Original Article

Neurological Evidence for Impairment of Supervisory Attentional System in Impulsive Children

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Abstract

Background & Aims: Supervisory Attentional System (SAS) model of information processing (Norman and Shallice, 1980) explains the overall voluntary cognitive control and regulation of mental processes during novel or complex tasks. From a functional point of view, “Impulsivity” is a multidimensional concept that incorporates failure of "response inhibitory control" –a key component in SAS– and other cognition processes. Even aggressive, suicidal, and violent behaviors are associated with impulsivity and difficulty in inhibiting responses. The aim of this descriptive-comparative study was to investigate whether SAS impairments play a role in impulsive behaviors of children.

***Materials & Methods*:** Students of 8 to 10 years old were categorized into groups of high impulsivity (1.2 SD higher than the mean (n=25)) and low impulsivity (1.2 SD higher than the mean based on the Conners' Teacher Rating Scale (CTRS-RS)). SAS performance was assessed by Continuous Performance Test (CPT), Go/No Go (GNG), and Tower of London Test (TOL).

***Results*:** In CPT, higher commission score (p=0.025, F=5.40); in GNG, lower inhibitory control and omission (p< 0.001, F=16.27; p=0.016, F=6.27; p=0.006, F=8.46); and in TOL, higher time test, time total, error, and lower results scores (p=0.015, F=6.34; p=0.027, F=5.18, p=0.001, F=13.49; p=0.001, F=12.50) were obtained by the more impulsive participants.

Conclusion: Taken together, a multivariate analysis of variance in all three tests revealed that response inhibitory control is negatively ***associated*** with high impulsivity, indicating the correlativity of SAS impairment with impulsivity. This finding introduces quantifiable means of assessing SAS impairment in impulsive children, which can help improve the diagnosis and treatment strategies of impulsivity-related disorders.

Keywords: Impulsivity, Impulsive children, Inhibitory Control, Response Inhibition, Supervisory Attentional System (SAS)

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Introduction

Attention, control, and voluntary control of mental processes (volition) are three main closely interconnected processes involved in task execution. Volition fits closely with self-regulation of behavior and thought (1). These functions emerge in childhood and mature as the child and his/her caregiver’s relationship develops within the culture’s socialization process.

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Therefore, a normal person would have a strong subjective feeling of intentional or voluntary control of their behavior (1), which can be achieved only by focusing and keeping one's attention on the task at hand (2).

Cognitive control as a key (1980) shed light upon the role of attention in controlling actions, by first distinguishing "automatic" from "controlled" actions, and then by defining different mechanisms of attention used in action control. The deliberate conscious control consists of two main components: Supervisory Attentional System (or SAS), and cognition process called Contention Scheduling (3). Between the two, it can be said that SAS is responsible for all the usual cognitive processes which are not accessible to Contention Scheduling (4).

From sensory perception to activation of schemas, mental processing, and action, SAS as described by Norman and Shallice (1980) works via a "horizontal thread" for learned or routine tasks, and a "vertical thread" for more complicated or novel tasks involving a number of intentional monitoring, controlling, and feedback systems. For difficult or branched routes in which dominos cannot fall in a routine sequence on their own, additional intervention in the form of a vertical thread comes to aid, and both threads work together to form a sophisticated cognitional attentional system(5).

SAS consists of 4 sub-processes mostly performed in the frontal lobe including analysis of the task; strategy generation; monitoring; and flexible revision of these strategies based on feedback (6).

The role of attention in relation to SAS can be simply described as controlling activation and inhibition of schemas (i.e. choosing between different domino paths) (3). Inhibitory control in itself is a broad term with many definitions, among which the closest to the SAS theory was provided in 1961 by English et al. "Restraining or stopping a process from continuing or preventing a process from starting although the usual stimulus is present; or the hypothetical nervous state or process that brings about the restraint" (7). By this definition, inhibitory control can occur in different levels, from purely cognitive to behavioral inhibitory control (8). The latter is considered as an important parameter for assessment of SAS in action, owing to the fact that behavioral inhibitory control or response inhibitory control when tasks are involved, is a time-consuming process that can be measured by different means. One of the behavioral tasks used for measurement of inhibitory control in preclinical or clinical settings uses decision-making paradigms, where the subject has to choose between action with immediate reward or another action that is more rewarding in the long run (8).

