Isr J Psychiatry Relat Sci Vol 43 No. 2 (2006) 74–80

Computerized Neuropsychological Examination of Impulsiveness: A Selective Review

Semion Kertzman, MD, Haim Grinspan, MD, Moshe Birger, MD, and Moshe Kotler, MD

Forensic Division, Beer Yaakov Mental Health Center, Be'er Yaacov, Israel

Abstract: There is a rapidly accumulating body of knowledge related to the neurobiology of impulsiveness from multidisciplinary neuropsychological and neuroimaging studies. This paper reviews recent research on impulsiveness in the context of neuropsychological theory and research. It has been emphasized that the controversy regarding the results of neuropsychological studies is related to different aspects of impulsiveness. The term "impulsivity" is related to more than one anatomical network among several brain regions. Impaired inhibition control, which has cognitive and behavioral dimensions, has a heterogeneous nature. Analysis of performance suggests that impulsivity includes three cognitive mechanisms: "prepotent inhibition," "interruptive inhibition" and "interference control," each having separate neurological bases. Based on neuropsychological data it has been stated that both the orbitofrontal cortex, dorsolateral prefrontal cortex and anterior cingulate cortex are functionally disturbed among impulsive individuals. Bringing together knowledge from clinical experience, neuroimaging examination and neuropsychological assessment will lead to better and wider understanding of behavioral symptoms in clinical psychiatric practice.

Introduction

Self-harm and externally-directed impulsive behaviors are relatively common in psychiatric populations. Impulsiveness is an important clinical issue, related to various psychiatric diagnoses such as schizophrenia, mood disorders, impulse control disorders and alcohol/drug abuse (1). Impulsiveness was, until recently, typically assessed in the clinical setting with self-report scales and psychiatric examination. Self-assessment questionnaires are biased by low self-awareness and test-taking attitudes, which may lead to an inaccurate evaluation of impulsiveness (2). Moreover, these scales are designed to measure long-standing behavioral tendencies (trait) and they are less suited to repeated evaluation over short periods of time (state) (3). There has been much interest in obtaining objective measures of impulsiveness as state parameters using computerized neuropsychological tasks (4), which potentially promise to be sensitive to treatment manipulation, and provide a quantitative measure of the elemental behavioral tendencies that constitute this concept (5). However, most performance measures of impulsiveness have been developed based on differing theoretical assumptions, and vary in fundamental ways. There are few studies that have related any one task to another (6). Recent neuropsychological studies provide support for the notion that impulsiveness is a multifaceted cognitive concept (7). This article will attempt to integrate different neuropsychological concepts into the complex clinical assessment of impulsivity.

Impulsiveness can be defined as a neurocognitively based inability to conform behavior to its context or consequences. It appears to be strongly related to the "rapid-response" model of "answering before thinking" (8). In order to examine the "rapid-response" concept, a neuropsychological battery should test the patient's ability to inhibit motor responses to non-target stimuli in different cognitive situations (9). For these notions, two performance measures (reaction time and number of errors) are analyzed as a speed-accuracy tradeoff (10).

Response control

A key component of cognitive process is the ability to suppress or override competing behavioral responses. Response control is a cognitive process involved in decision-making in situations in which

Address for Correspondence: Semion Kertzman, MD, Forensic Division, Be'er Yaakov Mental Health Center, Be'er Yaakov 70350, Israel. E-mail: kertzman@Animascan.com

non-relevant information should be inhibited. Inhibition includes different neuropsychological mechanisms (11): 1) the ability *to delay* appropriate responses *before* checking all alternatives ("prepotent inhibition"), 2) the ability *to stop* an inappropriate response *after* the context has changed ("interruptive inhibition"), 3) the ability *to protect* the period of delay (a certain amount of time, in which no decision is taken) from disruption of competing events ("interference inhibition").

1. Prepotent inhibition

There are two main tasks used to examine prepotent inhibition: the Matching Familiar Figures Test (MFFT) and the Continuous Performance Test (CPT). Although they are used in different experimental situations, they both deal with the same mechanism of inhibition control. However, the MFFT performance requires several abilities in addition to response inhibition (e.g., visual search, hypothesis testing). Kagan and coauthors introduced the MFFT for examination of the "reflection-impulsivity" dimension (12). The MFFT presents situations with several alternatives available, but with only one correct answer. The "response time" and "amount of errors" are direct measures of the ability to delay response before examining and evaluating hypotheses carefully. Subjects who respond quickly and err are said to be impulsive. It was found that non-impulsive "reflective" subjects examined more variants, made more eye fixations per stimulus and scanned all alternatives before answering than did impulsive subjects. The relation between "response time" and accuracy raised the argument that there are four types of response: 1) fast and accurate; 2) slow and accurate ("reflective"); 3) fast and inaccurate ("impulsive"); 4) slow and inaccurate.

