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SHORT COMMUNICATION

Relationships between trait impulsivity and cognitive control: the effect of attention switching on response inhibition and conflict resolution

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Abstract This study examined the relationship between trait impulsivity and cognitive control, as measured by the Barratt Impulsiveness Scale (BIS) and a focused attention dichotic listening to words task, respectively. In the task, attention was manipulated in two attention conditions differing in their cognitive control demands: one in which attention was directed to one ear at a time for a whole block of trials (blocked condition) and another in which attention was switched pseudo-randomly between the two ears from trial to trial (mixed condition). Results showed that high impulsivity participants exhibited more false alarm and intrusion errors as well as a lesser ability to distinguish between stimuli in the mixed condition, as compared to low impulsivity participants. In the blocked condition, the performance levels of the two groups were comparable with respect to these measures. In addition, total BIS scores were correlated with intrusions and laterality index in the mixed but not the blocked condition. The findings suggest that high impulsivity individuals may be less prone to attentional difficulties when cognitive load is relatively low. In contrast, when attention switching is involved, high impulsivity is associated with greater difficulty in inhibiting responses and resolving cognitive conflict than is low impulsivity, as reflected in error-prone information processing. The conclusion is that trait impulsivity in a non-clinical population is manifested more strongly when attention switching is required than during maintained attention. This may have important implications for the conceptualization and treatment of impulsivity in both non-clinical and clinical populations.

Keywords Cognitive control · Attention · Laterality · Top-down processing · Dichotic-listening

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Introduction

Trait impulsivity is associated with individual differences in a variety of aspects of cognitive functioning (Buelow and Suhr 2009; Evenden 1999; Leshem and Glicksohn 2007; Whiteside and Lynam 2001). Several potentially dissociable cognitive domains related to impulsivity include attention switching, maintenance of attention, and suppression of motor responses that have been rendered prepotent (“response inhibition”) (Dickman 1985, 1990; Kenemans et al. 2005). These functions involve top-down cognitive processes and are part of a set of functions attributed to the term “cognitive control,” or “executive control,” such as monitoring goal-directed behavior, resolving cognitive conflicts, and overcoming habitual responses (Westerhausen and Hugdahl 2010).

Much of the discussion regarding the nature of the deficits underlying impulsivity is centered on basic deficits in two putative cognitive functions, namely selective attention and inhibition (Barkley 1999; Enticott et al. 2006; Evenden 1999; Nigg 2001). Selective attention refers to the ability to initiate and maintain focus on a limited part of available information (Kenemans et al. 2005). This type of cognitive function is necessary to focus processing on relevant information and to filter out distracting, irrelevant information (Gehring and Knight 2002). Two different types of processes are encompassed by selective attention.

The first is sustained attention (or vigilance), which refers to the ability to maintain a consistent behavioral response during continuous and repetitive activity (Pardo et al. 1991). The second is attention switching, which involves processes that change the mapping between stimulus attributes and response attributes. Specifically, attention switching shifts the state of the information processing system from one mode of processing to another (Gehring and Knight 2002). Both sustained and switching mechanisms require a major top-down cognitive control function, namely inhibition or inhibitory control (Miller and Cohen 2001), which refers to the suppression of ongoing actions or prepotent reactions (Barkley 1999; Kenemans et al. 2005; Nigg 2001).

While several studies of impulsivity emphasize the involvement of executive control in impulsive cognitive and behavioral responses (Franken et al. 2005), few studies examine trait impulsivity in relation to both bottom-up and top-down processing of incoming stimuli (Dickman 2000; Franken et al. 2005).

Dichotic listening (DL) tasks have been used to investigate bottom-up and top-down perceptual, attentional, and cognitive control processes in both non-clinical populations and impulsivity-related disorders (Dramsdahl et al. 2011; Hare and Jutai 1988; Hugdahl et al. 2012; Øie et al. 2012). DL was originally designed to estimate hemispheric specialization for speech sound information processing (see Hugdahl 2005; Westerhausen and Hugdahl 2010), using a task in which two acoustically similar stimuli are simultaneously presented to the two ears and the participant must identify, detect, or discriminate between them. Although both ears are represented in both hemispheres, strong processing preferences have been observed, such that a right-ear advantage (REA) reflects the left-hemisphere (LH) specialization usually observed for linguistic material and a left-ear advantage (LEA) reflects the right-hemisphere (RH) specialization that often occurs for non-verbal material (i.e., emotional tones) (Bryden and MacRae 1988; Grimshaw et al. 2003; Westerhausen and Hugdahl 2010). In focused attention DL paradigms, participants are required to detect verbal stimuli in one ear, and responses are believed to be affected by top-down/attention-driven verbal processes associated with the LH and therefore the right ear. Thus, attending to the right ear in a verbal task facilitates the stimulus-driven REA (Hugdahl et al. 2009; Westerhausen et al. 2009), while attending to the left ear during a verbal task creates interference between top-down/instruction-driven processes and the bottom-up/stimulus-driven right-ear dominance (Bryden et al. 1983; Hugdahl and Andersson 1986; Hugdahl et al. 2000, 2009). The solution is to inhibit processing, or suppress response to the right-ear stimulus, which, due to the lateralized function of the LH, produces a strong cognitive conflict when the instruction is to attend to the stimulus presented in the left ear. Thus, the focused attention paradigm creates a conflict between bottom-up and top-down processes, and its resolution is believed to require cognitive control (Miller and Cohen 2001; Westerhausen et al. 2009). Failure to resolve such conflicts under focused attention conditions likely results in increased "intrusion errors," which involve positive responses when the target occurs in the unattended ear. Meanwhile, failure to inhibit responses likely results in increased "false alarm" (FA) errors, which involve positive responses when the target is absent. These commission errors (intrusions and FAs) reflect failure of top-down attentional processing to inhibit bottom-up processing (Leshem 2013; Westerhausen et al. 2009).