Studies have shown that in paradigms measuring impulsive selection, one or more actions should be inhibited in order to reach the goal after a certain amount of time or effort, as a top-down process (8). Impulse is the inclination towards a certain act or behavior, and relatively impulsivity is defined as the combination of strong impulses and dysfunctional inhibitory process i.e. we can approximate impulsivity to disinhibition as they are distinct though overlapping (8-11). When impaired, a person's inhibitory system is not able to efficiently prevent impulsive acts (12-16), backed up by neurological evidence (14, 17, 18). Many have tested this correlation from the psychopathological viewpoint, some mixed results such as the case with Major Depression and others (19-22), and some concrete evidence when it comes to Deficit/Hyperactivity Disorder (ADHD) (13, 18, 23) among some other cognitive disorders (24-27).

An overall review of findings indicates a stronger focus on the impulsivity- inhibitory control circuits and their neural and developmental correlations rather than underlying cognitive bases (10, 15, 25, 28, 29). Uncovering cognitive impairments, if any, would pave the way for non-clinical diagnostic and treatment approaches for impulsive children, who, in many cases, are not exposed to regular clinical assessments and treatments. A profitable line of research might be to explore to what extent the correlation between inhibition and supervision on attentional mechanisms (via SAS) and impulsivity can be empirically demonstrated. Therefore, the current study sought to continue this focus and find whether an impaired SAS is involved in high impulsivity. Specifically, to address the following research questions: How different do impulsive children perform in attention-demanding tasks, particularly the ones that require response inhibition? Is there a correlation between impairment of supervisory attentional system and the index of impulsivity in children?

Participants:

By convenience sampling of 9 primary schools (among the total of 1405 students, aged 8 to 10 years old) in Bafgh city, Iran, at the beginning of the academic year 2018, 537 students (336 female) were selected. Based on the Cochran formula (30), with the confidence level of 95, the required sample size of 301 subjects was calculated. However, as it was possible for the researchers, more students were tested in order to avoid probable subject drop out or excluding subjects due to exclusion criteria. For assessment of the impulsivity level in these students, their main teachers (n=17) were chosen for the study.

$$n = \frac{z^2 pq}{e^2}$$

Instruments:

Conners' Teacher Rating Scale: As a reliable screening tool for an assessment of child behavior in school (31, 32), Conners' Teacher Rating Scale (Revised) Short Form (CTRS-RS) (32) was chosen for assessment of impulsivity in this study. CTRS-RS's sub-scales included Opposition, Cognitive Problems/Inattention, Hyperactivity, and ADHD index. Reliability and validity of the latest version have been confirmed through independent studies; reliability means that CTRS-RS has a strong internal consistency in its sub-scales; and validity means that it measures state-level sustained attention, impulsivity, and reaction time (32, 33). In Iran, the normalized and standardized version by the Sina Institute of Behavioral Researches was purchased and implemented (34). The reliability of the test for all scales is reported to be 0.76.

Continuous Performance Test (CPT): As described by Conners' et al., the CPT can be used for assessment of response inhibitory control (35, 36). Two variables measured by CPT are used in this research, omission errors which indicate inattention, and commission errors which indicate impulsivity (35, 36). In fact, CPT is not a single test but a combination of different forms of tests, which follow one general pattern: the participants are asked to pay attention to a set of relatively simple stimuli, whether visual or auditory, and detect the target from non-target stimuli and respond accordingly by pressing a certain key on the keyboard (35, 37). Differences in CPT versions are related to the stimuli, event rate, and signal probability(36). Ultimately, all CPT tasks present a standard set of performance measures (31, 32, 35, 37, 38), among which the inhibitory control was the focus of this study.

The CPT used for this study included 150 stimuli in total, 20% of which (30 stimuli) showed the target that participants were required to respond to. Each stimulus appeared on the screen for 200 milliseconds, and then was changed by 1-second intervals. Total duration of one test including the experimental round was 200 seconds (37). In order to observe the attention span of participants, the 150 stimuli were divided into three groups of 50, and as a result, three separate reaction times were recorded for each individual. The reliability coefficient of different parts of the test was between 52% and 93%.

Go/No-Go Test (GNG)(39, 40): Among neurological tests, ancillary processes involved in choices of Go/No-Go represent the inhibitory control factor (41, 42), activating the brain regions involved in SAS including inferior frontal gyrus and anterior insula, as well as prefrontal cortex (indirectly)(43).

As the name suggests, Go/No-Go test requires the participants to respond when presented with "Go" stimuli and do not respond (i.e. inhibit their response) when presented with "No-Go" stimuli. In simple GNG tests, the No-Go stimuli is constant through the test, which is the method chosen for this research. The test consisted of 40 stimuli in total (44), each stimulus appeared for 3 seconds and the interval between stimuli appearances were 3 seconds. 70% of trials were "Go" and 30% were "No-Go"(45).

