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BRIEF REPORT

Voluntary and involuntary attention vary as a function of impulsivity

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Abstract In the present study we examined, first, whether voluntary and involuntary attention manifest differently in people who differ in impulsivity (measured with the Barratt Impulsivity Scale). For Experiment 1, we used the spatial cueing task with informative and noninformative spatial cues to probe voluntary and involuntary attention, respectively. We found that participants with high impulsivity scores exhibited larger involuntary attention effects, whereas participants with low impulsivity scores exhibited larger voluntary attention effects. For Experiment 2, we used the correlated-flanker task to determine whether the differences between groups in Experiment 1 were due to high-impulsive participants being less sensitive to the display contingencies or to high-impulsive participants having a greater spread of spatial attention. Surprisingly, high-impulsive participants showed a greater sensitivity to contingencies in the environment (correlated-flanker effect). Our results illustrate one situation in which involuntary attention associated with high impulsivity can play a useful role.

Keywords Spatial attention · Individual differences · Impulsivity · Voluntary attention · Involuntary attention

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Trait impulsivity has been shown to influence a range of psychological processes, including decision-making, career and social success, eating behavior, driving, and psychopathology (Dickman, 1993; Evenden, 1999). It has also been linked to attention in various tasks, including the stop-signal paradigm (Logan, Schachar, & Tannock, 1997), the attentional blink (Li, Chen, Lin, & Yang, 2005), and working memory tasks (Cools, Sheridan, Jacobs, & D'Esposito, 2007). These studies revealed performance deficits in participants with high trait impulsivity. In the experiments presented here, we probed different types of attention using two paradigms and found that both performance benefits and costs are associated with impulsivity. In addition, in the second experiment we tested two accounts that provide mechanisms for the differences we found between high- and low-impulsive participants on attention tasks.

Experiment 1

Spatial attention refers to the ability to select and prioritize parts of the environment for processing while ignoring others. Voluntary attention is the type of attention that is goal-directed and determined by the relevant task at hand. Involuntary capture of attention results when stimuli are selected due to saliency rather than to task relevance (Jonides, 1981). In Experiment 1, voluntary and involuntary attention were investigated using the spatial-cueing paradigm shown in Fig. 1.

We varied voluntary and involuntary attention in separate blocks by varying the proportions of trials on which the target appeared in the cued location. In the involuntary-attention condition, the target location was random with respect to the cue location. To investigate voluntary attention, in separate blocks, the cue was made predictive of the

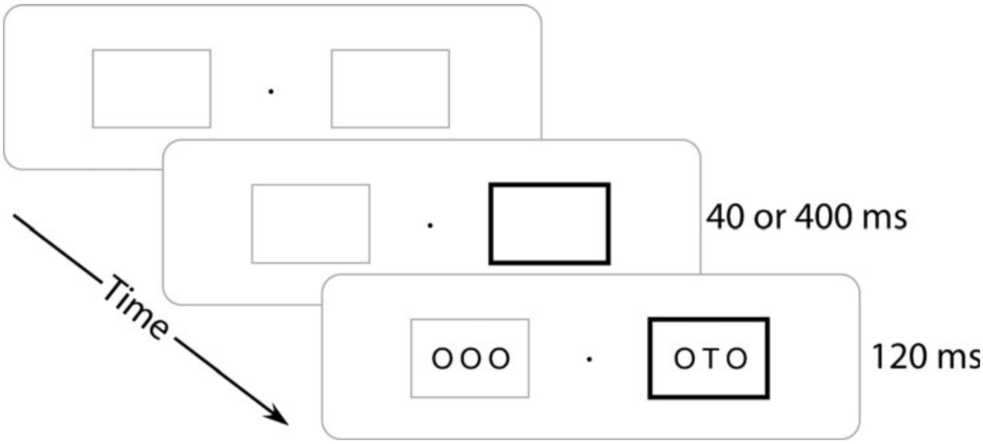

Fig. 1 Sequence of events within a trial. The rectangles indicate possible target locations, and the thick rectangle represents a peripheral cue. Target stimuli were either Fs or Ts, flanked by Os on either side. The cues and targets are drawn to scale

target location. The difference between predictive and nonpredictive cues indicates the contribution of voluntary attention.

To further separate voluntary and involuntary attention, we also varied the cue–target interval (also referred to as the *stimulus onset asynchrony* [SOA]). Involuntary attention is known to be transient (Posner, Cohen, & Rafal, 1982; Posner, Snyder, & Davidson, 1980), and the cueing effect disappears as SOA increases. In contrast, voluntary-attention effects are observed for longer SOAs and can be sustained (e.g., Wright & Richard, 2000).