From a neuropsychological viewpoint, imaging studies have shown that the focused attention DL task involves inferior parietal and prefrontal cortex (PFC), indicating the recruitment of a cortical attentional network (Hugdahl et al. 2000; Jäncke et al. 2001; Jäncke and Shah 2002) and in line with the known role of the PFC in executive functions (Banfield et al. 2004; Fellows 2004; Stuss and Levine 2002). As findings from neuroimaging and lesion studies support the idea that different components of impulsivity are largely associated with the PFC (Bechara 2005; Bechara et al. 2000a; Kalenscher et al. 2006; Berlin et al. 2004; Gansler et al. 2011; Horn et al. 2003; McHugh and Wood 2008; Torregrossa et al. 2008), DL is ideal for studying cognitive control functions related to trait impulsivity, such as response inhibition and conflict resolution.

The aim of the current study was to examine the role of trait impulsivity in attention switching and additional measures of cognitive control, namely conflict resolution and response inhibition. More specifically, the study constituted a preliminary investigation of the relationship between trait impulsivity and inhibitory control and conflict resolution by manipulating attention in a dichotic listening to words and affects task (DLWA). The DLWA word task (Bryden and MacRae 1988) consists of four dichotically paired words spoken in four different emotional tones and requires the participant to detect a target word (word task) in each ear (Bryden and MacRae 1988). In the current study, the task involved two different attention conditions: one involving sustained attention, in which attention was directed to one ear at a time for a whole block of trials (blocked condition), and one involving attention switching, in which attention was switched pseudo-randomly between the two ears from trial to trial (mixed condition). As reviewed above, word detection is associated with a REA/LH dominance. Therefore, word detection when attending to the left ear maybe more complex, due to interference between stimulus-driven/bottom-up and instruction-driven/top-down processing that requires greater cognitive control (Bryden et al. 1983; Hugdahl and Andersson 1986; Hugdahl et al. 2000, 2009; Westerhausen et al. 2009). In addition, the detection of words spoken in specific emotional prosodies was used to add a distraction mode to this task (Carretié et al. 2008; De Pascalis et al. 2009; Scott et al. 2009).

The two attention conditions involve different attentional demands that impose different amounts of cognitive load on the participants. In the mixed condition, performance requires at least two processes: the ability to maintain a set (errors due to distraction) and the ability to shift attention between ears (perseverative errors). When a decision rule depends on the identity of a stimulus in a spatial location (e.g., press yes if you hear the word “bower” in your left ear), and shifting occurs between locations, then the relevant shift might be between sets of stimulus–response mapping rules (Crone et al. 2004; Wager et al. 2004). Once a task set is implemented, it stays in a given state of activation of until it has to be changed (Schneider and Logan 2005), for example when a new instruction (task demand) is presented. Switch costs arise from an endogenous, executive control process that reconfigures the cognitive system to implement the relevant task set for task instruction alternations (Rogers and Monsell 1995).

As such, the mixed condition, in which attention is switched between the two ears unpredictably, appears to involve a greater load on cognitive control, as it poses high demands on both the attention and inhibition systems in terms of capacity and flexibility (Hugdahl et al. 2009; Wager et al. 2004). As a consequence of these relatively high attention demands, compared to the blocked condition, the mixed condition may be particularly suitable for detecting cognitive differences between non-clinical participant groups exhibiting high versus low impulsivity. When associations between trait impulsivity and attention switching, inhibitory control, and conflict resolution are found, groups consisting of highly impulsive individuals may function as a valid model for deficient cognitive control in impulsivity-related clinical disorders.

To the best of my knowledge, this is the first study to investigate goal-directed behavior by comparing the effects of switching (mixed) and sustained (blocked) attention-to-ear conditions in non-clinical impulsive individuals. Most experimental paradigms that are used to study cognitive control and response inhibition in both non-clinical and clinical impulsive participants, such as the Stroop task (Enticott et al. 2006; Kertzman et al. 2006; Lansbergen et al. 2007), go/no-go, or stop-signal tasks (Landau et al. 2012), show inconsistencies between clinical and non-clinical impulsive participants. For example, neuropsychological studies have shown that individuals with ADHD exhibit overall worse performance on behavioral inhibitory tasks (e.g., stop-signal task, Stroop task, go/no-go task) (Lijffijt et al. 2004; Lijffijt et al. 2005; Rubia et al. 1999; Whelan et al. 2012) compared to individuals without ADHD. In contrast, data on impulsivity within the normal population are not fully consistent with behavioral inhibition deficits (Avila et al. 2004; Avila and Parcet 2001; Horn et al. 2003; Lansbergen et al. 2007; Lijffijt et al. 2004; Logan et al. 1997). Explanations for the contradictory findings vary across studies, based on differences in psychometric and methodological variables and in how impulsivity is defined. One possibility is that clinical populations characterized by impulsivity have a more generalized cognitive impairment (Winstanley et al. 2006) and exhibit qualitatively different behavior from non-clinical impulsive individuals. Another is that high trait impulsivity in the general population is not extreme enough to reveal differences in inhibitory control and that the frequently used response inhibition tasks described above are often not demanding enough and therefore not sensitive enough, to detect differences between non-clinical participants with high versus low trait impulsivity (Markus and Jonkman 2007; Rubia et al. 2005). This is in accordance with Dickman’s (1993) argument that differences in performance between high and low non-clinical impulsive individuals are reflected especially in highly attention-demanding tasks requiring attention shifting. It is possible that in non-clinical populations, impulsive individuals have the ability to inhibit their responses but are less effective or efficient than non-impulsive individuals (Markus and Jonkman 2007; Shen et al. 2014) when task demands require more effortful inhibitory control to yield good performance.