Specific dependent variables (apart from personal info and impulsivity level) are reaction time (RT), commission error which occurs when a No-Go stimulus is followed by a response, omission error which occurs when there is no response to a Go stimulus, and finally inhibitory control parameter is obtained by total number of responses minus the two errors of commission and emission (46).

Tower of London Test (TOL): The Tower of London Test (TOL) (47) is a neuropsychological tool that is administrated for surveying executive functions when it comes to planning and problem solving (48). Since Norman and Shallice have proposed the notion of SAS as a controller of the non-routinized activity in executive functions (49), the results of TOL are highly associated with measuring the functionality of SAS in action (planning, inhibitory control and abstraction of logical rules) (47).

In this test, twelve problems were administered to each participant. In each problem three beads, one red, one green and one blue, had to be moved from the starting configuration on three sticks of unequal length to a target configuration in a minimum number of moves; each participant was given three trials to complete the test (50). After completing each problem (or in case of failure after three trials), the participant was given the next problem to solve.

Procedure:

17 elementary teachers filled out Conners' Teacher Rating Scale for their students (n=537), meaning a student/teacher ratio of 31.5. The following inclusion criteria were implemented: (1) After statistical review of their answer sheets, teachers whose answer sheets showed ceiling and floor effects were eliminated from the study. (2) Students having the minimum average score of 16 out of 20 in school achievement; (3) Not diagnosed with any psychological or physiological problems or disorders, based on interviewing their teachers and reviewing their medical records; (4) Not using any particular drugs or treatments, based on interviewing their teachers and reviewing their medical records; (5) Having consented to participate in this study willingly, both the students and their parents, as well as school authorities. The students' parents were informed prior to the tests and have given their consent; students were also informed and asked if they were willing to participate in the experiment. Unwillingness from either the school/parents or the students meant no further participation.

A total of 174 students were excluded and the remaining 363 students (219 female) were divided into two groups. Participants with the scores of 1.2 SD higher than the mean (M=51.27) were selected as high impulsivity group (n=35) and those with 1.2 SD lower than mean (M=51.27) were selected as low impulsivity group (n=35). A number of students were not willing to participate in all three tests and therefore they were eliminated from the study, also in order to balance the group sizes, within each group, finally 25 students who had the highest and lowest scores among each group were chosen. As a result, two even groups of 25 students with relatively high impulsivity (16 male and 9 female; mean age 8.00±0.00) level and relatively low impulsivity level (9 male and 22 female; mean age 9.00±0.00) were selected for further investigations, named *high imp* and *low imp*, respectively.

Three tests including Continuous Performance Test (CPT), Go/No-Go Test (GNG), and Tower of London Test (TOL) were administered following a quasi-experimental process.

All tests were conducted inside the school of each participant, in an empty, calm, and well-lit classroom. Students were called to the classrooms in groups. First, the researcher explained how the tests should be done by showing the procedure on the computer screen to the participants. Before the actual test, the researcher made sure the participants fully understood the instructions by first administering one or two practice session to each one; then the group left the classroom and students came back in one by one after their name was called out in order to take the test. Duration of the CPT was 200 seconds and GNG was 240 seconds; totally a time frame of 440 seconds was considered for the first two tests. TOL time limit was 2000 seconds; nonetheless, for each participant, the test completion time duration was measured individually. Upon finishing each set of tests, the child was rewarded with biscuits and asked to leave the room. All tests were conducted on a 14" laptop screen display (Sony VAIO PCG-61411l, Intel Core i3, Windows 7 64-bit), using test software standardized and licensed by the Institute for Behavioral & Cognitive Sciences (SINA).(37) The same course of action was followed for all participants. This study has been approved by the ethics committee of Shahid Beheshti University. The method of this research was descriptive-comparative and obtained data were analyzed by SPSS 19.

Results

Table 1. Demographic characteristics of the sample

Group	Gender	Number	Age		Conners Rating Score	
			Mean	St. Dev	Mean	St. Dev
High Impulsivity	Male	16	8	0.71	91.81	8.73
	Female	9	8	0.59	85.55	16.26
	Total	25	8	0.59	89.56	16.25
Low Impulsivity	Male	3	9	1.15	28.33	0.57
	Female	22	9	0.51	28.04	0.21
	Total	25	9	0.58	28.08	0.27

Conners' Teacher Rating Scale: In order to categorize the subjects in study groups according to their scores in Conners Teacher Rating Scale, upper and lower extreme scores were chosen and assigned in High Impulsivity and Low Impulsivity groups as shown in Table 1: *Demographic characteristics of the sample*

Continuous Performance Test (CPT):

In the first phase, multivariate analysis of variance was performed for measuring the effects of impulsivity, gender, and the combination of both, on mixed linear models (MLM) of CPT (Table 2). The results show that the effect of impulsivity on the MLM of CPT is statistically significant ($p=0.007$). Furthermore, the effect of gender and combination of group*gender on the MLM of CPT are not statistically significant.