Both predictive cues (voluntary attention) and nonpredictive cues (involuntary attention) have the same general behavioral effect: faster RTs for targets in the cued than in the uncued location. However, previous studies using similar designs have reported behavioral differences between voluntary and involuntary attention (e.g., Prinzmetal, McCool, & Park, 2005; Prinzmetal, Park, & Garrett, 2005), as well as differences in neural activity, measured using fMRI (Esterman et al., 2008) and EEG (Landau, Esterman, Robertson, Bentin, & Prinzmetal, 2007).

The goal of Experiment 1 was to determine whether individual differences in impulsivity, as measured by the Barratt Impulsivity Scale (BIS-11; Patton, Stanford, & Barratt, 1995), would be reflected in measures of voluntary and involuntary attention. We predicted that high-impulsive individuals would show greater involuntary attention effects than would low-impulsive individuals, whereas low-impulsive individuals would show greater voluntary attention effects than would high-impulsive individuals.

Method

Participants The total sample included 48 participants (33 female, 15 male), 17–31 years of age. Two recruitment strategies were employed: Twenty of the participants were recruited from the University of California, Berkeley, Research Participation Program, and the remaining volunteers were selected on the basis of a prescreening test (BIS-11) administered to this subject pool, from which we recruited those whose BIS scores were one or more standard deviations away from the mean, allowing for a wide range of scores.

Procedure The sequence of events within a trial is shown in Fig. 1. Half of the participants began with the nonpredictive-cue condition, and half with the predictive-cue condition. In the nonpredictive-cue condition, the cue location was random with respect to the target location. This condition consisted of four blocks of 80 trials per block. In the predictive-cue condition, the target appeared in the cued location on 80 % of the trials, and there were six blocks of 80 trials. In addition to manipulating trial probability, we utilized differences in the time courses of voluntary and involuntary attention to probe the two types of attention. Half of the blocks had a cue–target SOA of 40 ms, while the remaining blocks had a cue–target SOA of 400 ms. The order of the SOA conditions was counterbalanced between participants. Each attention condition (predictive or nonpredictive cues) began with at least one block of practice at the SOA that would be used for the first data block. Before the predictive blocks, participants were told that the location of the cue was predictive of the target location and that they should attend to it. In the nonpredictive blocks, participants were told that the cue location was random with respect to the target location and that they should ignore it.

Participants responded verbally to the targets by naming the target letter (F or T) into a microphone that triggered a voice-operated relay and that recorded reaction times (RTs). The experimenter manually recorded the verbal response. The experimenter also monitored eye movements with a video camera, as described in Prinzmetal, McCool et al. (2005) and Prinzmetal, Park et al. (2005). Participants received negative feedback for incorrect responses and for breaks of fixation at the end of the trial. The percent correct and the mean RT were displayed to the participant at the end of each block.

Stimuli The stimuli were presented on a 15-in. monitor at a viewing distance of 48 cm. This distance was held constant with a chinrest. The centers of the squares were 6.4 deg of visual angle from the fixation point. The letters were in 36-point Helvetica font; the monitor background was white, and the fixation point, target letters, and cue were black. The placeholder boxes were one-pixel wide and gray and were easily visible to all participants. The cue box was three pixels wide and black.

Results and discussion

The BIS-11 scores averaged 65.7 (*SD* = 13.5) and ranged from 41 to 93. Thus, the group of participants included a wide range of BIS-11 scores. We performed a median split of the participants, classifying them into high (mean = 77.2) and low (mean = 54.2) impulsivity groups. All trials containing eye movements or incorrect responses and trials with RTs below 100 ms or above 2,000 ms were removed from further analysis (1.6 % of trials).

The average RTs for correct trials are presented in Table 1. We conducted an analysis of variance (ANOVA) that included Group (high or low impulsive) as a between-subjects factor and Cue Predictability (predictive or nonpredictive), SOA (40 or 400 ms), and Trial Type (cued or uncued) as within-subjects factors.

