD may be enhanced to some extent, which leads to non-significant group differences.

As for the associations between Go/NoGo task-evoked P3 responses and CPT performance, different patterns were observed in the two groups. For children with ADHD, longer P3 latencies at Fz and Cz induced by the Go/NoGo task were correlated with longer RT on the CPT. Supported by previous research reporting the positive association between P3 and RT in one test (Nieuwenhuis et al., 2005), our finding may suggest children with ADHD displayed similar response patterns while performing the two neuropsychological tasks. Additionally, increased reaction time variability (indexed by large RTSE) was found to be associated with long P3 latencies at Cz in ADHD. As previous research has showed that increased reaction time variability may result from long RTs, which are due to inattention (Tamm et al., 2012), the correlations of long P3 latency elicited by the Go/NoGo task with long RT as well as with high RTSE on the CPT could be two sides of the same coin in our study. For TD children, longer Fz-P3 latencies on the Go/NoGo task were linked to less omission errors on the CPT, indicating that TD children with longer P3 latencies on the Go/NoGo task were more attentive (indexed by less omission errors) on the CPT relative to those children with shorter P3 latencies. Moreover, longer P3 latencies at Fz and Cz were associated with decreased reaction time variability (indexed by small RTSE), which is in contrast to the result found in the ADHD group (i.e., longer P3 latencies was linked to increased reaction time variability). As discussed before, in ADHD, long P3 latencies on the Go/NoGo task were correlated with long RTs and with high reaction time variability on the CPT, both of which may reflect lapses in attention (Nieuwenhuis et al., 2005; Tamm et al., 2012). However, TD children with longer P3 latencies on the Go/NoGo task tended to exhibit less omission errors and less reaction time variability (indexed by RTSE) on the CPT, both of which are indicators of attentiveness. Furthermore, as the P3 latency is related to the time required for the evaluation of task stimulus (i.e., prolonging the time for stimulus evaluation is linked to longer P3 latency) (Picton, 1992), it could be referred from the inconsistent correlation patterns that the prolongation of time necessary for the evaluation of stimulus is associated with lapse in attention for children with ADHD but is associated with allocation with attention for TD children. However, this inference warrants further investigation from the studies with different task paradigms. Overall, our findings may suggest that the correlates of P3 responses with other variables (e.g., behavioral performance or cognitive processes) could vary across groups, yielding different implications when interpreting the correlations. Differential correlation patterns displayed in the two groups suggest different underlying mechanisms may be involved while children with ADHD and TD children are performing neuropsychological tasks. Finally, although findings from our study and functional magnetic resonance imaging (fMRI) studies have revealed distinct patterns of brain activity relevant to reaction time variability in individuals with ADHD and healthy individuals (Rubia, Smith, Brammer, & Taylor, 2007; Suskauer et al., 2008), considerably more research is needed to further investigate the associations between P3 responses and reaction time variability. Finally, it is noted that RTSE is used in the vast majority of studies, including our study, to index reaction time variability, but RTSE is easily cofounded by being a measure of central tendency (Tamm et al., 2012). Therefore, future studies using other indicators (e.g., ex-Gaussian indicators) are useful to confirm the patterns of P3-reaction time variability correlations in children with ADHD and TD children.

Although the current study advances the literature on the associations between P3 responses and CPT performance in children with ADHD and TD children, findings need to be cautiously interpreted due to several limitations. First, comorbid disorders were not controlled for in this study. As comorbid disorders have been shown to affect children’s behavioral performance on neuropsychological tasks, behavioral patterns may differ with the existence of comorbid disorders in ADHD. Second, the generalizability of the current findings to other age or gender groups is limited by the small age range of the sample—between approximately 8 and 12 years—and the sample composition (i.e., mostly male participants). Third, and most importantly, the small sample size may preclude a definitive statement for our findings in this study.

Conclusion

To the best of our knowledge, this is the first study to explore the link between Go/NoGo task-elicited P3 responses and CPT performance in children with ADHD and typically developing children. The current findings indicate that different mechanisms are involved while children with ADHD and TD children are performing neuropsychological tasks. However, future studies with a larger sample size and investigating the effects of other factors on the P3-CPT associations are warranted to validate our present observations and also enhance our understanding on the underlying mechanisms in ADHD.

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References

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders DSM-IV-TR*. Washington, D.C.: American Psychiatric Association.

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (5th ed.)*. Arlington, VA: American Psychiatric Association.