Table 2. Multivariate Tests (CPT)

Effect		Value	F	Hypothesis df	Error df	Sig.	η
Group	Wilks' Lambda	.76	4.56b	3.00	44.00	.007	.237
Gender	Wilks' Lambda	.97	.39b	3.00	44.00	.760	.026
Group*Gender	Wilks' Lambda	.96	.64b	3.00	44.00	.590	.042

In the second phase, the outcome of the multivariate analysis of variance on the CPT parameters i.e. tests of between-subjects' effects (Table 3) shows statistically significant effect of impulsivity on the commission (p=0.025). Besides, comparison of means demonstrates that the high impulsivity group possesses a higher commission (M=8.97±1.86) than the low impulsivity group (M=1.41±2.67). No significant difference was observed in other parameters.

Table 3. Tests of Between-Subjects Effects (CPT)

Source	Dependent Variable	F(df)	p	η
Group	Omission	2.47(1,42)	.123	.051
	Commission	5.41(1,42)	.025	.105
	Total RT	.01(1,42)	.931	.000
Gender	Omission	.48(1,42)	.492	.010
	Commission	.27(1,42)	.607	.006
	Total RT	.05(1,42)	.828	.001
Group * Gender	Omission	.14(1,42)	.705	.003
	Commission	.59(1,42)	.446	.013
	Total RT	.058(1,42)	.810	.001

Go/No-Go Test (GNG): Table 4 demonstrates the descriptive statistics of GNG with dependent variables including omission, commission, and total reaction time (RT).

In the first phase, multivariate analysis of variance was performed for measuring the effects of impulsivity, gender, and the combination of both on mixed linear models (MLM) of GNG (Table 4). The results show that the effect of impulsivity on the MLM of GNG is statistically significant (p=0.003). Furthermore, the effect of gender and the combination of gender*group on the MLM of GNG is not statistically significant.

Table 4. Multivariate Test (GNG)

Effect		Value	F	Hypothesis df	Error df	p	η
Group	Wilks' Lambda	.73	5.41b	3.00	44.00	.003	.270
Gender	Wilks' Lambda	.92	1.22b	3.00	44.00	.313	.077
Group*Gender	Wilks' Lambda	.94	.87b	3.00	44.00	.463	.056

In the second phase, the outcome of the multivariate analysis of variance on the GNG parameters i.e. tests of between-subjects effects (Table 5) shows a statistically significant effect of impulsivity on the inhibitory control, omission, and commission (p< 0.001, p=0.016, p=0.006, respectively). Besides, comparison of means demonstrates that the high impulsivity group possesses lower inhibitory control (M=24.76±1.25) than the low impulsivity group (M=33.95±1.91), on the contrary, omission and commission of the former are higher than the latter. No significant difference was observed regarding the RT.

Table 5. Multivariate Tests (GNG)

Source	Dependent Variable	F(df)	p	Ŋ
Group	RT	.08(1,42)	.778	.002
	Inhibitory Control	16.28(1,42)	.000	.261
	Omission	6.28(1,42)	.016	.120
	Commission	8.46(1,42)	.006	.155
Gender	RT	1.30 (1,42)	.260	.027
	Inhibitory Control	.82(1,42)	.370	.017
	Omission	.00 (1,42)	.948	.000
	Commission	1.92	.172	.040
Group * Gender	RT	.80(1,42)	.376	.017
	Inhibitory Control	1.54(1,42)	.222	.032
	Omission	.94(1,42)	.338	.020
	Commission	.44(1,42)	.512	.009

Tower of London Test (TOL): Table 6 demonstrates the descriptive statistics of TOL with dependent variables including omission, commission, and total reaction time (RT).

In the first phase, multivariate analysis of variance was performed for measuring the effects of impulsivity, gender, and the combination of both, on mixed linear models (MLM) of TOL (Table 6). The results show that the effect of impulsivity on the MLM of TOL is statistically significant (p=0.001). Furthermore, the effect of gender and the combination of gender*group on the MLM of TOL is not statistically significant.