There was a significant main effect of trial type, but not of group or cue predictability. Specifically, participants responded more quickly when targets appeared in the cued location rather than in the uncued location [$F(1, 46) = 95.65$, $p < .01$]. The cueing effect was larger when the cue was predictive [Trial Type × Cue Predictability: $F(1, 46) = 25.27$, $p < .01$], indicating, as expected, that when the cue is nonpredictive, the results only reflect involuntary attention, whereas when the cue is predictive, both voluntary and involuntary attention are engaged. The cueing effect was larger with predictive cues at the long SOA, but larger with nonpredictive cues at the short SOA (Trial Type × Cue Predictability × SOA), but this difference did not reach statistical significance [$F(1, 46) = 3.95$, $p = .053$]. This trend reflects the general finding that the effects of involuntary attention are larger for short SOAs and that the effects of voluntary attention are larger for longer SOAs (see, e.g., Warner, Juola, & Koshino, 1990).

Table 1 Raw reaction time results from Experiment 1

	SOA 40 ms		SOA 400 ms	
Impulsivity	Cued	Uncued	Cued	Uncued
Predictive Cue				
High	706	723	712	746
Low	686	727	682	725
Nonpredictive Cue				
High	701	724	735	739
Low	695	699	701	713

There was a significant three-way interaction involving impulsivity (Group). To illustrate this, we computed the cueing effect as uncued RT – cued RT (see Fig. 2). When the cue was predictive (voluntary attention), the cueing effect was 25 versus 42 ms for the high and low impulsivity groups, respectively. When the cue was nonpredictive (involuntary attention), the pattern reversed, 14 versus 8 ms for the high and low impulsivity groups, respectively. Thus, high-impulsive participants demonstrated more involuntary attention than did low-impulsive participants, and low-impulsive participants had more voluntary attention than did high-impulsive participants.

Importantly, there was a significant four-way interaction of impulsivity, cue predictability, SOA, and trial type, $F(1, 46) = 7.50$, $p < .01$. To understand this interaction, we performed separate ANOVAs for the predictive and nonpredictive cue blocks.

For the predictive blocks, we found significant effects of trial type [$F(1, 46) = 78.45$, $p < .01$] and an interaction of group and trial type [$F(1, 46) = 4.97$, $p < .05$]. Specifically, the low-impulsive participants showed a larger cueing effect than did the high-impulsive participants for predictive-cue blocks. Interestingly, not only do low-impulsive participants utilize the information in the predictive cue more than high-impulsive participants do, but they do so in as little as 40 ms. There is precedent for fast switches in voluntary attention: Warner et al. (1990) found that with practice, participants could switch their voluntary attention to the location opposite the cue in under 50 ms. Thus, our low-impulsive group responded like highly practiced participants.

For the nonpredictive blocks, we found a significant Trial Type × SOA × Group interaction, $F(1, 46) = 4.97$, $p < .05$. As predicted, the high- and low-impulsive participants differed mostly at the short SOA, at which the effects of involuntary attention were greatest (Fig. 2). Note that the increased cueing effect in this condition was driven primarily by the RTs for the uncued trials. Specifically, high-impulsive participants had longer RTs for uncued trials, suggesting that they were more distracted by the cue (Table 1). In addition to suggesting that high-impulsive participants have greater involuntary attention, these data suggest that these participants are mostly distracted by nonpredictive information rather than also showing attentional capture benefits. This conclusion is

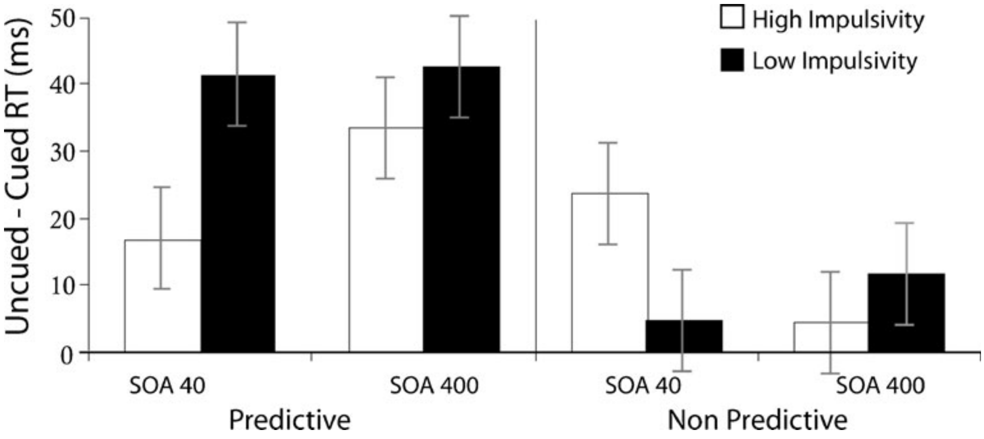

Fig. 2 Cueing effects as a function of group, cue predictability, and SOA. The error bars in the figure are calculated from the highest-order interaction, as specified by Loftus and Masson (1994) for a mixed design

tentative, due to the fact that the present design did not have a neutral cue with which we could assess whether the longer uncued RTs were indeed costs (as opposed to the faster cued RTs being benefits). In addition, Experiment 2 presents a design in which the scope of involuntary attention and its implications, costs or benefits, are more directly assessed.