Broyd, S. J., Johnstone, S. J., Barry, R. J., Clarke, A. R., McCarthy, R., Selikowitz, M., & Lawrence, C. A. (2005). The effect of methylphenidate on response inhibition and the event-related potential of children with attention deficit/hyperactivity disorder. *International Journal of Psychophysiology, 58*(1), 47-58. doi:10.1016/j.ijpsycho.2005.03.008

Chen, Y. L., Shen, L. J., & Gau, S. S. (2017). The Mandarin version of the Kiddie-Schedule for Affective Disorders and Schizophrenia-Epidemiological version for DSM-5 - A psychometric study. *Journal of the Formosan Medical Association, 116*(9), 671-678. doi:10.1016/j.jfma.2017.06.013

Cheung, C. H. M., McLoughlin, G., Brandeis, D., Banaschewski, T., Asherson, P., & Kuntsi, J. (2017). Neurophysiological correlates of attentional fluctuation in attention-deficit/hyperactivity disorder. *Brain Topography, 30*(3), 320-332. doi:10.1007/s10548-017-0554-2

Chiang, H. L., Chen, Y. J., Lo, Y. C., Tseng, W. Y., & Gau, S. S. (2015). Altered white matter tract property related to impaired focused attention, sustained attention, cognitive impulsivity and vigilance in attention-deficit/ hyperactivity disorder. *Journal of Psychiatry & Neuroscience, 40*(5), 325-335.

Chiang, H. L., & Gau, S. S. (2014). Impact of executive functions on school and peer functions in youths with ADHD. *Research in Developmental Disabilities, 35*(5), 963-972. doi:10.1016/j.ridd.2014.02.010

Chiang, H. L., Huang, L. W., Gau, S. S., & Shang, C. Y. (2013). Associations of symptoms and subtypes of attention-deficit hyperactivity disorder with visuospatial planning ability in youth. *Research in Developmental Disabilities, 34*(9), 2986-2995. doi:10.1016/j.ridd.2013.06.020

Egeland, J., & Kovalik-Gran, I. (2010). Measuring several aspects of attention in one test: the factor structure of conners's continuous performance test. *Journal of Attention Disorders, 13*(4), 339-346. doi:10.1177/1087054708323019

Epstein, J. N., Langberg, J. M., Rosen, P. J., Graham, A., Narad, M. E., Antonini, T. N., . . . Altaye, M. (2011). Evidence for higher reaction time variability for children with ADHD on a range of cognitive tasks including reward and event rate manipulations. *Neuropsychology, 25*(4), 427-441. doi:10.1037/a0022155

Fallgatter, A. J., Ehlis, A. C., Rosler, M., Strik, W. K., Blocher, D., & Herrmann, M. J. (2005). Diminished prefrontal brain function in adults with psychopathology in childhood related to attention deficit hyperactivity disorder. *Psychiatry Research, 138*(2), 157-169. doi:10.1016/j.pscychresns.2004.12.002

Faraone, S. V., Asherson, P., Banaschewski, T., Biederman, J., Buitelaar, J. K., Ramos-Quiroga, J. A., . . . Franke, B. (2015). Attention-deficit/hyperactivity disorder. *Nature Reviews Disease Primers, 1*, 15020. doi:10.1038/nrdp.2015.20

Gau, S. S., Chong, M. Y., Chen, T. H., & Cheng, A. T. (2005). A 3-year panel study of mental disorders among adolescents in Taiwan. *American Journal of Psychiatry, 162*(7), 1344-1350. doi:10.1176/appi.ajp.162.7.1344

Gau, S. S., Huang, Y. S., Soong, W. T., Chou, M. C., Chou, W. J., Shang, C. Y., . . . Lee, P. (2007). A randomized, double-blind, placebo-controlled clinical trial on once-daily atomoxetine in Taiwanese children and adolescents with attention-deficit/hyperactivity disorder. *Journal of Child and Adolescent Psychopharmacology, 17*(4), 447-460. doi:10.1089/cap.2007.0091

Groom, M. J., Scerif, G., Liddle, P. F., Batty, M. J., Liddle, E. B., Roberts, K. L., . . . Hollis, C. (2010). Effects of motivation and medication on electrophysiological markers of response inhibition in children with attention-deficit/hyperactivity disorder. *Biological Psychiatry, 67*(7), 624-631. doi:10.1016/j.biopsych.2009.09.029

Hung, S. J. R., Gawrilow, C., Hsieh, M. H., & Gau, S. S. F. (2017). The effects of methylphenidate on the Go/NoGo performance in children with attention-defi cit/hyperactivity disorder. *Taiwanese Journal of Psychiatry (Taipei), 31*(1), 49-59.