Overall, this study makes two important contributions. First, the use of two attention conditions that differ in their cognitive demands (sustained versus switching) can greatly extend our current understanding of the effects of switching attention on response inhibition in non-clinical impulsive individuals. In particular, this comparison can provide insight into the relationship between impulsivity and attention, and help distinguish whether impulsive individuals have a generalized attentional deficit or a more specified attentional deficit reflecting separate cognitive functions. The second, related contribution involves examination of the ability to inhibit responses when conflict resolution is required (inhibiting the impulse to respond to a distractor), while taking into account the processing demands unique to each attention condition and how they affect the variations in performance between individuals with high and low trait impulsivity.

The comparison between the attention conditions enables examination of response inhibition and cognitive conflict resolution in relation to trait impulsivity, as assessed by the Barratt Impulsiveness Scale (BIS-11;

Patton et al. 1995). To evaluate response inhibition and cognitive conflict resolution processes, the following objective indices, drawn from signal detection methods, were applied: hits and d' indices, which refer to the ability to detect the relevant stimulus during the presentation of a competing stimulus (i.e., the ability to maintain response performance); false alarm index, which refers to the ability to stop an ongoing response; and intrusion index, which refers to the ability to withhold a prepotent response to interfering stimuli. Based on the review above, the effect of trait impulsivity on response inhibition and cognitive resolution was expected to be more pronounced in the mixed than in the blocked condition, which seems to involve a greater load on cognitive control (Hugdahl et al. 2009; Markus and Jonkman 2007). In addition, impulsive responses are presumed to arise when bottom-up processes dominate cognitive/top-down control processes, which may be the case when more errors are exhibited in DL tasks. Two main predictions were examined. First, participants with high compared to low BIS scores were expected to be less able to exert cognitive control, especially in the mixed condition. Performance deficits would be reflected in error-prone information processing, namely in reduced d' value and increased FAs and intrusion errors. Second, participants with high compared to low BIS scores were expected to exhibit greater laterality effects, especially in the mixed condition, due to greater difficulty to modulate the bottom-up right-ear dominance for words using top-down/executive control processes.

Methods

Participants

Forty undergraduate students, all native English speakers, from the University of California, Los Angeles (UCLA, 20 student), and from the International B.A. Program for US foreign students at Bar-Ilan University, Israel (28 females; mean age 21.30, range 19–28), completed this experiment for course credit. Independent sample t tests between the two samples for demographic variables revealed no significant differences in sex [UCLA 12 females, Bar-Ilan University 16 females, $t(38) = -1.4$, $p > .1$] but significant differences in age [UCLA $M = 20.25$, SD = 1.1, Bar-Ilan University $M = 22.35$, SD = 2.6, $t(38) = 3.3$, $p = .002$]. There were no significant differences between the samples on the impulsivity variable [UCLA $M = 64.4$, SD = 7.6, Bar-Ilan University $M = 63$, SD = 10.2, $t(38) = -.43$, $p > .1$].

All participants completed a shortened version of the Edinburgh Handedness Inventory (Oldfield 1971), involving a seven-item scale with potential scores ranging from −14, indicating maximum left handedness, to 14, indicating maximum right handedness (0 indicates ambidextrous status). All participants were right-handed (i.e., assumed to have left-hemisphere dominance for word processing), as indicated by scores between 12 and 14 on the Handedness Inventory. Note that handedness is considered the most transparent of functional asymmetries and reflects cerebral asymmetry rather than asymmetry of the hands themselves (Corballis 2010). Right-handed individuals more often have a strong left-hemisphere specialization for language than do left-handed individuals, who are more likely to show right-hemisphere dominance for language (Hugdahl 2005). Thus, the inclusion of solely right-handed participants allows control of handedness effects on brain asymmetry and presumably enhances the right-ear advantage (contralateral to the left hemisphere) for word detection.

None of the participants reported a history of neurological illness or hearing deficits.

Apparatus

The Barratt Impulsiveness Scale (BIS-11; Patton et al. 1995)

This scale is comprised of 30 items, each scored on a 4-point graded scale: rarely/never (1), occasionally (2), often (3), or almost always/always (4). Several items are reverse coded, and a higher score indicates greater impulsiveness. This questionnaire is widely used as a measure of trait impulsivity and comprises three subscales: motor (MI, motor and perseverance), cognitive (AI, attention and cognitive instability), and non-planning (NP, self-control and cognitive complexity). The BIS also provides a total score, which indicates a global measure of impulsiveness (Stanford et al. 2009). The BIS-11 has adequate reliability ($\alpha = .78$) in the current sample.

Dichotic listening to words and affects (DLWA)

The stimuli consisted of the words "bower," "dower," "power," and "tower," spoken in sad, happy, angry, and neutral voices (Bryden and MacRae 1988). These stimuli were presented through Müller headphones, on a 3.00 GHz Intel Pentium D personal computer, running Windows XP, using E-Prime 2.0 software (Schneider et al. 2002). A 17-inch LCD monitor with a refresh rate of 75 Hz and a resolution of 1280 × 1024 pixels was used. Stimuli were digitized in 16 bits at a sampling rate of 44.1 kHz and edited to a common duration of 500 ms. The four words were each spoken in four different emotional tones of voice, resulting in 16 distinct stimuli (types; generator list). Each member of the generator list was next paired with each other, excluding pairs with the same word or pairs with the same emotion. This yielded a list of 144 distinct stimulus pairings. Of this list, 36 stimulus pairs included the "target word" in the attended ear (hits), 36 stimulus pairs included "target word" in the unattended ear (potential intrusion non-targets), and 72 trials did not include the target in either ear (simple non-targets). To highlight the contrast between trials that included the targets in the unattended ear and those that included no targets at all, a subset of the stimuli that included 2/3 targets, 2/3 non-target potential intrusions, and 2/3 simple non-targets was employed. Blocks of trials were then constructed, consisting of three repetitions of the target set ($24 \times 3 = 72$), three repetitions of the potential intrusion set ($24 \times 3 = 72$), and one repetition of the simple non-target set (48) for a total of 192 trials. This stimulus set systematically excluded the same stimulus combinations in the targets, potential intrusions, and simple non-targets.