The CPT is a well-recognized measure of sustained attention and impulsiveness (inhibitory impairment as measured by Go/No-Go paradigm) (13). Most versions of the CPT randomly present on a computer screen stimuli for 100–200 ms each, at a rate of 1 per 2 seconds. The whole tests last for 10–30 minutes, continuing without pause (for review: see 14). Subjects respond to the target stimulus by pressing a button. In its "classical" concept CPT requires a maintenance of attention in order to detect and respond to periodically appearing rare targets. Errors of commission occur when the subject incorrectly responds to non-target (false alarms) stimuli; such a response is considered to be a measure of impulsiveness. Errors of omission occur when the subject omits pressing the button when a target stimulus appears; such a response is considered to be a measure of inattention (14). A relatively new measure of impulsiveness is the post-commission reaction time — the ability to notice an error made in a previous response. Commission errors (false alarms) are increased in incarcerated psychopaths, juvenile delinquents, adults with disorders of impulse control, and children with attention-deficit hyperactivity disordered (ADHD) (14). Psychopaths were found to be less likely to slow down and respond more quickly after punishment (14). This tendency to speed up (short post-commission time) has been taken as further evidence for the failure of impulsive individuals to learn from punishment.

The impulsive examinee showed significantly slower response time than healthy subjects. First results in the field of impulsiveness were non-concordant with theoretical assumptions of their more rapid responses to stimuli. In order to understand this paradox, it should be taken into account that CPT is a complicated task, assuming "Go" and "No-Go" responses. When response complexity in performance is increased, requiring subjects to respond as quickly as possible, impulsive individuals appear to be slower, not faster (3, 15). More impulsive subjects showed a significantly slower response time in the decision stage of reaction (15). Based on the work of Logan et al. (16), the response model suggested a race between two independent processes: "Go" and "Stop." The "Go" situation triggers the go process and the "Stop" situation initiates the stop process. The process that finishes first wins the race. If the go process finishes first, the response is executed. And vice versa: If the stop process finishes first, the response is inhibited. Slowness of impulsive subjects may be the result of impaired speed of inhibition in situations in which there is an inability to withhold responses to "stop" signal (16).

The psychomotor slowness and inattention on CPT are related to dopamine hypofunctioning (17), but the higher number of commissions is associated with lower 5-HT levels (18, see later).

2. Interruptive inhibition

The Stop Signal Tasks (SST) is a measure of the ability to stop quickly and to change behavior in relation to suddenly changing information. The SST challenges the capacity to inhibit an act in progress, which involves processes of response inhibition (16). The SST requires the participant to respond to a "Go" signal. In addition, periodically and randomly on some of the presentations, an imperative "Stop" signal will appear (always occurs shortly *after* presentation of Go stimuli). An inhibition of motor response after "Stop" signals appears is required for accurate performance.

The "Stop" signal requires participant to interrupt a response already started (16). Longer periods of delay intervals ("Stop" after "Go") are associated with diminished probability of inhibiting the response. The outcome of SST situation depends on the speed of "Go" process, the delay between "Go" stimulus and "Stop" signal, and the speed of the "Stop" process. There are two versions of the Stop Signal Task: one with "Stop" signals presented at fixed intervals and a second applying a tracking mechanism to vary the interval between the "Go" and the "Stop" signal. The ability to initiate and to change behavior in relation to changing information is believed to be under the control of a neural circuit involving the subgenual sector of the anterior cingulate cortex (ACC) which appears to be critical for this type of impulsivity (19).