Johnstone, S. J., Barry, R. J., Markovska, V., Dimoska, A., & Clarke, A. R. (2009). Response inhibition and interference control in children with AD/HD: a visual ERP investigation. *International Journal of Psychophysiology, 72*(2), 145-153. doi:10.1016/j.ijpsycho.2008.11.007

Johnstone, S. J., Dimoska, A., Smith, J. L., Barry, R. J., Pleffer, C. B., Chiswick, D., & Clarke, A. R. (2007). The development of stop-signal and Go/Nogo response inhibition in children aged 7-12 years: performance and event-related potential indices. *International Journal of Psychophysiology, 63*(1), 25-38. doi:10.1016/j.ijpsycho.2006.07.001

Jonkman, L. M., Kemner, C., Verbaten, M. N., Koelega, H. S., Camfferman, G., v.d. Gaag, R.-J., . . . van Engeland, H. (1997). Event-related potentials and performance of attention-deficit hyperactivity disorder: Children and normal controls in auditory and visual selective attention tasks. *Biological Psychiatry, 41*(5), 595-611. doi:10.1016/S0006-3223(96)00073-X

Kim, K. H., Kim, J. H., Yoon, J., & Jung, K. Y. (2008). Influence of task difficulty on the features of event-related potential during visual oddball task. *Neuroscience Letters, 445*(2), 179-183. doi:10.1016/j.neulet.2008.09.004

Klorman, R. (1991). Cognitive event-related potentials in attention deficit disorder. *Journal of Learning Disabilities, 24*(3), 130-140. doi:10.1177/002221949102400301

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38*(3), 557-577. doi:10.1017/S0048577201990559

Lawrence, C. A., Barry, R. J., Clarke, A. R., Johnstone, S. J., McCarthy, R., Selikowitz, M., & Broyd, S. J. (2005). Methylphenidate effects in attention deficit/hyperactivity disorder: electrodermal and ERP measures during a continuous performance task. *Psychopharmacology (Berl), 183*(1), 81-91. doi:10.1007/s00213-005-0144-y

Lin, H. Y., Gau, S. S., Huang-Gu, S. L., Shang, C. Y., Wu, Y. H., & Tseng, W. Y. (2014). Neural substrates of behavioral variability in attention deficit hyperactivity disorder: based on ex-Gaussian reaction time distribution and diffusion spectrum imaging tractography. *Psychological Medicine, 44*(8), 1751-1764. doi:10.1017/s0033291713001955

Lin, H. Y., Hwang-Gu, S. L., & Gau, S. S. (2015). Intra-individual reaction time variability based on ex-Gaussian distribution as a potential endophenotype for attention-deficit/hyperactivity disorder. *Acta Psychiatrica Scandinavica, 132*(1), 39-50. doi:10.1111/acps.12393

Lin, Y. J., & Gau, S. S. (2017). Differential neuropsychological functioning between adolescents with attention-deficit/hyperactivity disorder with and without conduct disorder. *Journal of the Formosan Medical Association, 116*(12), 946-955. doi:10.1016/j.jfma.2017.02.009

Lin, Y. J., & Gau, S. S. (2018). Developmental changes of neuropsychological functioning in individuals with and without childhood ADHD from early adolescence to young adulthood: a 7-year follow-up study. *Psychological Medicine*, 1-12. doi:10.1017/s0033291718001599

Lin, Y. J., Lo, K. W., Yang, L. K., & Gau, S. S. (2015). Validation of DSM-5 age-of-onset criterion of attention deficit/hyperactivity disorder (ADHD) in adults: Comparison of life quality, functional impairment, and family function. *Research in Developmental Disabilities, 47*, 48-60. doi:10.1016/j.ridd.2015.07.026

Liu, Y. C., Liu, S. K., Shang, C. Y., Lin, C. H., Tu, C. L., & Gau, S. S. F. (2006). Norm of the Chinese Version of the Swanson, Nolan and Pelham, Version IV Scale for ADHD. *Taiwanese Journal of Psychiatry (Taipei), 20*, 290-304.