Procedure

First, all participants were presented with a 1-kHz sine wave audio tone through headphones to ensure equal hearing in both ears, and to allow modification or calibration on one or both of the two channels if necessary. All participants reported equal hearing at the standardized balance level. Participants were then introduced to each of the 16 types of stimuli presented binaurally, with error feedback provided after each trial. If a mistake was made, the binaural set was presented again. Next, there was a practice block of ten dichotic pairs with error feedback provided after each trial. The task required participants to detect the target word "bower" by pressing "Yes" on the keyboard with the index finger when the target occurred in the attended ear and "No" on the keyboard with the middle finger otherwise. As response hand could have an activation effect on the contralateral hemisphere in general, and could therefore be associated with confounding effects, participants were asked to respond only with their right (dominant) hand. Each participant received two blocks, corresponding to two combinations of target and ear: (1) target word in the left ear, and (2) target word in the right ear.

These combinations were presented in two experimental conditions. In the blocked condition, participants attended to one ear for an entire block of 192 trials and then to the other ear for the following block of 192 trials. In the mixed condition, attention was directed alternately to one or the other ear within the same block of trials. The mixed condition included $192 + 192 = 384$ trials. The attended ear in both the blocked and mixed conditions was signaled by an arrow (endogenous) presented briefly to the left or right of fixation and by a simultaneous tone (exogenous). The order of attention conditions was counterbalanced across participants, as was the order of attended ear in the blocked condition. The session ended with the impulsivity questionnaire.

Each trial consisted of four events. First, the fixation mark was presented in the middle of the screen for 500 ms, followed by a visual arrow cue and an auditory beep directing attention to the left or to the right ear, presented for 100 ms. After a 250-ms delay, the participant had 2500 ms to respond to the stimulus. The stimulus onset asynchrony (SOA) was set at 350 ms, to unify the effects of the exogenous and endogenous cues and to allow enough time to orient attention (Müller and Rabbitt 1989). Thus, the average trial lasted 3300 ms. Overall, the experiment took approximately 45 min to complete.

Statistical analysis

BIS-11 total scores ranged from 48 to 87 with a median score of 62.5. Participants were classified as having high or low BIS scores by median split (Fig. 1).

To evaluate behavioral responses, three direct indices were computed: proportion of hits, proportion of intrusions (positive responses when the target occurred in the unattended ear), and proportion of false alarms (FAs when no target was presented). In addition, to control for individual variability in response bias, d' index and response bias (β) were also computed. Based on a signal detection paradigm (Green and Swets 1966), a sensitivity d' index ($d' = z[p(\text{hit})] - z[p(\text{FA})]$) was calculated for each condition, as the mean difference between the percentage of correct responses (hit rate) and the percentage of false alarms (FA rate). Lower d' index values indicate a random

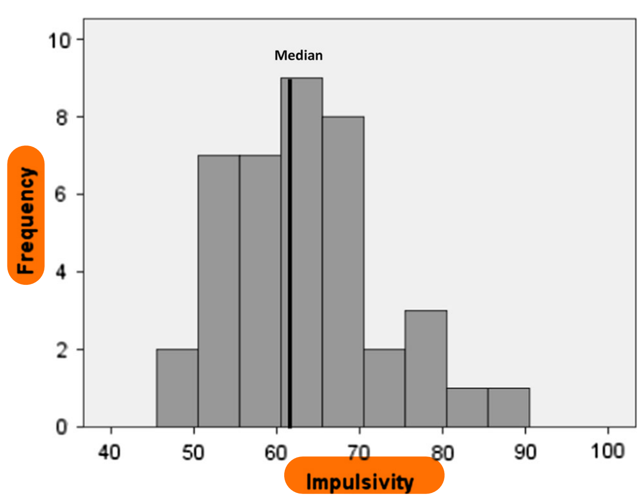

Fig. 1 Distribution of mean scores on the Barratt Impulsiveness Scale (BIS). *Bold line* represents the median split (median = 62.5, SD = 8.9)

level of performance and an inability to distinguish between stimuli, and higher d' index values indicate a better performance level and ability to discriminate more accurately between stimuli. Response bias (β) reflects the level of internal certainty in deciding whether the signal stimulus (i.e., the target) was presented or only the noise (i.e., only the distractor) was presented. This measure was calculated using the formula $\exp\{-0.5 \times d' \times [z(p(\text{hit}))] + z(p(\text{FA}))]\}$. As the bias toward saying "no" increases (stringent decision criteria), resulting in lower a hit rate and FA rate, β increases over 1.0 on an open-ended scale. As the bias toward saying "yes" increases (liberal/lax decision criteria), resulting in higher hit and FA rates, β approaches 0. Lastly, accuracy laterality index (LI) was calculated for each attention condition as the percentage difference of correct responses (hit rate) between right (R) and left (L) ear scores, as follows: $\text{LI} = (\text{R} - \text{L})/(\text{R} + \text{L})$ if $(\text{R} + \text{L}) \leq 1$ and $\text{LI} = (\text{R} - \text{L})/[(1 - \text{R}) + (1 - \text{L})]$ if $(\text{R} + \text{L}) > 1$. The LI is independent of the total proportion of responses corresponding to the input of either ear (i.e., proportion of correct reports), and reflects the relative number of responses corresponding to the left-ear and right-ear input (with positive values indicating a right, and negative values a left-ear advantage) (Tallus et al. 2007). Specifically, it expresses the observed ear difference as a proportion of the total performance level in both ears.

