Attentional blink in adolescents with varying levels of impulsivity

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Abstract

We explore the temporal attention function in a non-clinical sample of adolescents varying in impulsivity, as assessed with the Barratt Impulsiveness Scale. In a Rapid Serial Visual Presentation task, in which two targets (T_1 and T_2) were presented in close temporal proximity among distractors, participants tried to identify T_1 and detect T_2 in one (dual-task) experiment and only to detect T_2 in a second, control (single-task) experiment. The sensitivity of T_2 detection was analyzed using signal detection theory. The attentional blink – the impairment in T_2 detection following the identification of T_1 – was increased in magnitude and protracted in adolescents with high impulsivity, compared with those with low impulsivity. Moreover, a few more participants with high impulsivity appeared to have a blink temporally weighing toward a later time, an observation also made in children with attention deficit hyperactivity disorder (ADHD) in an earlier study. Taken together, these findings suggest impairment in temporal attention in adolescents with high impulsivity. As in ADHD children, a gating deficit may play a central role in this attention impairment. © 2004 Elsevier Ltd. All rights reserved.

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1. Introduction

Impulsivity is an important behavioral construct that has attracted considerable clinical attention (Allen et al., 1998; Askenazy et al., 2003; Barratt et al., 1999; Brady et al., 1998; Cools et al., 2003; Corruble et al., 2003; Corruble et al., 1999; Dougherty et al., 1999a,b; Dougherty et al., 2000; Hoptman et al., 2000; Kashden et al., 1993; Lejoyeux et al., 1998; Mulder et al., 1999; Soloff et al., 2003; Swann et al., 2000; Welch and Fairburn, 1996). Perhaps because of the wide range of behavioral conditions in which impulsivity is involved, current knowledge of the biological or psychological basis of

impulsivity has drawn heavily on studies of psychiatric disorders in which impulsivity is manifested. In particular, as impulsivity is a core behavioral deficit in children with attention deficit hyperactivity disorder (ADHD), a myriad of studies have addressed impulsivity-related issues in this disorder (Babinski et al., 1999; Barkley, 1992; Burns and Walsh, 2002; Bussing et al., 2002; Chhabildas et al., 2001; Gomez, 2003; McKay and Halperin, 2001; Oades et al., 2002; Overtoom et al., 1998; Perchet et al., 2001; Retz et al., 2003; Rubia, 2002; Vitacco and Rogers, 2001).

Laboratory measures of impulsivity have mainly focused on two different but not mutually exclusive dimensions: inability to delay reward, leading to a tendency to choose immediate small rewards over larger delayed ones (Monterosso and Ainslie, 1999; Sagvolden et al., 1998; Solanto et al., 2001; Sonuga-Barke et al., 1992); and inability to withhold inappropriate response, leading to errors of commission on tests that require updating of response strategy based on contextual

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information. In the latter conceptual framework, many studies have reported an increased number of commission error (response to a non-target) in the Continuous Performance Test (CPT), for instance, as a measure of higher impulsivity (Corkum and Siegel, 1993; Dougherty et al., 1999b; Inoue et al., 1998; Klorman et al., 1988; Parasnis et al., 2003), although the specificity of this finding has been questioned in others (Barkley, 1992; Epstein et al., 2003; Thompson and Nichols, 1992; see also Riccio and Reynolds, 2001 for a review). Likewise, increased failures in withholding a response (response despite signal to stop) in a go/no-go or stop-signal task have been suggested to reflect impulsivity in ADHD or other psychiatric disorders (Brown et al., 1989; Dougherty et al., 2003; Horn et al., 2003; LeMarquand et al., 1999; Marinkovic et al., 2000; Oades et al., 2002; Trommer et al., 1991). Within a broader conceptual scheme, increased perseverative error in the Wisconsin Card Sorting Test (i.e., an error made when one continues to sort card according to an earlier rule despite having been told that the rule is incorrect) has been suggested to implicate defective inhibitory function, leading to premature decision and response in the patients (Gansler et al., 1998; Gorenstein et al., 1989; Houghton et al., 1999; Loge et al., 1990; Rapport et al., 2001; Reeve and Schandler, 2001; Wilding et al., 2001). Behavioral paradigms less structured than these neuropsychological tests have also been used to study impulsivity in ADHD. For instance, using a variant of Posner's cuing paradigm, Perchet and colleagues characterized the neurophysiological correlates of attentional shifting (Perchet et al., 2001). It was found that, compared to healthy participants, ADHD children demonstrated more anticipatory errors along with physiological evidence for deficient early perceptual processing. The results were suggested to implicate motor impulsivity in these children. In essence, these neuropsychological studies have looked for an experimental analogue of behavioral impulsivity. They have provided an objective measure of impulsivity and an important first step toward delineating the perceptual, attention and decision processes underlying impulsivity.

