

ENVIRONMENTAL STIMULATION DOES NOT REDUCE IMPULSIVE CHOICE IN ADHD: A “PINK NOISE” STUDY

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Abstract

Objective: The preference for sooner smaller over larger later rewards is a prominent manifestation of impulsivity in ADHD. According to the State Regulation Deficit (SRD) model, this impulsive choice is the result of impaired regulation of arousal level and can be alleviated by adding environmental stimulation to increase levels of arousal.

Method: In order to test this prediction we studied the effects of adding background “pink noise” on impulsive choice using both a classical and new adjusting choice delay task in a sample of 25 children with ADHD and 28 controls.

Results: Children with ADHD made more impulsive choices than controls. Adding noise did not reduce impulsive choice in ADHD.

Conclusion: The findings add to the existing evidence on impulsive choice in ADHD but no evidence is found for the SRD model’s explanation of this behavioral style. Alternative explanations for impulsive choice in ADHD are discussed.

Keywords: ADHD, Pink Noise, Delay Aversion, State Regulation Deficits, Impulsivity.

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a lifespan disorder characterized by symptoms of inattention and/or hyperactivity-impulsivity (DSM-IV-TR, American Psychiatric Association, 2000). These symptoms can lead to substantial deficits in social and academic functioning. The State Regulation Deficit (SRD) model postulates that these symptoms and deficits occur because of problems with regulating energetic factors such as stimulus-related phasic alertness (arousal) and tonic readiness to respond (motor activation) in response to the changing requirements of environmental settings (Sergeant, 2005; van der Meere, 2002). The model is based upon the cognitive energetic framework of Sanders (1983) which incorporates concepts such as effort, arousal and activation into the basic information processing framework so that task performance is predicted to be influenced not only by cognitive capacity but also by environmentally-determined levels of arousal and activation and the extent to which variations in these energetic factors can be managed to ensure optimal performance.

The SRD model has typically been invoked to explain the effect of manipulating contextual factors on information processing performance. For instance, there is a well – established effect of event rate (ER) on performance (Sergeant, 2005; van der Meere, 2002). Several studies have shown that individuals with ADHD are more vulnerable to ER manipulations than their peers across a range of tasks involving different cognitive processes (Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989; Conte, Kinsbourne, Swanson, Zirk, & Samuels, 1986; Metin, Roeyers, Wiersema, van der Meere, & Sonuga-Barke, 2012; Scheres, Oosterlaan, & Sergeant, 2001; van der Meere, Stemerding, & Gunning, 1995; see van der Meere, 2002 and van der Meere, Börger, & Wiersema, 2010 for reviews). According to the SRD model a fast ER is predicted to lead to over-activation and fast, impulsive responses; while slow responses and inattentive errors are predicted under slow ER because of

under-activation (Metin et al., 2012). In one study non-optimal states were also induced by stimulant medication which normally improves performance under slow ERs but seemed to trigger more errors when combined with a fast ER (van der Meere, Shalev, Börger, & Wiersema, 2009). This finding has been interpreted as the result of the combination of two putative stimulating factors (fast ER and medication).

The effect of external energetic factors on information processing performance in ADHD has been well studied. In contrast, there have been no studies of their effects on performance on tasks requiring little or no information processing. For instance, children with ADHD prefer smaller sooner (SS) over larger later (LL) rewards more than typically developing children on simple choice tasks (Antrop et al., 2006; Bitsakou, Psychogiou, Thompson, & Sonuga-Barke, 2009; Kuntsi, Oosterlaan, & Stevenson, 2001; Marco et al., 2009; Sonuga-Barke, Taylor, Sembi, & Smith, 1992). Typically this has been explained as either the result of (i) an impulsive drive for immediate reward (IDIR; Marco et al., 2009); (ii) heightened discounting of delayed rewards (Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2012); (iii) an aversion for delay (Sonuga-Barke, Sergeant, Nigg, & Willcutt, 2008) or (iv) a breakdown in inhibitory-based executive processes (Barkley, 1997).