The data were analyzed with separate univariate repeated-measures analyses of variance (ANOVAs). The first ANOVA was attention condition (AC) (mixed, blocked) × ear (left, right) × impulsivity (low, high), with dependent variables proportion hits, proportion FAs, proportion intrusions, and the d' and β indices. The second ANOVA consisted of (AC) (mixed, blocked) × impulsivity (low, high) with laterality index (LI) as the dependent variable. In both ANOVAs, impulsivity level was treated as between-subjects variable.

Table 1 presents the significant effects of the ANOVAs for each of the dependent variables and reports means (SDs) and effect sizes.

Degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ($\varepsilon < .75$). Significant interactions were followed up with paired t tests, with a Bonferroni correction at .05.

Responses with latencies shorter than 150 ms were regarded as premature anticipatory responses and were excluded from analysis. Responses with latencies more than three standard deviations above the sample mean were regarded as distractions and were excluded from analysis as well. This resulted in rejection of 2 % of trials.

Gender is considered a factor that can affect ear advantage as well as cognition (e.g., Grimshaw et al. 2003; Sommer 2010; Springer and Deutsch 1997; Wadnerkar et al. 2008) and impulsivity (Cross et al. 2011). To check for the existence of such effects, gender was initially included as a between-subjects factor, but showed no significant main effects or interactions and was subsequently removed from the analyses.

In addition, to examine whether cognitive control (inhibitory control and conflict resolution) is related to trait impulsivity, Pearson correlations between the DL measures (hits, intrusions, FAs, d' index, LI) and BIS subscales and total score were computed for each AC.

Results

The effects of impulsivity on word processing and ear advantage

Proportion hits

There was a main effect of AC, with overall higher hit rate in the blocked than in the mixed condition. This was qualified by two-way AC × ear (Table 1) interaction, showing a significant REA, $t(39) = 3.2$, $p = .003$, in the blocked condition, but no significant difference between the ears in the mixed condition, $t(39) = -.13$, $p = .9$.

No main effect or interactions were found for impulsivity.

Proportion FAs

Main effects were found for both AC and ear, with more FAs overall in the mixed than in the blocked condition, and in the left than in the right ear (Table 1). There was a marginally significant main effect of impulsivity, indicating more FAs in the high than in the low impulsivity group. This was qualified by a two-way AC × impulsivity interaction (Table 1), showing significantly more FAs in the mixed than in the blocked condition. $t(18) = 3.7$, $p = .001$, $d = .87$, for the high impulsivity group, but not for the low impulsivity group, $t(20) = .58$, $p > .1$. In the mixed condition, there was a significant difference between the two groups group, $t(38) = -2.6$, $p = .014$, $d = -.84$, showing more FAs for the high than the low impulsivity group. In the blocked condition, the difference between the two groups did not reach significance, $t(38) = -.95$, $p > .1$.

Proportion intrusions

There were main effects of AC and ear, showing more intrusions in the mixed than in the blocked condition and more intrusions coming from the right than from the left ear (Table 1). There was a main effect of impulsivity, indicating that the high impulsivity group had overall more

Table 1 Analysis of main effects and interaction of 2 (AC) × 2 (ear) × 2 (impulsivity)

	AC	Ear	Impulsivity	Mean (SD)	F	p	η^2
Proportion hits							
AC					5.4	.026	.12
	Mixed			.63 (.14)			
	Blocked			.67 (.16)			
AC × ear					18.4	<.001	.33
	Mixed	Left		.63 (.16)			
		Right		.62 (.17)			
	Blocked	Left		.63 (.17)			
		Right		.71 (.19)			
Proportion false alarms							
AC					10.7	.002	.22
	Mixed			.23 (.13)			
	Blocked			.19 (.11)			
Ear					16.4	<.001	.3
		Left		.24 (.12)			
		Right		.19 (.11)			
Impulsivity					3.8	.058	.1
			Low	.18 (.09)			
			High	.25 (.12)			
AC × impulsivity					6.4	.016	.15
	Mixed		Low	.19 (.09)			
			High	.29 (.14)			
	Blocked		Low	.18 (.11)			
			High	.21 (.10)			
Proportion intrusions							
AC					15.7	<.001	.3
	Mixed			.31 (.11)			
	Blocked			.27 (.09)			
Ear					25.9	<.001	.41
		Left		.32 (.09)			
		Right		.26 (.10)			
Impulsivity					4.5	.04	.92
			Low	.26 (.09)			
			High	.32 (.08)			
AC × impulsivity					7.8	.008	.2
	Mixed		Low	.27 (.08)			
			High	.36 (.11)			
	Blocked		Low	.25 (.09)			
			High	.28 (.09)			
d' prime							
AC					19.1	<.001	.34
	Mixed			.98 (.54)			
	Blocked			1.3 (.54)			
Ear					9.2	.004	.2
		Left		.96 (.53)			
		Right		1.3 (.66)			
AC × ear					9.8	.003	.21
	Mixed	Left		.87 (.58)			
		Right		1.1 (.68)			