Here we adopt a slightly different approach to examine impulsivity in this study. We examine whether impulsivity is a consequence of impaired cognitive function; specifically, whether it is correlated with a deficit in temporal attention in the first place. One could hypothesize that defective temporal attention lead to inefficient and strenuous processing of information and individuals may have learned to adapt to this difficulty by moving attention away from the current task before channeling processed information for adequate actions. This premature switch from one cognitive agenda to another may thus manifest as behavioral impulsivity. We explore this issue in a non-clinical sample of adolescents by

examining whether there is a correlation between self-reported impulsivity as assessed by the Barratt Impulsiveness Scale (BIS, Patton et al., 1995) and temporal attention function, as demonstrated in a rapid serial visual presentation (RSVP) paradigm.

The RSVP task has been used extensively in the literature to explore the temporal characteristics of information processing (Broadbent and Broadbent, 1987; Chun and Potter, 1995; Raymond et al., 1992; Reeves and Sperling, 1986; Shapiro et al., 1994; Ward and Duncan, 1996; Weichselgartner and Sperling, 1987; see also Shapiro et al., 1997 for a review) and, more recently, to examine attention deficits in people with neurological and psychiatric disturbances (Hollingsworth et al., 2001; Husain et al., 1997; Li et al., 2002; Li et al., 2004; Rizzo et al., 2001; Rokke et al., 2002). Fig. 1 illustrates a typical example of this behavioral paradigm, in which a series of stimuli are presented in rapid succession and the

Fig. 1. A typical RSVP paradigm and attentional blink. (a) Single-target task. A stream of characters appears rapidly one after another. The participant's task is to identify whether there is an "X" in the stream. (b) Dual-target task. The visual display is exactly the same as in the single-target task. The participant has to identify the character that appears brighter than the others (T₁, an "S" in this case) and then detect whether there is an "X" (T₂) in the characters that follow T₁. (c) Attentional blink. The detection rate of "X" in the single-target (filled circles) and dual-target (open circles) task is plotted with respect to the time "lag" between T₁ and "X". Characteristically, the detection rate of "X" in the dual-target task drops for a period of several hundred mseconds after the identification of T₁, compared to that in the single-target task.

participants are required to identify either one (control experiment) or two targets. In this example task the participants have to discriminate the first target and detect the presence of a specified character, X, under the dual-task condition. In the control, single-task condition, the participant is required only to detect the character X. One can vary the task difficulty by adjusting the duration of presentation of the visual stimulus and by manipulating the physical similarity between the target and the distractors. With these parameters appropriately set, we are able to examine how attention and processing resources are temporally allocated to effectively deal with the rapidly changing inputs, by comparing the respective performances of the participants for each of the two task conditions.

Characteristically, when the participants are required to identify two targets (as compared to one target), an attentional “blink” in the processing of the second target or T_2 is observed for a few hundred milliseconds after the identification of the first target or T_1 (Raymond et al., 1992; Fig. 1(c)). Two recent studies have employed this technique to examine the attention deficit in patients with ADHD (Hollingsworth et al., 2001; Li et al., 2004). Compared to healthy participants, the patients exhibited a deeper and wider attentional blink; namely, the blink is greater in magnitude and temporally more extended. Interestingly, some ADHD children appeared to have a blink quite normal in magnitude but temporally displaced toward a later time, a result that can be explained by a gating model of temporal attention (Li et al., 2004). The primary goal of the current study is thus to demonstrate whether similar observations could be extended to a non-clinical sample of adolescents with higher level of impulsivity.

2. Methods

2.1. Participants

Written consent was obtained from all of the participants after the nature and the procedures of the study were explained in details, in strict accordance to the institute guidelines. Six hundred and sixty-two adolescents (325 males, 337 females; ages 15–17 years) from the Ho-Ping High School of the Taipei city completed screening with a Chinese version of the Barratt Impulsiveness Scale version 11 (BIS-11, Patton et al., 1995), the Maudsley Obsessive Compulsive Inventory (Hodgson and Rachman, 1977), the Buss-Perry Aggression Questionnaire (Buss and Perry, 1992) and the Children's Depression Inventory (Kovacs, 1985). The detailed psychometric properties of the Chinese versions of these scales will be presented in a separate work. The BIS-11 is a 30-item self-report questionnaire designed to measure impulsivity. All items are measured on a 4-point

scale (1 = rarely/never; 2 = occasionally; 3 = often; 4 = almost always/always). The total score thus ranges from 30 to 120, with a higher score indicating higher impulsivity. Eleven of the 30 items are scored in a reverse order to avoid response bias. The BIS-11 has been translated into Italian and Japanese with good internal consistency and test–retest reliability (Fossati et al., 2001; Someya et al., 2001). The Chinese version employed in the current study also demonstrated good internal consistency with a Cronbach's α of 0.81.