We also performed a correlational analysis with BIS-11 as a continuous variable. For the nonpredictive session, BIS-11 scores correlated positively with the cueing effect, $r = .199$. For the predictive session, BIS-11 scores correlated negatively with the cueing effect, $r = -.260$. These correlations are significantly different, $z = 2.21$, $p < .05$.

Although the high- and low-impulsive participants displayed different patterns of cueing effects, there was no overall difference in RTs between the two groups of participants, $F(1, 46) = 0.489$, n.s. Overall, the participants were quite accurate (97.6 %) in reporting the identity of the target (T or F), and the only significant effect on accuracy was trial type, $F(1, 46) = 7.77$, $p < .01$; participants were slightly more accurate when the target was in the cued location (98.1 %) rather than the uncued location (97.0 %).

We found that low-impulsive participants have more voluntary attention, and high-impulsive participants have more involuntary attention. There are at least two possible accounts of these findings. According to a *probability-learning* account, low-impulsive participants may be more sensitive to the information carried by the cues. Therefore, if the cue was predictive, they more efficiently utilized it (and if it was nonpredictive, more efficiently ignored it) than did the high-impulsive participants. Alternatively, according to a *spatial-distribution* account, the impulsivity groups might differ in their abilities to restrict attention to a certain location and to avoid locations deemed irrelevant. Hence, low-impulsive participants may be better at honing in on a relevant location while filtering out irrelevant locations. High-impulsive participant may operate with a broader distribution of attention.

Experiment 2

Experiment 2 was designed to examine the probability-learning and distribution-of-spatial-attention accounts using the correlated flanker paradigm (Carlson & Flowers, 1996; Miller, 1987). The targets were always at fixation and were surrounded by symbols. Unbeknownst to the participants, certain symbols were correlated with certain targets. The probability learning and spatial distribution accounts make opposite predictions with respect to impulsivity. According to the *probability-learning* account, low-impulsive participants should have greater flanker effects, as compared to high-impulsive participants. According to the *spatial-distribution* account, low-impulsive participants should show smaller flanker effects, given that the "cues" (correlated flankers) are implicit and are placed outside the relevant target location.

We followed the procedure of Carlson and Flowers (1996) closely. Participants responded with a buttonpress whether the target was a letter (ABCDEFGH) or a digit (23456789). The targets were surrounded by two identical flankers, which participants were told to ignore. The flankers were the symbols "*," "@," and "#." There was a correlation between the identity of the flanker and the target class, such that one flanker predicted a letter target, another predicted a digit target, and one was neutral with respect to target identity. However, participants were not told of this correlation, but were only told to ignore the flankers. There were two assignments of flankers to categories, shown in Table 2. Half of the participants had each flanker assignment. Thus, for the participants with Assignment 1, if the flanker was a "*," the target was a letter with high probability and a number with low probability. We termed trials in which the flanker was correlated with the target *consistent* trials. Likewise, trials in which the flanker was accompanied by the opposite target were termed *inconsistent* trials. In addition, neutral trials, in which the flanker was not associated with either of these classes, were included (always a "#" flanker).

Table 2 Assignment groups based on flanker–target probabilities in Experiment 2

	Assignment 1			Assignment 2		
	*	@	#	*	@	#
Letter	66.6 %	8.3 %	25.0 %	8.3 %	66.6 %	25.0 %
Digit	8.3 %	66.6 %	25.0 %	66.6 %	8.3 %	25.0 %

Previous investigators (Carlson & Flowers, 1996; Miller, 1987) had found that participants were faster on consistent trials and slower on inconsistent trials (*correlated-flanker effect*). Interestingly, postexperimental questionnaires revealed that the majority of participants were unaware of the probability manipulation. Furthermore, the magnitude of the correlated-flanker effect was unrelated to awareness of the correlated nature of the stimuli. Finally, informing participants of the correlation did not influence the magnitude of the correlated-flanker effect.