Table 1 continued

	AC	Ear	Impulsivity	Mean (SD)	*F*	*p*	η^2
	Blocked	Left		1.05 (.56)			
		Right		1.5 (.75)			
AC × impulsivity					5.5	.025	.13
	Mixed		Low	1.14 (.50)			
			High	.81 (.55)			
	Blocked		Low	1.28 (.50)			
			High	1.26 (.58)			
Response bias (β)							
AC × ear					12.1	.001	.24
	Mixed	Left		1.02 (.31)			
		Right		1.2 (.38)			
	Blocked	Left		1.1 (.37)			
		Right		1.09 (.47)			
Laterality index							
AC					29.2	<.001	.44
	Mixed			−.01 (.30)			
	Blocked			.17 (.34)			
AC × impulsivity					4.5	.041	.11
	Mixed		Low	.06 (.28)			
			High	−.09 (.31)			
	Blocked		Low	.17 (.34)			
			High	.16 (.36)			

All $df = 1$; proportion intrusions: right-ear intrusions while focusing attention to the left ear indicate interference by a target in the unattended right ear, whereas a left-ear intrusions while attending to the right ear indicate interference by a target in the unattended left ear

intrusions than the low impulsivity group. This was qualified by two-way AC × impulsivity interaction (Table 1), showing significantly more intrusions in the mixed than in the blocked condition for the high impulsivity group, $t(18) = 4.1$, $p = .001$, $d = .95$, but not for the low impulsivity group, $t(20) = .97$, $p < .1$. In the mixed condition, there were significantly more intrusions in the high than in the low impulsivity group, $t(38) = -2.9$, $p = .006$, $d = -.94$. In the blocked condition, the difference between the two groups did not reach significance, $t(38) = -1.03$, $p < .1$ (Fig. 2a).

d′ index

There were main effects of AC and ear. These were qualified by two-way AC × ear interaction, showing more accurate detection in the right than in the left ear, especially in the blocked condition (Table 1). There was two-way AC × impulsivity interaction (Table 1), showing that for the high impulsivity group, there was significantly less accurate detection in the mixed, $t(18) = -3.9$, $p = .001$, $d = -.90$, than in the blocked condition. In the low impulsivity group, there was no significant difference in performance level between the two ACs, $t(20) = -1.8$, $p = .08$. In the mixed condition, there was a significant difference between the two groups, $t(38) = 1.9$, $p = .05$, $d = .62$, showing more accurate discrimination between the stimuli in the low than in the high impulsivity group. In the blocked condition, the differences between the two groups did not reach significance, $t(38) = .10$, $p > .1$ (Fig. 2b).

Response bias (β)

There was two-way AC × ear interaction, showing stringent decision criteria (over 1.0) in both AC and ears. In the mixed condition, there was a higher value for words presented in the right than in the left ear, whereas in the blocked condition, there was a higher value for words presented in the left than in the right ear (Table 1).

No main effect or interactions were found for impulsivity.

Laterality index

There was a main effect of AC, which was qualified by two-way AC × impulsivity interaction (Table 1). In the high impulsivity group, there was a significantly reduced

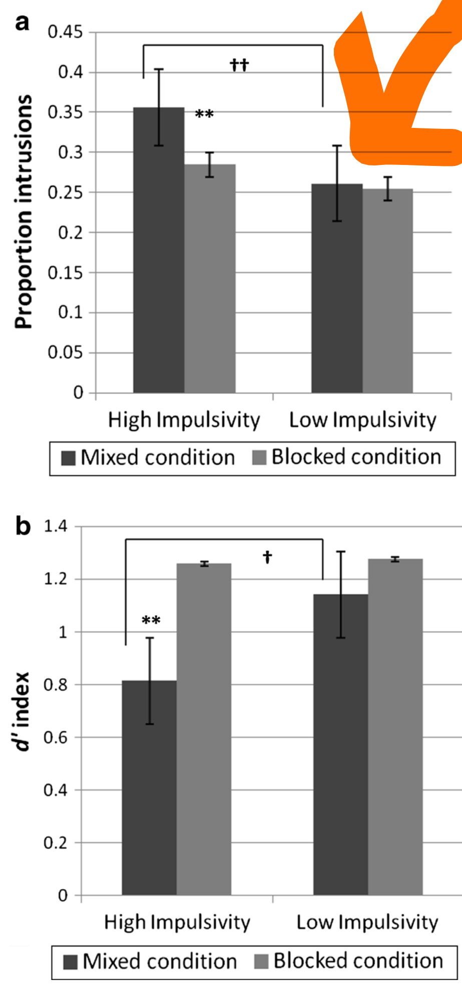

Fig. 2 **a** Mean proportion of intrusion index for attention condition × impulsivity interaction. Significantly more intrusions in the mixed than in the blocked condition in the high impulsivity group alongside a nonsignificant difference between the two attention conditions in the low impulsivity group. Also, a marginally significant effect shows more intrusions in the high than in the low impulsivity group in the mixed condition, alongside a nonsignificant difference in intrusions between the two groups in the blocked condition. **b** Mean of detection sensitivity (d' index) for the attention condition × impulsivity interaction, showing significantly less accurate performance in the mixed than in the blocked condition in the high impulsivity group alongside a nonsignificant difference between the two attention conditions in the low impulsivity group. Also, there is a significant difference between the high and low impulsivity groups in the mixed condition alongside a nonsignificant difference between the two groups in the blocked condition. *Small bars* standard error of the mean; $^{**}p = .001$; $^{\dagger}p = .05$; $^{\dagger\dagger}p = .006$

REA in the mixed condition as compared to the blocked condition, $t(18) = -5.8$, $p < .001$, $d = -1.34$, whereas in the low impulsivity group, there was a REA in both ACs, which was significantly stronger in the blocked than in the mixed condition, $t(20) = -2.1$, $p = .04$, $d = -.48$. The differences in laterality between the two groups did not reach significance in both the mixed, $t(38) = 1.5$, $p > .1$, and the blocked, $t(38) = .01$, $p > .1$, conditions (Fig. 3).