Screening was conducted over a period of two hours on a school day with the permission of the school authority. The total impulsivity score of all 662 participants ranged from 47 to 108 (mean $\pm$ standard deviation: 72.5 ± 8.7) and appeared to follow a normal distribution (Fig. 2). We developed a selection sequence of the subjects based on their impulsivity score and gender and planned to recruit 32 subjects (16 males and 16 females) each with the lowest, intermediate and highest impulsivity score to further take part in the attentional blink study. For a variety of personal reasons, many of them declined to participate. Toward the end of the study period, we had 20 (9 males, 17.0 ± 1.2 years; 11 females, 17.2 ± 0.9 years), 31 (14 males, 16.2 ± 1.7 years; 17 females, 16.3 ± 1.4 years) and 18 (8 males, 16.5 ± 1.5 years; 10 females, 17.3 ± 0.5 years) of the children with low (mean $\pm$ standard deviation: 56.8 ± 3.1), intermediate (72.4 ± 1.1) and high (91.6 ± 4.1) impulsivity scores, respectively, who completed the behavioral task. There is no difference in age or gender composition between the three groups. Fifteen of the 20 subjects in the low impulsivity group had their total impulsivity score one and a half standard deviations lower than the average, and all of them in the high impulsivity group had a total score two standard deviations above the average. All of the participants had normal or corrected-to-normal vision. They also denied ever having seizure, brain injury, or been seen by a psychiatrist.

Fig. 2. The distribution of the total BIS-11 score of our 662 subjects. The total impulsivity score was binned every five points.

The testing took place in an interview room at the Department of Psychology, National Taiwan University. Although the room was not sound proof, the setting was quiet and free of interruptions. Only the participant and the person who administered the test were allowed in the room. The test was in most cases conducted on a weekend or a holiday and any time during the day.

(a) ㄅ, ㄆ, ㄇ, ㄏ, ㄎ, ㄌ, ㄍ, ㄗ, ㄘ, ㄙ, ㄨ, ㄩ, ㄣ, ㄤ,
ㄛ, ㄜ, ㄝ, ㄞ, ㄟ, ㄠ, ㄡ, ㄢ, ㄣ, ㄤ, ㄥ, ㄦ, ㄧ,

own pace by pressing appropriate keys on the keyboard at the end of each trial. The XLC appeared in half of the trials pseudorandomly at one of the six serial positions ("lags") following the number, with each position repeated 20 times in an experiment. In a second, control, experiment (single-task condition), participants were instructed to ignore the number and only to detect the XLC. They thus answered only one question in the single-task condition. The visual stimuli and test settings were otherwise the same in the two task conditions. Participants pressed the space bar to initiate a trial at their own pace and took approximately 80 min to complete the test.

The detection sensitivity for the XLC was computed for each time lag using receiver operating characteristic (ROC) analysis based on signal detection theory (Macmillan and Creelman, 1991). Because the boundary between response categories (“1” for absolutely sure and “2” for relatively confident, for instance) was not clear-cut and the data set we collected for each subject was relatively small, we employed the algorithm developed by Metz and Pan to properly estimate the ROC curves (Metz and Pan, 1999; http://www-radiology.uchicago.edu/krl/KRL_ROC/ROC_analysis_by_topic.htm#PROPROC). A deterioration of the detection sensitivity of XLC in the dual-task compared to the single-task condition has been termed an “attentional blink” (Raymond et al., 1992). The attentional blink was thus a measure of how the performance in detecting the second target had been affected by the additional task of having to identify the first target. The attentional blink could be quantified on two aspects: overall magnitude and temporal profile. The former was derived by summing up the decrease in detection sensitivity at each individual time lag and the latter represented the pattern of altered sensitivity over a time period of 600 ms examined in the current study.