3. Interference inhibition

Interference control is the ability to inhibit the response to information irrelevant to goal-directed behavior (11). The Stroop Color-Word Test is seen as the "gold standard" measure of interference control (20). The Stroop test requires patients to name the ink colors of words referring to colors in which the words themselves are printed with colored letters. In some cases (congruent condition), the color name is the same as the color's letters, e.g., the word "red" printed in red, while in other cases (incongruent condition), they are different, e.g., the word "red" printed in blue, green or yellow. When subjects are required to report the ink color of the word, more difficulties are experienced in the incongruent condition. This can be measured by an increased amount of time required to complete the task (the Stroop interference effect). One explanation for the interference effect is that word reading and the naming of colors are conflicting. Word reading is an automatic, reflex-like practiced process. In contrast, color naming is relatively novel, and is susceptible to interference from other conflicting processes. Thus, when the two conflicting responses are queued the same stimulus, the response associated with the weaker process will require more resources. The measure of inhibition ability is the relative response delay in Stroop interference condition (as measured by RT incongruent condition — RT neutral condition). In contrast, the time required in the congruent condition is slightly less than that required in the neutral condition (facilitation effect). In a variation of the above paradigm, when subjects are asked to name the word rather than to report the ink color, interference is also observed in the incongruent condition (the reversed Stroop effect). Recent studies have adopted computerized presentation of stimuli, which enables a more precise measurement of reaction time for Stroop performance. In recent years, measuring of the vocalizing a verbal response RT has been replaced by more simple manual key-press measure of reaction time, and no difference was found between the two methods of measurement in control subjects. Studies of interference control usually support evidence for a difficulty in interference control in impulsive subjects (11, 21). Recently, the Stroop test was used for evaluation of the integrity of the prefrontal cortex (PFC) and anterior cingulate cortex (22). First, the damage of prefrontal cortex, which is critical for inhibitory ability, is associated with slowness in Stroop performance (23). Slowness of responses is more prominent in the non-congruent condition of Stroop task, in which an examinee makes intensive use of his working memory and requires the prefrontal cortex activation during interference control (7, 24). Second, solving of problems, while weighing alternate solutions, involves activation of the anterior cingulated girus, and the basal ganglia (25–27). Damage of the anterior cingulated girus is associated with lower accuracy in interference control in Stroop performance (28).

Neuro-imaging and neuropsychological association

"Inhibition" refers to mechanisms by which the nervous system suppresses information, restricts its use, or restrains its transmission from one area of the brain to another. Inhibitory control and error monitoring are critical functions of the human brain (17).

The ability to inhibit movement is critical for response selection processes, which in turn contribute to accurate performance. This inhibitory process does not simply stop the flow of movement but is an active process that can suppress already prepared activation of the motor cortex (17). Lesion and imaging studies have shown that the orbitofrontal cortex (OFC) plays an important role in inhibition of inappropriate responses. The orbitofrontal cortex is involved in representing the reward value of stimuli and in the rapid learning of associations between visual stimuli and rewarding or punishing outcomes. Patients with OFC impairment often failed to switch their choices after obvious "losses" and were not able to take correct action between risky decisions associated with reward expectations (29). This impairment has been associated with difficulty in responding correctly to punishments, which in turn influence difficulties in learning from experience (30). Difficulties in learning from experience may influence impulsive and socially inappropriate behavior.

Response inhibition was associated with activation of the orbito-frontal cortex, superior temporal gyrus, anterior cingulate cortex, inferior parietal lobule (31), and dorsolateral prefrontal cortex (32, 33) predominantly on the right side. Impulsive patients had less activation of prefrontal cortex during response inhibition than did non-impulsive subjects (31). The defective neural activity ("immature brain") during response inhibition performance was found among patients with drug and alcohol addiction (34, 35).

Inhibitory control and performance monitoring (error processing) are critical for behavioral control. Research findings provide evidence for a distributed error processing system in the brain that overlaps partially, but not completely, with brain regions involved in response inhibition. In particular, the rostral anterior cingulate cortex and posterior cingulate girus, anterior insular cortex were activated only during error-processing, but not during response inhibition (36, 37).