Method

A total of 50 participants were recruited. They were randomly placed in one of the assignment groups (see Table 2). The task was to identify the central target as a number or a letter and to respond by pressing a button.

The stimuli were presented in 28-point Times font in the center of the monitor described in Experiment 1. The three characters were presented with one space between characters and in a rectangle that subtended 0.8 deg high and 3.4 deg wide. The rectangle was always in view. On each trial, the target and flankers were in view until the observer responded.

Each participant engaged in one block of 32 practice trials and six blocks of 64 trials on which data were collected. Accuracy feedback was given as before. After task completion, the participants were given two questionnaires. The first was to assess their awareness of the correlation between the flankers and targets. They were asked to estimate (1) when the target was a letter, on what percentage of trials it was flanked by a "*," "@," or "#," and (2) when the target was a number, on what percentage of trials it was flanked by a "*," "@," or "#." For each participant, we calculated the correlation of the participant's response with the actual percentage of each kind of trial. Following the awareness correlation, the participants took the Barrett Impulsivity Scale.

Results and discussion

Correct RTs were analyzed as in Experiment 1, with Flanker Condition and Impulsivity (median split = 60) as factors. As is shown in Fig. 3, there was a significant difference between the consistent, neutral, and inconsistent flanker conditions [$F(2, 96) = 20.96$, $p < .01$]. Unlike in Experiment 1, high-impulsive participants were slower than low-impulsive participants [$F(1, 48) = 9.88$, $p < .05$]. The difference between flanker conditions significantly interacted with impulsivity [$F(2, 96) = 3.21$, $p < .05$].

To further examine the flanker effect, for each participant we calculated a flanker effect index, as follows: inconsistent RT – consistent RT. This difference was about twice as large for the high- as for the low-impulsive participants (33.5 vs. 15.6 ms), $t(48) = 2.21$, $p < .01$ (one-tailed). Furthermore, we found a positive correlation between BIS-11 (as a continuous variable) and the flanker effect index, $r = .23$, $p = .054$. Thus, high-impulsive participants were influenced by the flanker to a greater extent than were the low-impulsive participants.

As reported above, the two impulsivity groups differed in overall RTs: High-impulsive participants had longer RTs than did the participants with low impulsivity scores. One should be cautious in interpreting the interaction with the Impulsivity Group factor, given these overall differences (see Loftus, 1978). For instance, the interaction may represent a floor on RTs for low-impulsive participants. Hence, these participants might not be able to show as much of a difference as high-impulsive participants; slower participants typically have a greater variance of RTs than do faster participants. To address this issue, we applied a normalization transformation on the data using the neutral condition. We divided both the consistent and the inconsistent RT performance by the RT for the neutral condition for each participant. We then subjected the normalized values to an ANOVA with Flanker Type (consistent, inconsistent) as a within-subjects factor and Impulsivity (high, low) as a between-subjects factor. This analysis revealed a significant main effect of flanker type [$F(1, 48) = 38.8$, $p < .001$]:

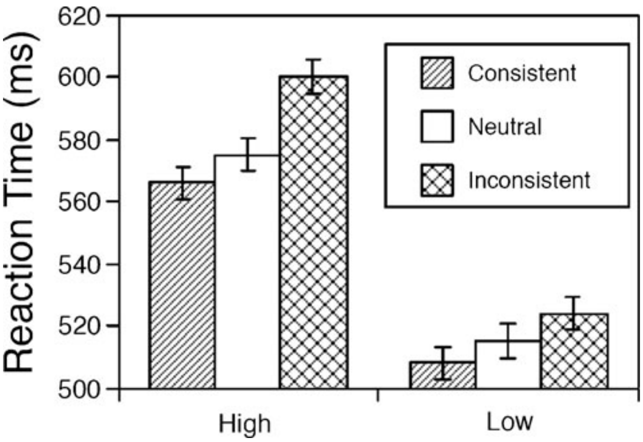

Fig. 3 Results from Experiment 2 for the high and low impulsivity groups. Error bars are calculated as in Fig. 2

Participants were faster in the consistent than in the inconsistent condition (flanker effect). In addition, there was a Group × Flanker Type interaction [$F(1, 48) = 4.64, p < .05$]: High-impulsive participants had a larger flanker effect than did low-impulsive participants. As expected, normalization of the data eliminated the difference between the impulsivity groups [$F(1, 48) = 1.168, p = .28$]. Similarly, a Mann–Whitney test and an analysis on the inverse of the RTs (Ratcliff, 1993) provided further evidence that the differences in the flanker effect were unlikely to be the result of overall RT differences between the groups.[1]