3.1. General Performance in the RSVP task

The three groups correctly identified the number (T_1) in $90.9 \pm 5.9\%$ (mean $\pm$ standard deviation, low impulsivity), $89.5 \pm 5.6\%$ (intermediate impulsivity), and $87.7 \pm 7.3\%$ (high impulsivity) of the trials, which were not statistically different ($F_{2,66} = 1.345$, $p = 0.268$, one-way ANOVA). Post hoc comparisons showed no difference between any two groups, either. This result suggested all three groups of participants were adequately engaged in this attention task, which made it possible to compare their performance in the identification of T_2 between single- and dual-task conditions (i.e., attentional blink). We also computed response bias (in units of root-mean-squared standard deviation, with a

negative value indicating a positive bias) for each participant (Macmillan and Creelman, 1991). A response-bias index is to measure the subject's willingness to say "yes"; i.e., to say that they are (very) confident that there is an X-like character following T_1 . A response-bias index is therefore a monotonic function of both the hit and false-alarm and can be formulated based on different bias statistics (Macmillan and Creelman, 1991). The results showed that the response bias did not differ between the three groups (mean $\pm$ standard deviation: -0.32 ± 0.45 , low impulsivity; -0.23 ± 0.51 , intermediate impulsivity; -0.09 ± 0.43 , high impulsivity; $F_{2,66} = 1.163$, $p = 0.319$, one-way ANOVA)

3.2. Attentional blink

Fig. 4 plots the T_2 detection sensitivity across the 6 time lags both for the single- and dual-task conditions. We derived for all three groups of participants the attentional blink by subtracting the sensitivity in the dual-task condition from that in the single-task condition. The results from a repeated measures ANOVA with time lag as the within-subject variable and group as the between-subject variable showed that the three groups differed in the magnitude of attentional blink ($F_{2,66} = 4.251$, $p = 0.018$, group main effect). The group $\times$ lag interaction was not significant ($F_{8,5,281.5} = 1.361$, $p = 0.209$, Greenhouse–Geisser correction), suggesting that the difference between groups did not vary with time lag. Post hoc comparisons show that there was a group main effect between the high and low impulsivity groups ($F_{1,36} = 9.606$, $p = 0.004$), with group $\times$ lag interaction approaching statistical significance ($F_{3,8,136.6} = 2.143$, $p = 0.082$, Greenhouse–Geisser correction). On the other hand, there was no difference between the high and intermediate impulsivity groups either in main effect ($F_{1,47} = 2.323$, $p = 0.134$) or in group $\times$ lag interaction ($F_{4,2,197.1} = 1.447$, $p = 0.218$, Greenhouse–Geisser correction) and between the intermediate and low impulsivity groups

either in main effect ($F_{1,49} = 2.806$, $p = 0.100$) or in group $\times$ lag interaction ($F_{3,4,168.5} = 0.405$, $p = 0.776$, Greenhouse–Geisser correction). Overall, these results showed that the magnitude of attentional blink appeared to increase in participants with higher impulsivity score. Also, the difference in the blink magnitude might vary with time lag when high and low impulsivity groups were compared.

Despite the relatively small sample size, we explored if there was a gender effect on attentional blink. A repeated measures ANOVA with time lag as the within-subject variable and group and gender as the between-subject variables showed that the group effect was significant ($F_{2,63} = 3.849$, $p = 0.026$), but not gender ($F_{1,63} = 1.377$, $p = 0.245$) or any of the two-way or the three-way interactions. Another repeated measures ANOVA limited to the data set with only high and low impulsivity subjects revealed essentially the same results, showing significant group effect ($F_{1,34} = 9.217$, $p = 0.005$) but not significant gender ($F_{1,34} = 2.905$, $p = 0.097$) or interaction effects.

We examined the temporal profile of attentional blink in each individual participant. While the majority of participants had a blink that peaked at earlier time lags, some (particularly those in the high impulsivity group) had the blink weighing toward later time lags. To quantify this observation, we computed for each individual participant the magnitude of the blink for an early time period, comprising lag-1 to lag-3, and a late time period comprising lag-4 to lag-6. A participant was considered to be an "early blinker" if there was a larger decrease in the detection sensitivity in the early time period and a "late blinker" if the reverse applied. The results showed that there were 17 and 3 early and late blinkers in the low impulsivity group, 25 early and 6 late blinkers in the intermediate impulsivity group, and 11 early and 7 late blinkers in the high impulsivity group. We examined for a difference in this frequency measure between groups in a hierarchical log-linear model with the group and blink period (early and late) as categorical variables. The results showed that there

Fig. 4. T_2 detection sensitivity in low (a), intermediate (b) and high (c) impulsivity group. Data are presented separately for the one-target (circle) and two-target (triangle) task and for each time lag. Each data point represents an average across all participants in the group. High-impulsivity participants demonstrate a blink larger in magnitude and protracted than the low-impulsivity participants. Please see text for statistics.

was a significant blink period main effect (partial $\chi^2 = 20.921$, $p < 0.000$), suggesting that there were overall more early blinkers. However, the group $\times$ blink period interaction was not significant (partial $\chi^2 = 3.305$, $p = 0.192$), suggesting that there was no difference in blink patterns among the three groups of participants.