Sonuga-Barke and colleagues recently extended the SRD model to explain impulsive choice in ADHD (Sonuga-Barke, Wiersema, van der Meere, & Roeyers, 2010). According to this extension of the SRD account, impulsive choice in ADHD results from impaired regulation of energetic state created during delay periods. As a consequence, children with ADHD are predicted to avoid low arousing or activating contexts (i.e., long delays) by seeking immediate stimulation or more frequent rewards in the environment (i.e., by choosing SS over LL; Sonuga-Barke et al., 2010). A key prediction of the SRD model is that if arousal or activation is experimentally increased during delay periods to more optimal or acceptable

levels, impulsive choices should reduce – children with ADHD will then tend to choose relatively more LL over SS outcomes.

In order to test this prediction we examined if adding extrinsic random environmental noise (in this case “pink noise”) during delay affects SS over LL preference in children with ADHD. There is good evidence that adding environmental stimulation in this way modifies arousal level. For instance, a high intensity noise level has been used successfully in several studies to improve attention capacity and selectivity (Baker & Holding, 1993; Davies & Jones, 1975; Hockey, 1970; Söderlund, Sikström, Loftesnes, & Sonuga-Barke, 2010; Söderlund, Sikström, & Smart, 2007; see Davies, 1968 and Sanders, 1983 for reviews) and it has been shown that high intensity noise affects autonomic indices of arousal such as heart rate and skin conductance (Davies, 1968; Hanson, Schellekens, Veldman, & Mulder, 1993). Furthermore, these effects appear to follow an inverted-U shaped curve: Noise increases performance when the subject is in an under-aroused state but addition of noise to an over-aroused state disturbs performance (Davies, 1968; Sanders, 1983). The beneficial effect of noise has also been confirmed in children with ADHD. Söderlund and colleagues demonstrated that the memory performance of children with attention problems improved under noise conditions while the performance of controls got worse (Söderlund et al., 2007, 2010).

Although no studies have examined the effects of adding random noise on ADHD children’s impulsive choice, one study has explored the effects of adding visual stimulation. In this study it was shown that presenting cartoons during delay differentially reduced impulsive choice in ADHD relative to typically developing controls (i.e., decreased preference for SS rewards in children with ADHD; Antrop et al., 2006). These results may be interpreted as a positive effect of environmental stimulation as predicted by the SRD model. They can also be explained by a decrease in the perception of the passage of time brought

about by the “non-temporal” stimulation employed (i.e., watching absorbing cartoons will reduce the perception of the length of the delay period). Therefore, “pink noise”, which would appear to be neutral with regard to time perception (not absorbing or interesting), provides a specific test of the SRD predictions.

In this study we measured impulsive choice by using two separate paradigms. First, we used a standard choice delay task (CDT) during which the children had to choose between SS and LL rewards (Sonuga-Barke et al., 1992). Second, in order to examine the generalization of the effects of ADHD and noise across tasks we supplemented the original measure with an adjusting choice delay task (A-CDT). In this task the delay for LL was adjusted on each trial, either up or down depending on the choices of the preceding trials, to find the point of delay indifference between SS and LL options. We predicted that children with ADHD would make more impulsive choices on both tasks (i.e., choosing SS more than LL relative to controls and have a lower point of delay indifference). In line with the SRD model, we predicted that adding “pink noise” would reduce impulsive choice in children with ADHD by increasing their preference for LL and increasing the point of delay indifference in the direction of that displayed by typically developing controls.

Method

Ethics approval was received from the Ethical Committee of Ghent University, Faculty of Psychology and Educational Sciences. All children and parents gave written informed consent before participating in the study.

Participants

Twenty-five children with ADHD and 28 typically developing controls were recruited for the study. All children were between 8 and 12 years old and had a total IQ (TIQ) above 80. TIQ was assessed by the short form of the Wechsler Intelligence Scale for Children – 3rd

edition (WISC-III; Grégoire, 2005). The groups did not differ in mean age ($F(1,51) = .95, p = .33$) and TIQ ($F(1,51) = 1.1, p = .3$). There were significantly more boys in the ADHD than the control group ($\chi^2(1, N = 53) = 4.77, p = .03$). Detailed information for TIQ, age and gender composition can be found in Table 1. The children did not have a history of hearing loss or a neuropsychiatric condition other than ADHD.