Pharmacological evidence of multifaceted concept of impulsivity

Impulsive behaviors have been associated with indices of low serotonin (or 5-hydroxytryptamine [5-HT]) neurotransmission: low CSF concentrations of 5-HT, blunted prolactin responses to 5-HT agonists, and disturbances to markers on platelets and in plasma. Acute tryptophan depletion, a procedure that transiently decreases 5-HT neurotransmission, has been reported to increase impulsive behaviors. Together, these studies support the hypothesis that low serotonergic tone plays an etiological role in the pathophysiology of impulsivity. Moreover, depletion of 5-HT was found to effect distinct aspects of impulsive behavior (38). Lifetime histories of impulsive acts have been reported to correlate negatively with glucose metabolism in the OFC and in the temporal cortex (39). This hypocortical activity in patients with borderline personality disorder is related to low 5-HT neurotransmission in the prefrontal cortex (PFC), anterior cingulate cortex (ACC) and orbitofrontal cortex (OFC) (40, 41). Impulsivity may be assumed to be a multifaceted construct with distinct neurochemical substrate. Dissociation was found between the effects of 5-HT 2A,C receptor antagonism, which decreased impulsivity in the choice reaction time task, but had no effect on the delayed reward task. And, 5-HT6 receptor antagonism, which had no effect on the choice reaction time performance, decreased impulsive responding in the delayed reward task (42). The results suggest that the choice reaction time and the delayed reward tasks do in fact measure different types of impulsive behavior, which are at least partially neurochemically distinct (42).

In accordance with previous conclusions about multifaceted concept of inhibition, dopamine and norepenephrine systems are essential to impulse control (43, 44) and possession of the DRD4 7-repeat allele appears to be associated with impulsiveness on neuropsychological tasks (45). Treatment with methylphenidate enhanced a "prepotent inhibition" but not "interference control" (46–48).

Conclusion

Neurocognitive deficits may be involved in impaired behavioral control that can lead to lower ability for socially appropriate behavior. Development of neuropsychological batteries for objective measurement of impulsiveness may clarify the association between cognitive and behavioral aspects of impulsivity and can facilitate prediction of future dangerous behavior. Neuropsychological tasks developed to simulate real-life decision-making processes may help to detect the specific cognitive mechanisms which may characterize different types of impulsiveness. Further studies will be necessary to clarify diagnostic specificity of inhibitory impairments. Combined use of neuropsychological assessment with functional neuro-imaging will further help understanding the biological basis of impulsive behavior and may help differentiate the psychopharmacological intervention. It could be suggested that orbitofrontal cortex, dorsolateral prefrontal cortex and anterior cingulated gyrus dysfunction may be involved in impulsive behavior.

Acknowledgement

The authors thank Anat Blaustein, MA, and David Cohen, MA, for their contribution to this work.

References

1. Moeller FG, Barratt ES, Dougherty DM, Schmitz JM, Swann AC. Psychiatric aspects of impulsivity. Am J Psychiatry 2001;158:1783–1793.
2. Evenden JL. Impulsivity: A discussion of clinical and experimental findings. J Psychopharmacology 1999; 13:180–192.
3. Keilp JG, Sackeim HA, Mann JJ. Correlates of trait impulsiveness in performance measures and neuropsychological tests. Psychiatry Res 2005;135: 191–201.
4. Holmes J, Hever T, Hewitt L, Ball C, Taylor E, Rubia K, Thapar A. A pilot twin study of psychological measures of attention deficit hyperactivity disorder. Behav Genet 2002;32:389–395.
5. Dougherty DM, Marsh DM, Mathias CW. Immediate and delayed memory tasks: A computerized behavioral measure of memory, attention, and impulsivity. Behavior Research Methods, Instruments and Computers 2002;34:391–398.
6. Dougherty DM, Bjork JM, Harper RA, Marsh DM, Moeller FG, Mathias CW, Swann AC. Behavioral impulsivity paradigms: A comparison in hospitalized adolescents with disruptive behavior disorders. J Child Psychol Psychiatry 2003;44:1145–1157.
7. Ridderinkhof KR, van den Wildenberg WP, Segalowitz SJ, Carter CS. Neurocognitive mechanisms of cognitive control: The role of prefrontal cortex in action selection, response inhibition, performance monitoring, and reward-based learning. Brain Cogn 2004;56:129–140.
8. Swann AC, Bjork JM, Moeller FG, Dougherty DM. Two models of impulsivity: Relationship to personality traits and psychopathology. Biol Psychiatry 2002;51: 988–994.
9. Lijffijt M, Bekker EM, Quik EH, Bakker J, Kenemans JL, Verbaten MN. Differences between low and high trait impulsivity are not associated with differences in inhibitory motor control. J Atten Disord 2004;8:25–32.
10. Keller J, Ripoll H. Reflective-impulsive style and conceptual tempo in a gross motor task. Percept Mot Skills 2001;92:739–749.
11. Barkley RA. Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. Psychological Bulletin 1997;121:65–94.
12. Kagan J, Rosman BL, Day D, Albert J, Phillips W. Information processing in the child: Significance of analytic and reflective attitudes. Psychol Monogr 1964;78: Whole No. 578.
13. Carter CS, Braver TS, Barch DM, Botvinick MM, Noll D, Cohen JD. Anterior cingulate cortex, error detection, and the online monitoring of performance. Science 1998;280:747–749.
14. Riccio CA, Reynolds CR, Lowe P, Moore JJ. The Continuous Performance Test: A window on neutral substrates for attention. Arch Clin Neuropsychology 2002; 17:235–272.
15. Exposito J, Andres-Pueyo A. The effects of impulsivity on the perceptual and decision stages in a choice reaction time task. Personality Individual Differences 1997; 22:693–697.
16. Logan GD, Schachar RJ, Tannock R. Impulsivity and inhibitory control. Psychological Science 1997;8:60–64.
17. Casey BJ, Tottenham N, Fossella J. Clinical, imaging, lesion, and genetic approaches toward a model of cognitive control. Dev Psychobiol 2002;40:237–254.
18. Waldvogel D, Van Gelderen P, Muellbacher W, Ziemann U, Immisch I, Hallett M. The relative metabolic demand of inhibition and excitation. Nature 2000;406:995–998.