Table 6. Multivariate Test (TOL)

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Group	Wilks' Lambda	.66	5.61b	4.00	43.00	.001	.343
Gender	Wilks' Lambda	.92	.97	4.00	43.00	.434	.083
Group * Gender	Wilks' Lambda	.91	1.11b	4.00	43.00	.365	.093

In the second phase, the outcome of the multivariate analysis of variance on the TOL parameters i.e. tests of between-subjects effects (Table 7) shows statistically significant effect of impulsivity on the time test, time total, error, and result (p=0.015, p=0.027, p=0.001, p=0.001, respectively). Besides, comparison of means demonstrates that the high impulsivity group possesses lower result (M=23.85±1.16) than the low impulsivity group (M=30.58±1.51), on the contrary, time test, time total, and error of the former are higher than the latter. No significant difference was observed regarding the template.

Table 7. Multivariate Tests (TOL)

Source	Dependent Variable	F	Sig.	Partial Eta Squared
Group	Time test	6.34	.015	.121
	Time late	1.30	.260	.027
	Time total	5.18	.027	.101
	Error	13.49	.001	.227
	Result	12.50	.001	.214

Gender	Time test	.66	.421	.014
	Time late	.91	.344	.019
	Time total	.08	.782	.002
	Error	.05	.816	.001
	Result	.78	.382	.017
Group * Gender	Time test	2.42	.126	.050
	Time late	.17	.685	.004
	Time total	1.70	.198	.036
	Error	2.85	.098	.058
	Result	06	.800	.001

Discussion

This study showed that the group of children with higher impulsivity had higher commission parameter scores in CPT; higher omission, commission, and lower inhibitory control parameter scores in GNG; and higher time test, time total, error, and lower results parameter scores in TOL.

These results all indicate that children with higher impulsivity gave more wrong answers (commission score) in CPT. GNG results show that in addition to giving more wrong answers, they missed more questions (omission score) as well. As expected, the higher impulsivity group could not control their attention, thoughts, and behaviors in the task (inhibitory control i.e. (omission + commission) -total results). In TOL, we observed the same pattern; more errors and lower test results of the highly impulsive children.

Literature shows (51-53) that highly impulsive participants would feel an urge to respond to each given stimuli and therefore they would finish the tests faster than the other participants, meaning lower total RT in CPT; RT in GNG; and time test and time total parameters in TOL. However, the study results showed no difference neither in total RT in CPT nor RT in GNG between the two groups, and even higher time test and time total scores in TOL for the higher impulsivity group. It can be rationalized by the fact that highly impulsive children tend to become easily distracted by irrelevant stimuli even though the test room and surrounding environment are kept under control (54-56).

To explain the above results, SAS is presumed to work as a mediator in cognitive functions such as inhibitory control, willed action, and the execution control (43, 57, 58) and it is found to show signs of dysfunction in the performance of CPT, GNG, and TOL tasks in high impulsive children. In other words, these children were not able to perform as well as they were supposed to in these tests (which are dedicated to measure the SAS).

To the best of our knowledge, all previous studies used the same methodology to investigate the SAS functionality, including the work of Gilsoul et al. (59) who administered CPT and GNG for measuring inhibition in light of attentional mechanisms; also Andre´s et al. (50) who re-examined a hypothesis directly proposed by Norman and Shallice with regard to SAS and brain's frontal lesions (24), among others (60).

Moreover, in this study we found that gender difference did not play a role in the performance of these tasks, this result is not consistent with some previous findings such as the study by Conners et al. (35). They reviewed the CPT results in more than eight hundred children of 9 to 17 years old and found that male participants had more impulsive errors, less variability, and faster RT.

The findings of this work are to be viewed under certain limitations. First, in order to assess cognitive control and inhibition in SAS, we wished to use Hayling Task as well; however, the standardized version of this task was not yet available in Persian language at the time of this experiment. More work is needed in order to study Hayling Task results in this concept as well. Second, the sample size is rather small; the initial sample sizes were 35 and 34, however due to unwillingness of a number of participants and also balancing the group sizes, we had to omit more students by random with the same impulsivity score, both within the lowest quarter in high impulsivity, and the highest quarter in low impulsivity, until reaching groups of twenty-five. The children chosen for this study were not officially tested for the possibility of being diagnosed with ADHD, therefore this study is unable to provide any statements with regard to the correlation of SAS or inhibitory control and ADHD; however, as impulsivity is a component in ADHD(61), the authors considered the benefits of this study with regard to diagnosis and treatment of ADHD.