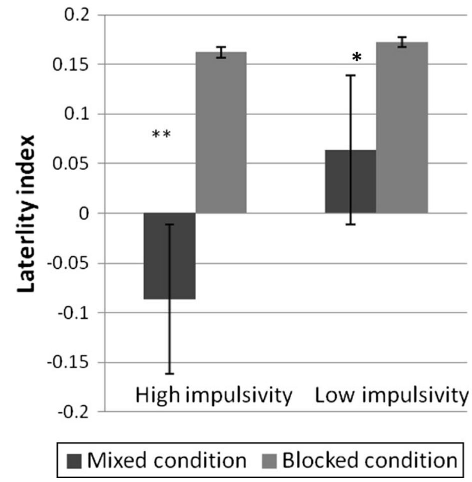

Fig. 3 Laterality index (LI) in the two attention conditions. The high impulsivity group showed a significant difference in ear advantage between the two attention conditions, with elimination of the REA in the mixed condition. The low impulsivity group showed a REA in both conditions, with a significant reduction in the mixed condition. $^{**}p = .001$; $^{*}p = .04$

Observed correlations between BIS subscales and total score and DL measures

To examine the relationship between trait impulsivity and DL measures, we looked at the correlations between the BIS subscales and total score and the five DL task measures, separately for each AC. In the mixed condition, BIS MI subscale was positively correlated with FA ($r = .39$, $p < .05$) and intrusions ($r = .40$, $p < .01$) and negatively correlated with d' ($r = -.43$, $p < .01$) and LI ($r = -.34$, $p < .05$). BIS NP subscale was positively correlated with intrusions ($r = .33$, $p < .05$) and negatively correlated with d' ($r = -.33$, $p < .05$). There were no other significant correlations for BIS subscale scores ($r_s < .3$, $p > .1$). BIS total score was positively correlated with intrusions and negatively correlated with LI (Fig. 4). There were no other significant correlations between BIS total score and hits, FAs, or d' indices, in both ACs ($r_s < .3$, $p > .1$).

Discussion

The goal of the present study was to examine the relationship between trait impulsivity and cognitive control, as measured by the BIS-11 and a focused attention DL to words task, respectively. In particular, the main focus was on the effect of attention switching on response inhibition and conflict resolution and on whether this effect would differ depending on trait impulsivity. For this purpose, participants were required to detect a target word, regardless of prosody, in two attention conditions that