The children in the control group were recruited from local schools and scout camps. All children were screened with the Disruptive Behaviour Scale (DBD; Pelham, Gnagy, Greenslade, & Milch, 1992) for ADHD, Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD). To exclude Autistic Spectrum Disorders the Social Communication Scale (SCQ; Rutter, Bailey, & Lord, 2003) and Social Responsiveness Scale (SRS; Constantino & Gruber, 2005) were administered to both groups. The DBD scores for ODD and CD can be found in Table 1. Children with ADHD were recruited from the community and an official diagnosis by a clinician was required. The ADHD, ODD and CD diagnoses were ascertained by a DSM-IV oriented parent interview (behavior module of the Diagnostic Interview Schedule for Children, DISC-IV; Shaffer, Fischer, Lucas, Dulcan, & Schwab-Stone, 2000) administered by an experienced clinical psychologist. Seventeen children were classified as ADHD-combined type, 6 children as inattentive type and 2 children as hyperactive-impulsive type. In addition, 10 children received ODD diagnosis and one had CD diagnosis. The children using stimulant medications were instructed to discontinue their medication 24 hours before testing.

Procedure

The children were tested in a quiet room. During testing an experimenter sat out of sight of the child. The CDT was always completed first and the A-CDT second. The children were told that they would only receive the money that they collected during the tasks and the

maximum amount that they could earn in the experiment was 12 euro. However, regardless of the points earned during the tasks, all children received 15 euro. This was accomplished by using a computerized head or tails game after the experimental sessions which always ended with a win. Children were tested for IQ after the choice tasks. Meanwhile the parents of the children with ADHD were interviewed in another room.

Tasks

Two different tasks measuring impulsive choice were programmed using E-prime software (version 2.0). In both tasks the children chose repeatedly between SS and LL rewards. At the start of each trial in both tasks the children saw two coins on the computer screen (5 cent and 10 cent). They were told that if they chose 5 cent, they would receive it immediately; but for the 10 cent reward they would have to wait for a while. The waiting time was displayed under the coins. The coins were displayed on the screen until the children made a response. Immediately after the response the delay period started during which a fixation cross was displayed. The duration of delay was always 2 sec for SS rewarded. The delay to the LL reward varied across task. At the end of each trial participants were shown the amount that they had earned on that trial (i.e., 5 or 10 cent), the total amount of money earned up to that point and the number of remaining trials. This information remained on the screen until the children made a response. There was no post-reward delay period and each new trial followed immediately after the reward was delivered in the previous trial. In both tasks the noise and no-noise trials were blocked and blocks were randomized at the individual level for each participant. The participants were allowed to take a break between the two tasks.

CDT. Children chose between fixed SS (5 cent after 2 sec) and LL (10 cent after 30 sec) options. The task consisted of a total of 40 trials (20 under noise and 20 without noise). The dependent variable was the percentage of LL choices.

A-CDT. In this task the same 5 and 10 cent rewards were used for the SS and the LL option respectively. The delay for SS was always 2 sec (as in the CDT). Initially, the delay for LL was set to 9 sec and adjusted either up or down at the end of each trial as a function of the choice made in that trial. If the child chose SS the delay to LL was reduced, while if the child chose LL the delay to that reward was increased. The increases or decreases in delay were exponential based on the power of 1.3 but were rounded to an integer. The delay for LL decreased until 1.3^3 (2.2) and increased up to 1.3^{14} (39.4) sec. The task consisted of 80 trials. The dependent variable was the adjusted mean delay for a LL reward, reflecting the point of delay indifference between the SS and LL option. The children completed two sessions of 20 trials under noise and two sessions of 20 trials in the neutral condition.

“Pink Noise”

Standard whole ear headphones were used to deliver 80 dB “pink noise” during the noise sessions. This choice of noise level was made because the same level was previously shown to improve performance of children with ADHD (Söderlund et al., 2007, 2010). “Pink noise” differs from true “white noise” in that the very high frequencies are trimmed to make it less aversive especially at higher intensity levels. The noise level was calibrated regularly throughout the study by using professional sound intensity meters implanted to an artificial head.

Analysis

The statistical analyses was conducted using SPSS statistical software (version 19). The results were analyzed within a single 2 x 2 x 2 ANOVA with noise (“pink noise” versus no noise) and task (CDT vs. A-CDT) as within-subject factors and group (ADHD vs. control) as a between subject factor.