As mentioned in the method section, the sample consisted of primary school students and tests (CPT, GNG, and TOL) were performed only once, and it would be desirable to perform the same tests in a follow-up study on the same 50 participants by conducting a longitudinal approach, particularly considering the effect of age on children's performance in these tests (e.g., Conners et al.'s longitude work on CPT (35)). Endeavoring to find the underlying clinical or cognitive causes of SAS defects could provide new possibilities of ADHD prevention, as well as guiding treatment interventions towards more cognitive measures besides the medical and behavioral treatments; as recent findings support the effective role of specific cognitive interventions in psychological disorders (40-49).

One of the methodological limitations of this study is that in the two groups with high and low impulsivity, participants were not matched with each other in terms of gender and age. Also, since the tests used in the present study are also used in assessing disorders such as ADHD, a more accurate test such as the Hayling test is needed to differentiate the disorder in SAS. As Hayling test was not translated into Persian and was not within the reach of the researchers, it is suggested that in future research, in addition to considering the larger age range, paying more attention be differential disorders as well as the same age and gender groups, researchers should administer more precise tests as Hayling. Unfortunately, because the researchers were conducting the research, knowledge of the subject matter of the research may have affected their performance as structures. It is better to do double-blinded study in future research.

References

1. Obeso I, Robles N, Marrón EM, Redolar-Ripoll D. Dissociating the Role of the pre-SMA in Response Inhibition and Switching: A Combined Online and Offline TMS Approach. Front Hum Neurosci 2013;7:150.
2. Posner MI, Rothbart MK. Attention, self-regulation and consciousness. Philos Trans R Soc Lond B Biol Sci 1998;353(1377):1915-27.
3. Hitch GJ, Hu Y, Allen RJ, Baddeley AD. Competition for the focus of attention in visual working memory: perceptual recency versus executive control. Ann N Y Acad Sci 2018;1424(1):64-75.
4. Bari A, Robbins TW. Inhibition and impulsivity: behavioral and neural basis of response control. Prog Neurobiol 2013;108:44-79.
5. Hofmann W, Friese M, Strack F. Impulse and Self-Control From a Dual-Systems Perspective. Perspect Psychol Sci 2009;4(2):162-76.
6. Nigg JT. Annual Research Review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. J Child Psychol Psychiatry 2017;58(4):361-83.
7. Weidacker K, Whiteford S, Boy F, Johnston SJ. Response inhibition in the parametric go/no-go task and its relation

to impulsivity and subclinical psychopathy. Q J Exp Psychol (Hove) 2017;70(3):473-87.

8. Hege MA, Stingl KT, Kullmann S, Schag K, Giel KE, Zipfel S, Preissl H. Attentional impulsivity in binge eating disorder modulates response inhibition performance and frontal brain networks. Int J Obes (Lond) 2015;39(2):353-60.
9. Nigg JT. Is ADHD a disinhibitory disorder?. Psychol Bull 2001;127(5):571.
10. Dalley JW, Robbins TW. Fractionating impulsivity: neuropsychiatric implications. Nat Rev Neurosci 2017;18(3):158-71.
11. Sach M, Enge S, Strobel A, Fleischhauer M. MPQ Control (versus Impulsivity) and Need for Cognition–Relationship to behavioral inhibition and corresponding ERPs in a Go/No-Go task. Pers Individ Dif 2018;121:200-5.
12. Castro-Meneses LJ, Johnson BW, Sowman PF. The effects of impulsivity and proactive inhibition on reactive inhibition and the go process: insights from vocal and manual stop signal tasks. Front Hum Neurosci 2015;9:529.
13. Brown MR, Benoit JR, Juhás M, Dametto E, Tse TT, MacKay M, Sen B, Carroll AM, Hodlevskyy O, Silverstone PH, Dolcos F, Dursun SM, Greenshaw AJ. fMRI investigation of response inhibition, emotion, impulsivity, and clinical high-risk behavior in adolescents. Front Syst Neurosci 2015;9:124. 14. Montojo CA, Congdon E, Hwang L, Jalbrzikowski M, Kushan L, Vesagas TK, Jonas RK, Ventura J, Bilder RM, Bearden CE. Neural mechanisms of response inhibition and impulsivity in 22q11.2 deletion carriers and idiopathic attention deficit hyperactivity disorder. Neuroimage Clin 2015;9:310-21.
15 Dekker MR, Johnson SL. Major depressive disorder and emotion-related impulsivity: Are both related to cognitive inhibition?. Cognitive Therapy and Research 2018;42(4):398-407.
16. Kertzman S, Vainder M, Aizer A, Kotler M, Dannon PN. Pathological gambling and impulsivity: Comparison of the different measures in the behavior inhibition tasks. Personality and Individual Differences 2017;107:212-8. 17. im Y, Jeong JE, Cho H, Jung DJ, Kwak M, Rho MJ, et al. Personality Factors Predicting Smartphone Addiction Predisposition: Behavioral Inhibition and Activation Systems, Impulsivity, and Self-Control. PLoS One 2016;11(8):e0159788.
18. Mullen J, Mathias CW, Karns TE, Liang Y, Hill-Kapturczak N, Roache JD, et al. Behavioral Impulsivity Does Not Predict Naturalistic Alcohol Consumption or Treatment Outcomes. Addict Disord Their Treat 2016;15(3):120-8.
19. Dougherty DM, Olvera RL, Acheson A, Hill-Kapturczak N, Ryan SR, Mathias CW. Acute effects of methylphenidate on impulsivity and attentional behavior among adolescents comorbid for ADHD and conduct disorder. J Adolesc 2016;53:222-30.
20. Kim M, Lee TH, Choi JS, Kwak YB, Hwang WJ, Kim T, et al. Neurophysiological correlates of altered response inhibition in internet gaming disorder and obsessive-compulsive disorder: Perspectives from impulsivity and compulsivity. Sci Rep 2017;7:41742.
21. Morein-Zamir S, Robbins TW. Fronto-striatal circuits in response-inhibition: Relevance to addiction. Brain Res 2015;1628(Pt A):117-29.
22. Dougherty DM, Lake SL, Mathias CW, Ryan SR, Bray BC, Charles NE, et al. Behavioral Impulsivity and Risk-Taking Trajectories Across Early Adolescence in Youths With and Without Family Histories of Alcohol and Other Drug Use Disorders. Alcohol Clin Exp Res 2015;39(8):1501-9.
23. Weafer J, Dzemidzic M, Eiler W 2nd, Oberlin BG, Wang Y, Kareken DA. Associations between regional brain physiology and trait impulsivity, motor inhibition, and impaired control over drinking. Psychiatry Res 2015;233(2):81-7.