Losier, B. J., McGrath, P. J., & Klein, R. M. (1996). Error patterns on the continuous performance test in non-medicated and medicated samples of children with and without ADHD: A meta-analytic review. *Journal of Child Psychology and Psychiatry, 37*(8), 971-987. doi:10.1111/j.1469-7610.1996.tb01494.x

Nieuwenhuis, S., Aston-Jones, G., & Cohen, J. D. (2005). Decision making, the P3, and the locus coeruleus-norepinephrine system. *Psychological Bulletin, 131*(4), 510-532. doi:10.1037/0033-2909.131.4.510

Nigg, J. T. (2001). Is ADHD a disinhibitory disorder? *Psychological Bulletin, 127*(5), 571-598. doi:10.1037/0033-2909.127.5.571

Overtoom, C. C., Verbaten, M. N., Kemner, C., Kenemans, J. L., Engeland, H. V., Buitelaar, J. K., . . . Koelega, H. S. (1998). Associations between event-related potentials and measures of attention and inhibition in the continuous performance task in children with ADHD and normal controls. *Journal of the American Academy of Child and Adolescent Psychiatry, 37*(9), 977-985. doi:10.1097/00004583-199809000-00018

Paul-Jordanov, I., Bechtold, M., & Gawrilow, C. (2010). Methylphenidate and if-then plans are comparable in modulating the P300 and increasing response inhibition in children with ADHD. *Attention Deficit and Hyperactivity Disorders, 2*(3), 115-126. doi:10.1007/s12402-010-0028-9

Paul, I., Gawrilow, C., Zech, F., Gollwitzer, P., Rockstroh, B., Odenthal, G., . . . Wienbruch, C. (2007). If-then planning modulates the P300 in children with attention deficit hyperactivity disorder. *Neuroreport, 18*(7), 653-657. doi:10.1097/WNR.0b013e3280bef966

Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology, 9,* 456-479. doi:10.1097/00004691-199210000-00002

Polanczyk, G., de Lima, M. S., Horta, B. L., Biederman, J., & Rohde, L. A. (2007). The worldwide prevalence of ADHD: a systematic review and metaregression analysis. *American Journal of Psychiatry, 164*(6), 942-948. doi:10.1176/ajp.2007.164.6.942

Prox, V., Dietrich, D. E., Zhang, Y., Emrich, H. M., & Ohlmeier, M. D. (2007). Attentional processing in adults with ADHD as reflected by event-related potentials. *Neuroscience Letters, 419*(3), 236-241. doi:10.1016/j.neulet.2007.04.011

Reid, R., Trout, A. L., & Schartz, M. (2005). Self-regulation interventions for children with attention deficit/hyperactivity disorder. *Exceptional Children*, *71*, 361-377.

Rubia, K., Smith, A. B., Brammer, M. J., & Taylor, E. (2007). Temporal lobe dysfunction in medication-naive boys with attention-deficit/hyperactivity disorder during attention allocation and its relation to response variability. *Biological Psychiatry, 62*(9), 999-1006. doi:10.1016/j.biopsych.2007.02.024

Senderecka, M., Grabowska, A., Szewczyk, J., Gerc, K., & Chmylak, R. (2012). Response inhibition of children with ADHD in the stop-signal task: an event-related potential study. *International Journal of Psychophysiology, 85*(1), 93-105. doi:10.1016/j.ijpsycho.2011.05.007

Shen, I. H., Lee, D. S., & Chen, C. L. (2014). The role of trait impulsivity in response inhibition: event-related potentials in a stop-signal task. *International Journal of Psychophysiology, 91*(2), 80-87. doi:10.1016/j.ijpsycho.2013.11.004

Shen, I. H., Tsai, S. Y., & Duann, J. R. (2011). Inhibition control and error processing in children with attention deficit/hyperactivity disorder: an event-related potentials study. *International Journal of Psychophysiology, 81*(1), 1-11. doi:10.1016/j.ijpsycho.2011.03.015

Strandburg, R. J., Marsh, J. T., Brown, W. S., Asarnow, R. F., Higa, J., Harper, R., & Guthrie, D. (1996). Continuous-processing-related event-related potentials in children with attention deficit hyperactivity disorder. *Biological Psychiatry*, *40*(10), 964-980. doi:10.1016/0006-3223(95)00545-5

Suskauer, S. J., Simmonds, D. J., Caffo, B. S., Denckla, M. B., Pekar, J. J., & Mostofsky, S. H. (2008). fMRI of intrasubject variability in ADHD: anomalous premotor activity with prefrontal compensation. *Journal of the American Academy of Child and Adolescent Psychiatry, 47*(10), 1141-1150. doi:10.1097/CHI.0b013e3181825b1f

Swanson, J. M., Kraemer, H. C., Hinshaw, S. P., Arnold, L. E., Conners, C. K., Abikoff, H. B., . . . Wu, M. (2001). Clinical relevance of the primary findings of the MTA: success rates based on severity of ADHD and ODD symptoms at the end of treatment. *Journal of the American Academy of Child and Adolescent Psychiatry, 40*(2), 168-179. doi:10.1097/00004583-200102000-00011