To determine whether participants were aware of the flanker–probability relation, we administered a questionnaire on which participants estimated the percentages of letter and digit trials in which the letter or digit was flanked by each of the three symbols (see the Method section). We then correlated their responses with the actual percentages of trials. The average correlation was $r(48) = .12$ and was not significantly different from 0 ($p > .2$). As in previous studies (Carlson & Flowers, 1996; Miller, 1987), participants had little idea of the correlation between the flankers and the targets. Using our measure, the difference between the high- and low-impulsive participants was not significant [$t(48) = 0.57$]. The mean correlations between participants' guesses and the actual percentages of flankers associated with each target were .077 and .155 for the high- and low-impulsive participants, respectively (both n.s.).

Experiment 2 demonstrated that when information is presented incidentally at locations that are irrelevant to target performance, high-impulsive participants showed greater sensitivity to this information than did low-impulsive participants. These data support the distribution-of-spatial-attention account proposed at the outset of this experiment. Low-impulsive participants might indeed be more effective at spatial filtering; at the same time, however, implicit correlations present in the displays will be less accessible to the low-impulsive participants.

In addition, Experiment 2 highlights the idea that, while high-impulsive participants may be limited in their ability to restrict the distribution of their spatial attention, their broad field of attention exposes them to information that at times may be useful. In the context of the natural visual environment, many important skills and capacities are learned and facilitated via incidental learning.

General discussion

In Experiment 1, we tested the hypothesis that impulsivity would be associated with different degrees of voluntary and involuntary attention. Specifically, high-impulsive participants would have a larger cueing effect for involuntary attention, because their attention would be more easily captured by a salient cue. Involuntary attention was probed using nonpredictive cues and short SOAs, and the results were consistent with the hypothesis. We also predicted that low-impulsive participants would be better able to selectively allocate voluntary attention to the cue. Voluntary attention was measured via predictive cues and long SOAs, and this confirmed the hypothesis.

Our data demonstrate the strengths (and weaknesses) of each end of the impulsivity spectrum in terms of different attentional consequences. Reaching a balance of voluntary and involuntary attention likely produces the most adaptive functioning. Consider a student reading a textbook in a noisy cafe. The ability to voluntarily attend to the textbook and to exclude distracting stimuli is useful. However, too much voluntary attention might make the student not notice the thief approaching the student's laptop. The story of Archimedes also comes to mind. Philosopher William Hamilton reported that "Archimedes . . . was so absorbed in geometrical meditation that he was first made aware of the storming of Syracuse by his own death-wound" (reported in James, 1890, p. 419). His life could have been saved by a little involuntary attention to the sounds of battle. Thus, it is critical to have a balance between voluntary attention (low impulsivity) and involuntary attention (high impulsivity).

High-impulsive participants exhibited more involuntary attention than did low-impulsive participants, and we argue that some degree of involuntary attention is important for survival. One might expect that in some aspect of an experimental task, high impulsives would show greater performance than low impulsives. We found that high-impulsive participants showed a greater correlated-flanker effect, although neither group showed awareness of the flanker correlation. These findings are in line with working memory studies documenting that, while low working memory capacity participants may encode more items in a display, some of those may not be the task-relevant items. (Vogel, McCollough, & Machizawa, 2005). We suggest that unintentional sensitivity to contingencies in the environment (an attribute of impulsivity) may play a useful role by allowing implicit learning outside of the current focus of voluntary attention.

In pathological populations, or at the extremes, impulsivity has been linked to maladaptive behavior, including overeating, risk taking, and even traffic accidents (Evenden, 1999). However, in our sample of normal, adaptive participants, impulsivity has its costs and benefits in terms of attention.

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[1] By the Mann–Whitney U test, high-impulsive participants had a significantly larger flanker effect, $U = 194, p < .05$. The inverse transformation of RTs (1/RT for each trial), on the other hand, makes skewed data more normal (Ratcliff, 1993). Here too, there was a significant difference between the high- and low-impulsive participants [$t(48) = 1.92, p < .05$, one-tailed].

In spatial attention, low impulsivity is associated with voluntary attention, but we argue that too much voluntary spatial attention may have negative consequences. In Experiment 2, low-impulsive participants were less sensitive to the contingencies of the flankers outside of their focus of attention. We suggest that the attentional processes associated with higher levels of impulsivity can play an adaptive role in implicit learning.

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