Results

LL preference on the CDT and mean adjusting delay on the A-CDT were strongly correlated ($r = .8$ and $r = .74$ for noise and no-noise conditions respectively). The effect of TIQ and comorbid symptoms (ODD/CD) were explored using correlation analyses, however they were not correlated with performance on either task ($r < .3$ and $p > .05$ for all dependent variables). For the CDT, age correlated with LL preference in the no-noise session ($r = .32$, $p = .02$), however the correlation was not significant for the noise session ($r = .22$, $p = .11$). For the A-CDT, age correlated significantly with the mean adjusting delay in the noise session ($r = .30$, $p = .02$). The correlations for the no-noise session of this task was not significant ($r = .22$, $p = .11$). The inclusion of age as a covariate did not change the results of the analyses presented below.

The summary statistics for task performance can be found in Table 2. The children with ADHD preferred the LL option less than controls ($F(1,51)=8.33$, $p=.006$; effect size Cohen's $d = .79$). There was no effect of noise on LL preference ($F(1,51)=.09$, $p=.77$) and the interaction between group and noise was not significant ($F(1,51)=.07$, $p=.79$). The interaction between group and task approached significance ($F(1,51)=3.55$, $p=.07$) with greater group difference at A-CDT task (the effects sizes were .72 vs .87 for CDT and A-CDT respectively). There was no interaction between noise and task ($F(1,51)=.05$, $p=.82$) and no three way interaction between noise, task and group ($F(1,51)=.89$, $p=.35$).

Discussion

In this study, we used two different tasks to test the extension of the SRD model of ADHD performance proposed by Sonuga-Barke and colleagues (2010): the prediction that impulsive choice (preference for SS over LL) in ADHD would be reduced by increasing arousal during delay by adding “pink noise”. There were a number of findings of note.

First, as seen in many previous studies children with ADHD chose SS over LL options more often than controls (Antrop et al., 2006; Bitsakou et al., 2009; Kuntsi et al., 2001; Marco et al., 2009; Sonuga-Barke et al., 1992; see also Bidwell, Willcutt, Defries, & Pennington, 2007; Scheres et al., 2006; Sjöwall, Roth, Lindqvist, & Thorell, 2012; for negative results) with case control effect sizes similar to those reported in previous reviews (Sonuga-Barke et al., 2008). This finding is consistent with a number of theoretical models. For instance, the Delay Aversion (DAv) model, as recently extended (Marco et al., 2009, Sonuga-Barke et al., 2010), postulates that inefficient neural signaling of delayed rewards in dopamine-modulated neural circuits leads to an impulsive drive for immediate rewards (IDIR), which over time creates negative affect in response to delay-rich settings (Sonuga-Barke et al., 2010). In choice settings, such as those presented in the current study, these two components (i.e., IDIR and delay aversion) produce impulsive choice of SS over LL options (Marco et al., 2009). Because a post-reward delay period was not included in our tasks the relative importance of delay aversion and IDIR could not be estimated. Interestingly, performance on the two tasks was correlated but the effect size in the A-CDT was higher than for the classical CDT. This suggests that the A-CDT will be a useful addition to neuropsychological batteries assessing reward related performance in ADHD.

Second, there was no beneficial effect of adding “pink noise” in the ADHD group in terms of reducing impulsive choice or increasing preference for LL options. This suggests that while in principle the SRD model can explain SS over LL preference as an expression of seeking optimally/acceptably arousing settings (Sonuga-Barke et al., 2010), the current results are not consistent with such an account – adding “pink noise” which should increase arousal levels during delay did not reduce SS preferences. However, it should be noted that the cognitive energetic model (Sanders, 1983) and the SRD model (Sergeant, 2005; van der Meere, 2002) postulate that there are two main energetic factors which influence cognitive

performance: (i) arousal, which is related to stimulus related alertness and (ii) activation, which is related to tonic motor readiness to respond. Hence, it cannot be excluded that SS preference in ADHD may be related to activation instead of arousal, which would imply that children with ADHD try to increase their motor activation to a desirable state by choosing the more frequent stimulus (i.e., SS reward). Future research should evaluate whether or not this is the case.