19. Bush G, Whalen PJ, Rosen BR, Jenike MA, McInerney SC, Rauch SL. The counting Stroop: An interference task specialized for functional neuroimaging-validation study with functional MRI. Human Brain Mapping 1998;6:270–282.
20. MacLeod CM. Half a century of research on the Stroop effect: An integrative review. Psychol Bull 1991;109: 163–203.
21. Rubia K, Russell T, Overmeyer S, Brammer MJ, Bullmore ET, Sharma T, Simmons A, Williams SC, Giampietro V, Andrew CM, Taylor E. Mapping motor inhibition: Conjunctive brain activations across different versions of go/no-go and stop tasks. Neuroimage 2001;13:250–261.
22. Harrison BJ, Shaw M, Yucel M, Purcell R, Brewer WJ, Strother SC, Egan GF, Olver JS, Nathan PJ, Pantelis C. Functional connectivity during Stroop task performance. Neuroimage 2005;24:181–191.
23. Pujol J, Vendrell P, Deus J, Junque C, Bello J, Marti-Vilalta JL, Capdevila A. The effect of medial frontal and posterior parietal demyelinating lesions on Stroop interference. Neuroimage 2001;13:68–75.
24. Hazeltine E, Bunge SA, Scanlon MD, Gabrieli JD. Material-dependent and material-independent selection processes in the frontal and parietal lobes: An event-related fMRI investigation of response competition. Neuropsychologia 2003;41:1208–1217.
25. Peterson BS, Skudlarski P, Gatenby JC, Zhang H, Anderson AW, Gore JC. An fMRI study of Stroop word-color interference: Evidence for cingulate subregions subserving multiple distributed attentional systems. Biol Psychiatry 1999;45:1237–1258.
26. Gruber SA, Rogowska J, Holcomb P, Soraci S, Yurgelun-Todd D. Stroop performance in normal control subjects: fMRI study. Neuroimage 2002;16:349–360.
27. Mead LA, Mayer AR, Bobholz JA, Woodley SJ, Cunningham JM, Hammeke TA, Rao SM. Neural basis of the Stroop interference task: Response competition or selective attention? J Int Neuropsychol Soc 2002;8: 735–742.
28. Swick D, Jovanovic J. Anterior cingulate cortex and the Stroop task: Neuropsychological evidence for topographic specificity. Neuropsychologia 2002;40:1240–1253.
29. Hornak J, O'Doherty J, Bramham J, Rolls ET, Morris RG, Bullock PR, Polkey CE. Reward-related reversal learning after surgical excisions in orbito-frontal or dorsolateral prefrontal cortex in humans. J Cogn Neurosci 2004;16:463–478.
30. Berlin HA, Rolls ET, Kischka U. Impulsivity, time perception, emotion and reinforcement sensitivity in patients with orbitofrontal cortex lesions. Brain 2004;127: 1108–1126.
31. Horn NR, Dolan M, Elliott R, Deakin JF, Woodruff PW. Response inhibition and impulsivity: An fMRI study. Neuropsychologia 2003;41:1959–1966.
32. Asahi S, Okamoto Y, Okada G, Yamawaki S, Yokota N. Negative correlation between right prefrontal activity during response inhibition and impulsiveness: A fMRI study. Eur Arch Psychiatry Clin Neurosci 2004;254: 245–251.
33. Goethals I, Audenaert K, Jacobs F, Van den Eynde F, Bernagie K, Kolindou A, Vervaet M, Dierckx R, Van Heeringen C. Brain perfusion SPECT in impulsivity-related personality disorders. Behav Brain Res 2005; 157:187–192.
34. Bjork JM, Hommer DW, Grant SJ, Danube C. Impulsivity in abstinent alcohol-dependent patients: Relation to control subjects and type 1-/type 2-like traits. Alcohol 2004;34:133–150.
35. Lee TM, Zhou WH, Luo XJ, Yuen KS, Ruan XZ, Weng XC. Neural activity associated with cognitive regulation in heroin users: A fMRI study. Neurosci Lett 2005; 382:211–216.
36. Menon V, Adleman NE, White CD, Glover GH, Reiss AL. Error-related brain activation during a Go/NoGo response inhibition task. Hum Brain Mapp 2001;12: 131–143.
37. Mathalon DH, Whitfield SL, Ford JM. Anatomy of an error: ERP and fMRI. Biol Psychol 2003;64:119–141.
38. Winstanley CA, Dalley JW, Theobald DE, Robbins TW. Fractionating impulsivity: Contrasting effects of central 5-HT depletion on different measures of impulsive behavior. Neuropsychopharmacology 2004;29:1331–1343.
39. Goyer PF, Andreason PJ, Semple WE, Clayton AH, King AC, Compton-Toth BA, Schulz SC, Cohen RM. Positron-emission tomography and personality disorders. Neuropsychopharmacology 1994;10:21–28.
40. Siever LJ, Buchsbaum MS, New AS, Spiegel-Cohen J, Wei T, Hazlett EA, Sevin E, Nunn M, Mitropoulou V. d, l-Fenfluramine response in impulsive personality disorder assessed with [^{18}F]fluorodeoxyglucose positron emission tomography. Neuropsychopharmacology 1999;20:413–423.
41. Leyton M, Okazawa H, Diksic M, Paris J, Rosa P, Mzengeza S, Young SN, Blier P, Benkelfat C. Brain Regional alpha-[11C]methyl-L-tryptophan trapping in impulsive subjects with borderline personality disorder. Am J Psychiatry 2001;158:775–782.
42. Talpos JC, Wilkinson LS, Robbins TW. A comparison of multiple 5-HT receptors in two tasks measuring impulsivity. J Psychopharmacol 2006;20:47–58.
43. King JA, Tenney J, Rossi V, Colamusi L, Burdick S. Neural substrates underlying impulsivity. Ann NY Acad Sci 2003;1008:160–169.