24. Norman DA, Shallice T. Attention to action: Willed and automatic control of behaviour. 2000.
25. Stuss DT, Knight RT, editors. Principles of Frontal Lobe Function. New York: Oxford University Press; 2002.
26. Davidson RJ, Schwartz GE, Shapiro D, editors. Consciousness and Self-Regulation. New York, USA: Springer SBM; 1986. p. 244.
27. Goldstein S, Naglieri JA. Handbook of Executive Functioning. Springer; 2014. p. 565.
28. Carlson SM, Moses LJ. Individual differences in inhibitory control and children's theory of mind. Child Dev 2001;72(4):1032-53.
29. Munakata Y, Herd SA, Chatham CH, Depue BE, Banich MT, O'Reilly RC. A unified framework for inhibitory control. Trends Cogn Sci 2011;15(10):453-9.
30. Gall MD, Borg WR, Gall JP. Educational Research: An Introduction. 8th Ed. Longman Publishing; 1996.
31. Conners CK. A teacher rating scale for use in drug studies with children. Am J Psychiatry 1969;126(6):884-8.
32. Conners CK, Sitarenios G, Parker JD, Epstein JN. Revision and restandardization of the Conners Teacher Rating Scale (CTRS-R): factor structure, reliability, and criterion validity. J Abnorm Child Psychol 1998;26(4):279-91.
33. Shaked D, Faulkner LMD, Tolle K, Wendell CR, Waldstein SR, Spencer RJ. Reliability and validity of the Conners' Continuous Performance Test. Appl Neuropsychol Adult 2020;27(5):478-87.
34. Khodadai M, Mashhadi A, Amani H. Conners' Teacher Rating Scale. Tehran: Institute for Behavioral & Cognitive Science; 2014. (Persian)
35. Conners CK, Epstein JN, Angold A, Klaric J. Continuous performance test performance in a normative epidemiological sample. J Abnorm Child Psychol 2003;31(5):555-62.
36. Epstein JN, Erkanli A, Conners CK, Klaric J, Costello JE, Angold A. Relations between Continuous Performance Test performance measures and ADHD behaviors. J Abnorm Child Psychol 2003;31(5):543-54.
37. Khodadai M, Mashhadi A, Amani H. Continuous Performance Test Software. Tehran: Institute for Behavioral & Cognitive Science; 2014. (Persian)
38. Bar-Yosef C, Weinblatt N, Katz N. Reliability and Validity of the Cognitive Performance Test (CPT) in an Elderly Population in Israel. Physical & Occupational Therapy in Geriatrics 2000;17(1):65-79.
39. Fang P, Zeng LL, Shen H, Wang L, Li B, Liu L, et al. Increased cortical-limbic anatomical network connectivity in major depression revealed by diffusion tensor imaging. PLoS One 2012;7(9):e45972.
40. Luria AR. The frontal lobes and the regulation of behavior. in PFL: Elsevier; 1973. p. 3-26.
41. Rubia K, Russell T, Overmeyer S, Brammer MJ, Bullmore ET, Sharma T, et al. Mapping motor inhibition: conjunctive brain activations across different versions of go/no-go and stop tasks. Neuroimage 2001;13(2):250-61.
42. Masharipov R, Kireev M, Korotkov A, Medvedev S. Non-selective response inhibition during an equal probability Go/NoGo task: Bayesian analysis of fMRI data. BioRxiv 2019:823625.
43. Cieslik EC, Mueller VI, Eickhoff CR, Langner R, Eickhoff SB. Three key regions for supervisory attentional control: evidence from neuroimaging meta-analyses. Neuroscience & biobehavioral reviews 2015;48:22-34.
44. Liddle PF, Kiehl KA, Smith AM. Event-related fMRI study of response inhibition. Hum Brain Mapp 2001;12(2):100-9.
45. Young ME, Sutherland SC, McCoy AW. Optimal go/no-go ratios to maximize false alarms. Behav Res Methods 2018;50(3):1020-9.
46. Hwang S, Meffert H, Parsley I, Tyler PM, Erway AK, Botkin ML, et al. Segregating sustained attention from response inhibition in ADHD: An fMRI study. Neuroimage Clin 2019;21:101677.
47. Shallice T. Specific impairments of planning. Philos Trans R Soc Lond B Biol Sci 1982;298(1089):199-209.
48. Anderson P, Anderson V, Lajoie G. The tower of