4. Discussion

A number of models have been proposed to explain attentional blink and they share common characteristics (Chun and Potter, 1995; Shapiro et al., 1997). According to a two-stage model, the attentional blink is the result of a limited-capacity second stage in which targets detected in the first stage are processed and consolidated serially (Chun and Potter, 1995). When the duration of this limited-capacity processing of T_1 exceeds the stimulus onset asynchrony between T_1 and T_2 , interference with the processing of T_2 occurs. This deficit suggests an intrinsic limitation of our central nervous system to deal with rapidly changing stimuli, highlighting the serial aspect of attentional function. An increased and protracted attentional blink thus suggests a less efficient processing mechanism in our subjects with high impulsivity when they have to deal with rapidly changing inputs. Moreover, more high impulsivity subjects have an attentional blink temporally displaced toward later time lags, compared to other participants. Overall, these results are similar to those obtained in children with ADHD in an earlier study (Li et al., 2004). This finding perhaps is not surprising given that impulsivity is a core behavioral deficit in children with ADHD.

To account for these findings, we have proposed an attention-gating model, in which a gate controls the flow of information from a perceptual buffer to a level where the cognitive processing required for target detection and identification takes place (Li et al., 2004). Since processing capacity is limited, attention gating facilitates perceptual and cognitive processing by allowing only an adequate amount of information to access this level at a given time. In this conceptual framework, a deficit or blink occurs when the processing resources are not available or when incoming stimuli saturate those processing resources. An attentional blink occurs also when the temporal mechanism of gating is altered. As in the ADHD children, high-impulsivity subjects of the current study appear to have a slower dynamics of gating, with more stimuli flowing in the second stage of processing. As a result, those subjects without adequate resources to process the extra “bits” of information would demonstrate a deeper and wider blink. On the other hand, those with more resources would be able to process the additional information and demonstrate not just lag-1, but also lag-2 or perhaps even lag-3, sparing. As a result, they would demonstrate a blink with a rela-

tively normal magnitude but temporally displaced toward later time lags. Therefore, when compared to those with low impulsivity, high-impulsivity subjects as a group showcase a profile of attentional blink displaced toward a later time.

The relationship between behavioral impulsivity and attention function has mostly been examined in terms of the performance of ADHD children in the CPT (see Barkley, 1992; Corkum and Siegel, 1993; for reviews). A recent study attempted to ascertain the specificity of sustained attention deficits in CPT in children with ADHD (Swaab-Barneveld et al., 2000). The results showed that sustained attention deficit was to a certain extent common to children with a variety of different psychiatric disorders. These sustained attention tests are thus sensitive but lacking in specificity in relation to ADHD participants (Riccio and Reynolds, 2001). The current study examines the relationship between impulsivity and attention function from a slightly different perspective. Our RSVP task concentrates on temporal control in attentional processing within a relatively short time scale. This paradigm thus explores a more restrictive aspect of attention function, compared to the CPTs and our results indexed a deficit in temporal attention in high-impulsivity individuals. It is important to note that the deeper and wider attentional blink as is observed in high-impulsivity subjects has also been observed in patients with dyslexia, with schizophrenia, and with depression, as well as in patients with focal brain lesions (Hari et al., 1999; Husain et al., 1997; Li et al., 2002; Li and Lin, unpublished results; Rizzo et al., 2001; Rokke et al., 2002). An increased attentional blink is thus not a finding specific to high impulsivity; instead, it may simply reflect limited processing capacity, which could occur in a variety of CNS conditions. On the other hand, our preliminary results on the altered temporal profile in attention blink in high-impulsivity subjects suggest that temporal dynamics is an important aspect of attention function that deserves further investigation.

There are a few important limitations in the current study. First, our subjects did not undergo a formal neurological or psychiatric examination; nor did they receive an IQ test or any other neuropsychological assessments. An IQ score would have been an important factor to examine in evaluating the current results. It is particularly relevant in view of the attention gating model, since an IQ score would have been a useful indicator of general processing resources in each individual subject. Likewise, we did not drug-screen or obtain a complete medication history of our subjects. We could thus not rule out the possibility that impaired performance in the high impulsivity subjects resulted from their use of medication or illicit substances. Finally, the small sample size has greatly limited the statistical power of the current study. Further work with a larger number of subjects will be required to replicate the current find-

ings and to examine whether the temporal profile of attentional blink indeed differs between high and low impulsivity subjects and whether gender plays a role in determining these results.

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