44. Hershey T, Black KJ, Hartlein J, Braver TS, Barch DM, Carl JL, Perlmutter JS. Dopaminergic modulation of response inhibition: An fMRI study. Brain Res Cogn Brain Res 2004;20:438–48.
45. Langley K, Marshall L, van den Bree M, Thomas H, Owen M, O'Donovan M, Thapar A. Association of the dopamine D4 receptor gene 7-repeat allele with neuropsychological test performance of children with ADHD. Am J Psychiatry 2004;161:133–138.
46. Scheres A, Oosterlaan J, Swanson J, Morein-Zamir S, Meiran N, Schut H, Vlasveld L, Sergeant JA. The effect of methylphenidate on three forms of response inhibition in boys with AD/HD. J Abnorm Child Psychol 2003;31:105–120.
47. Heiser P, Frey J, Smidt J, Sommerlad C, Wehmeier PM, Hebebrand J, Remschmidt H. Objective measurement of hyperactivity, impulsivity, and inattention in children with hyperkinetic disorders before and after treatment with methylphenidate. Eur Child Adolesc Psychiatry 2004;13:100–104.
48. Teicher MH, Lowen SB, Polcari A, Foley M, McGreenery CE. Novel strategy for the analysis of CPT data provides new insight into the effects of methylphenidate on attentional states in children with ADHD. J Child Adolesc Psychopharmacol 2004;14: 219–232.