Tamm, L., Narad, M. E., Antonini, T. N., O'Brien, K. M., Hawk, L. W., Jr., & Epstein, J. N. (2012). Reaction time variability in ADHD: a review. *Neurotherapeutics*, *9*(3), 500-508. doi:10.1007/s13311-012-0138-5

Uebel, H., Albrecht, B., Asherson, P., Börger, N. A., Butler, L., Chen, W., . . . Banaschewski, T. (2010). Performance variability, impulsivity errors and the impact of incentives as gender-independent endophenotypes for ADHD. *Journal of Child Psychology and Psychiatry, 51*(2), 210-218. doi:10.1111/j.1469-7610.2009.02139.x

Table 1

Demographic and clinical characteristics of study participants

Variable (Mean ± SD)	ADHD	TD	Statistics: $\chi 2/t$ value	Statistics: p value
	(N = 21)	(N = 20)		
Age (years)	9.84 ± 1.27	10.49 ± 1.12	t = 1.74	.090
Male, n (%)	17 (81.0)	18 (90.0)	$\chi 2$ = 0.67	.413
ADHD subtype, n (%)				
Combined	11 (52.4)	---	---	---
Inattentive	10 (47.6)	---	---	---
SNAP IV – mother report (T score)	(N = 20)	(N = 18)		
Total score	53.40 ± 7.05	43.58 ± 4.38	t = -5.09	< .001
Inattention	54.62 ± 8.75	44.33 ± 5.59	t = -4.26	< .001
Hyperactivity/ Impulsivity	51.65 ± 5.22	44.73 ± 3.45	t = -4.77	< .001
Oppositional defiant disorder	50.03 ± 9.51	41.61 ± 5.38	t = -3.31	< .001

Note. SNAP-IV = Swanson, Nolan, and Pelham IV Scale.

Table 2

Comparison of Conners' CPT performance between ADHD and TD children

Variable	ADHD	TD	Statistics		
(Mean ± SD)	(N = 21)	(N = 20)	*t* value	*p* value	Cohen's *d*
Omission errors	13.14 ± 12.66	9.20 ± 9.94	-1.11	.276	0.35
Commission errors	26.19 ± 5.36	22.85 ± 7.17	-1.70	.098	0.53
RT (ms)	425.05 ± 73.13	413.70 ± 69.79	-0.51	.614	0.16
RT standard error (ms)	14.38 ± 8.46	11.44 ± 6.99	-1.21	.233	0.38

Note. RT = reaction time; SD = standard deviation.

Table 3

Comparison of P3 latencies and amplitudes between ADHD and TD children

Variable (Mean ± SD)	ADHD (N=20)	TD (N=20)	Statistics		
			t value	*p* value	Cohen's *d*
Fz					
Latency	401.05 ± 71.68	412.70 ± 55.41	0.58	.569	0.18
Amplitude	3.95 ± 3.62	5.30 ± 3.19	1.25	.219	0.40
Cz					
Latency	385.75 ± 83.80	392.65 ± 72.99	0.28	.783	0.09
Amplitude	6.15 ± 4.74	5.88 ± 3.83	-0.20	.846	0.06
Pz					
Latency	306.50 ± 60.41	291.20 ± 39.88	-0.95	.350	0.30
Amplitude	8.27 ± 5.16	6.28 ± 6.96	-1.03	.309	0.32

Note. SD = standard deviation.

Table 4

Correlations of P3 response with Conners' CPT performance in ADHD and TD children

	ADHD (N=20)				TD (N=20)			
	Omis	Commis	RT	RTSE	Omis	Commis	RT	RTSE
Fz								
Latency	.151	.232	.493*	.353	-.584**	-.227	-.160	-.601**
Amplitude	-.088	-.044	.065	.073	.059	.138	-.180	-.223
Cz								
Latency	.264	.055	.566**	.524*	-.241	-.088	-.208	-.444*
Amplitude	-.140	-.053	.060	-.022	.067	.041	-.060	-.215
Pz								
Latency	-.179	.138	-.019	-.040	-.098	.023	-.083	-.116
Amplitude	.172	.121	.051	.007	-.175	-.069	-.014	-.210

Note. Omis = Omission errors; Commis = Commission errors; RT = reaction time; RTSE = reaction time standard errors. $^{*}p < .05$. $^{**}p < .01$.