Third, there are a number of additional implications of this negative result. Several studies have provided robust evidence for the impact of cognitive energetic factors on ADHD-related deficits in information processing tasks as predicted by the SRD model (Chee et al., 1989; Conte et al., 1986; Epstein et al., 2011; Kuntsi, Wood, van der Meere, & Asherson, 2009; Metin et al., 2012; Scheres et al., 2001; van der Meere, et al., 1995, 2009). Findings from electrophysiological studies have also supported the SRD model by showing that children with ADHD have a deficit in adjusting the allocated effort in suboptimal settings (Wiersema, van der Meere, Antrop, & Roeyers, 2006; Wiersema, van der Meere, Roeyers, Van Coster, & Baeyens, 2006). Furthermore it has been shown that “pink noise” itself improve information processing performance in ADHD (Söderlund et al., 2010). Given this, it may be the case that cognitive (i.e., tasks with a major information processing demand) and non-cognitive performance in ADHD (i.e., as in simple reward choice tasks used in the current study) are mediated by different neuropsychological systems – a view consistent with recent models highlighting the pathophysiological heterogeneity in ADHD (Kuntsi et al., 2010; Sonuga-Barke et al., 2010). Arousal regulation mainly involves the noradrenergic system (Berridge & Waterhouse, 2003). The noradrenergic neurons originating from the locus coeruleus are distributed to the entire brain and their activation level determines the arousal state of the organism (Aston-Jones, Rajkowski, & Cohen, 1999). On the other hand, delay discounting is mainly associated with dopamine and serotonin systems (Cardinal, 2006;

Gregorios-Pippas et al., 2009). The ventral striatum, which receives extensive dopaminergic input from the ventral tegmentum, is involved in coding delayed reward. Our findings suggest that these two systems may be independently involved in ADHD pathogenesis. In terms of its impact on reward related choice performance, extrinsic stimulation may need to be of a particular kind to have an effect. For instance, the DAv model, like the SRD model, predicts that environmental stimulation during delay periods should reduce impulsive choice. However, the DAv model specifies a different mechanism (i.e., environmental stimulation increases the perception of the passage of time and so reduces delay aversion) and makes a different prediction (i.e., only so called non-temporal stimulation that is interesting and engaging will reduce impulsive choice). This effect was seen in the study of Antrop and colleagues (2006) where presenting cartoons during delay normalized impulsive response style.

The current study had many strengths but there were also some limitations. First, there was no direct physiological measure of arousal and so we could not confirm that “pink noise” had the predicted effects on arousal. However, previous studies have confirmed such arousing effect of noise by using both behavioral (Davies, 1968) and electrophysiological measures (Hanson et al., 1993). Second, only one level of “pink noise” was used and if there is an inverted-U shaped relationship between noise level and performance, as predicted by certain accounts (Söderlund et al., 2007), it is possible that the noise level was not optimal in this context – either being too low to increase arousal or too high leading to over-arousal. Third, we did not include an alternative noise comparison condition which would allow a direct test of the importance of the non-temporal component of environmental stimuli.

In summary, our results confirm that children with ADHD make more impulsive choices than typically developing children. We did not find any beneficial effect of adding “pink noise” during delay as predicted by models which explain impulsive behavior in ADHD

with impaired regulation of arousal. It is possible that impaired arousal regulation and delay aversion make independent contributions to the neuropsychological spectrum of ADHD.

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Table 1

The characteristics of the ADHD and control group and the scores for comorbid symptoms

Measure	Group	
	ADHD (N = 25)	Control (N = 28)
Age in months ^a	122.1 (14.5)	126.2 (15.9)
Male:Female	22:3	16:12
TIQ ^a	107.4 (10.7)	110.5 (11.3)
ODD ^b		
Mean and SD	12.7 (1.8)	10.7 (.98)
Range ^c	10-16	10-13
CD ^b		
Mean and SD	11.7 (2.3)	11.1 (1.1)
Range ^c	10-19	10-14

Note: ^aMeans and standard deviations (SD), ^bMeasured by Disruptive Behavior Disorders Scale, ^cRange of standard scores, TIQ = total IQ, ODD = Oppositional Defiant Disorder, CD = Conduct Disorder.

Table 2

The performance^a of the ADHD and control group on both tasks.

Measure	Condition	
	Noise	No-Noise
CDT (% LL preference)		
ADHD	44.2 (28.6)	43.2 (25.9)
Control	61.3 (29.9)	64 (30.8)
A-CDT (Mean Adjusting Delay ^b)		
ADHD	12.1 (9.9)	13.2 (9.5)
Control	22 (12.8)	21.4 (12.1)

Note: ^aMeans and standard deviations (SD) for each dependent variable, ^bseconds, CDT = Choice Delay Task, A-CDT = Adjusting Choice Delay Task, LL= Large Later reward.