London test: Validation and standardization for pediatric populatons. Clin Neuropsychol 1996;10(1):54-65.

49. Morris RG, Ahmed S, Syed GM, Toone BK. Neural correlates of planning ability: frontal lobe activation during the Tower of London test. Neuropsychologia 1993;31(12):1367-78.
50. Andrés P. Supervisory attentional system in patients with focal frontal lesions. J Clin Exp Neuropsychol 2001;23(2):225-39.
51. Epstein JN, Conners CK, Sitarenios G, Erhardt D. Continuous performance test results of adults with attention deficit hyperactivity disorder. Clin Neuropsychol 1998;12(2):155-68.
52. Bezdjian S, Baker LA, Lozano DI, Raine A. Assessing inattention and impulsivity in children during the Go/NoGo task. Br J Dev Psychol 2009;27(Pt 2):365-83.
53. Houghton S, Douglas G, West J, Whiting K, Wall M, Langsford S, et al. Differential patterns of executive function in children with attention-deficit hyperactivity disorder according to gender and subtype. J Child Neurol 1999;14(12):801-5.
54. Narimani M, Abassi M, Bagiyan MJ, Rezaie A. The effectiveness of impulse control and attention training on emotional processing, impulsiveness and distractibility in students with dyscalculia. Research in Cognitive and Behavioral Sciences 2016;5(2):1-22.
55. Cassuto H, Ben-Simon A, Berger I. Using environmental distractors in the diagnosis of ADHD. Frontiers in human neuroscience 2013;7:805.
56. Bioulac S, Micoulaud-Franchi JA, Maire J, Bouvard MP, Rizzo AA, Sagaspe P, et al. Virtual Remediation Versus Methylphenidate to Improve Distractibility in Children With ADHD: A Controlled Randomized Clinical Trial Study. J Atten Disord 2020;24(2):326-335.
57. Karbach J, Kray J. Executive functions. In: Cognitive training. Springer; 2016. p. 93–103.
58. Frith CD, Friston KJ, Liddle PF, FRACKOWIAK RJ. (1991) Willed action and the prefrontal cortex in man: a study with PET. In: Discovering the Social Mind. Psychology Press; 2016. p. 117–26..
59. Gilsoul J, Simon J, Hogge M, Collette F. Do attentional capacities and processing speed mediate the effect of age on executive functioning? Neuropsychol Dev Cogn B Aging Neuropsychol Cogn 2019;26(2):282-317.
60. Andrés P, Van der Linden M. Age-related differences in supervisory attentional system functions. J Gerontol B Psychol Sci Soc Sci 2000;55(6):P373-80.
61. Winstanley CA, Eagle DM, Robbins TW. Behavioral models of impulsivity in relation to ADHD: translation between clinical and preclinical studies. Clin Psychol Rev 2006;26(4):379-95.