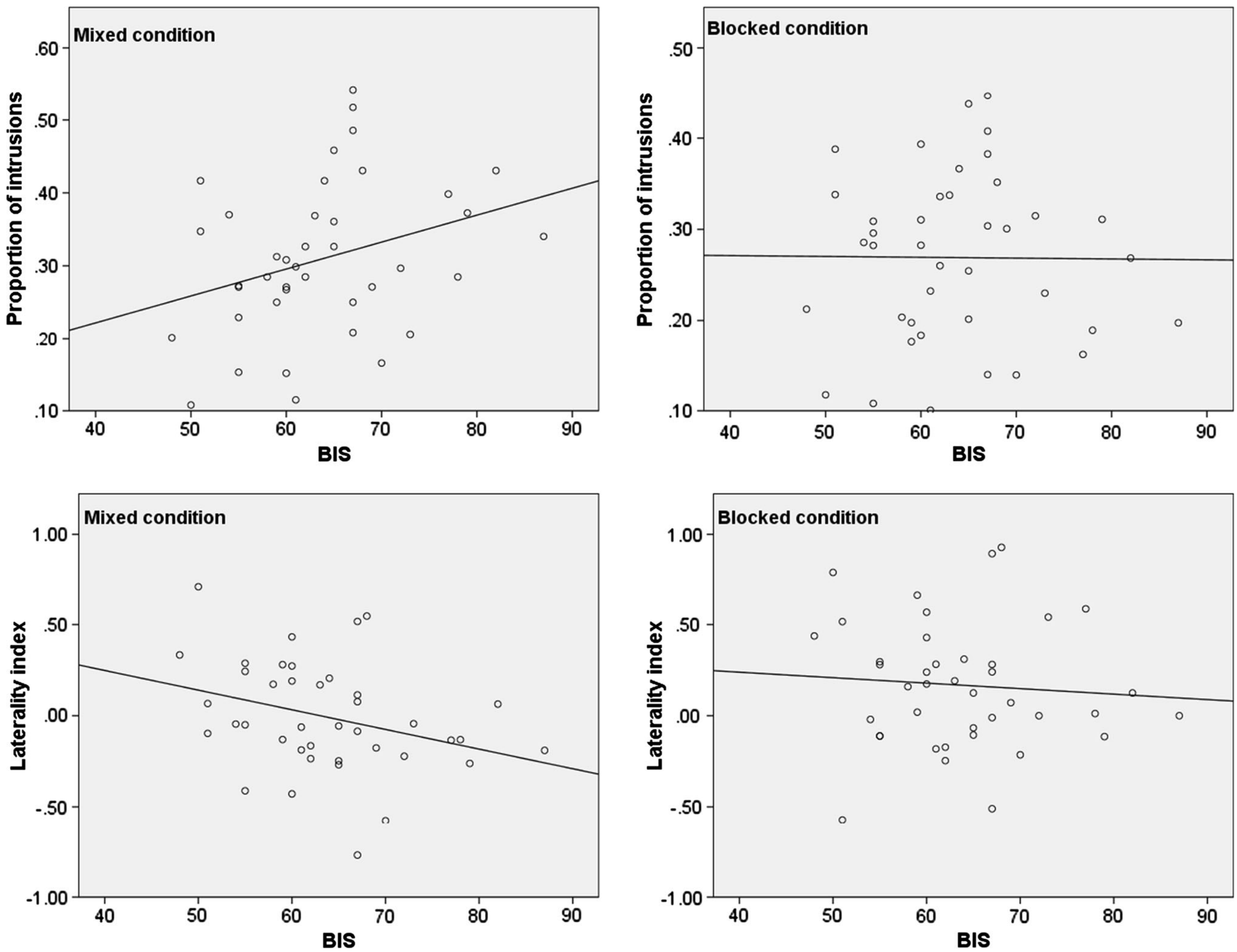

Fig. 4 Correlations between Barratt Impulsiveness Scale (BIS) score, proportion of intrusions, and laterality index. The correlation between BIS score and intrusions was significantly positive in the mixed ($r = .31, p < .05$) but not in the blocked ($r = -.01, p > 1$) condition. The correlation between BIS score and laterality index is significantly negative in the mixed ($r = -.32$, $p < .05$) but not in the blocked ($r = -.08$, $p > 1$) condition

differed in their cognitive demands. The overall results showed an adverse effect of impulsivity on performance, such that high impulsivity was associated with higher FA and intrusion rates than was low impulsivity. Comparison between the mixed and blocked attention conditions showed higher intrusion and FA rates, as well as a lower d' value for the mixed condition, especially in the high impulsivity group. Furthermore, only the mixed condition revealed differences between impulsivity groups, with the high impulsivity group exhibiting greater difficulties in inhibiting responses and resolving conflicts than the low impulsivity group when attention switching was involved. In contrast, the blocked condition did not reveal differences in performance between the impulsivity groups. This is in accordance with the prediction of poorer performance for the high impulsivity group in the mixed condition.

The findings indicate that sustained attention—the ability to maintain a consistent behavioral response during continuous and repetitive activity (Posner and Petersen 1990) and switching attention—the mental flexibility that enables shifts in attentional focus between stimuli (Wager et al. 2004), recruit separate underlying cognitive mechanisms to implement inhibition control and conflict resolution. This is in line with imaging studies showing that neural trajectories for rule maintenance and rule switching may be associated with different subregions of the prefrontal cortex. The ability to maintain a rule online and inhibit interference has been associated with activity in both the dorsal and ventral lateral prefrontal cortex, whereas the ability to perform different types of switching, including location switching, is associated with the dorsal lateral prefrontal cortex (Crone et al. 2004) as well as premotor cortex and parietal cortex (Wager et al. 2004).

The finding that performance differences between the high and low impulsivity groups occurred in the mixed but not in the blocked condition can be explained in terms of perceptual and cognitive load, in accordance with Lavie's load model (Lavie 1995; Lavie et al. 2004). According to this theory, the perceptual load incurred while processing relevant stimuli directly determines the extent to which irrelevant information is also processed. Specifically, tasks involving low perceptual load allow parallel processing of the target and the distractor, whereas tasks with high perceptual load deplete the participant's pool of capacity-limited resources, which eliminates or reduces processing of the distractor (Forster and Lavie 2007; Jerger et al. 2013).

Although it is difficult to determine the degree of perceptual load in both conditions based on the present study design, the DL focused attention condition is considered computationally simple and less cognitively complex (Gazzaniga 2000; Jerger and Martin 2006) than the DL divided attention paradigm and other cognitive tasks requiring working memory. The focused attention paradigm also strengthens selective attention to the attended ear and enhances performance in healthy participants (Hugdahl et al. 2000, 2009). In the present study, this was especially true for the blocked condition, in which participants were pre-cued to direct attention to repeated stimuli presented to one ear at a time (Kallman and Corballis 1975) for an entire block. As such, participants were given a listening strategy directing them to one ear, which has been shown to minimize cognitive load (Jerger and Martin 2006). Also, when a task becomes more practiced, its reliance on cognitive control is reduced (Miller and Cohen 2001). Conversely, in the mixed condition, participants were pre-cued to switch their attention between the ears such that attention and expectation differ systematically from trial to trial, requiring additional cognitive resources such as cognitive flexibility and a greater need for active maintenance in the selective state, thereby creating greater cognitive load.

According to Lavie et al. (2004), an active attentional control mechanism is needed for rejecting irrelevant distractors even when these are perceived (in low perceptual load). This form of control depends on higher cognitive functions that are required for actively maintaining current processing priorities to ensure that low-priority stimuli do not gain control of behavior. Thus, contrary to the predicted effect for perceptual load, high load on cognitive functions drain the capacity available for active control and results in increased processing of irrelevant distracters (Lavie et al. 2004). Selective spatial attention, as opposed to divided attention, is widely thought to reduce distractor interference at both perceptual and post-perceptual levels, respectively, by focusing perceptual resources on the attended location and by blocking (post-perceptual) distractors that survive perceptual selection (Lavie et al. 2004). Linnell and Caparos (2011) used a variable-separation flanker paradigm to test whether the effects of perceptual and cognitive load on spatial focus attention remain when, respectively, cognitive load is high and perceptual load is low. They found that decreasing cognitive load only causes spatial attention to focus when perceptual load is high and the stimulus encourages this. In addition, they showed that perceptual load exerts its focusing effect only with the engagement of cognitive resources when cognitive load is low. They concluded that perceptual and cognitive mechanisms exert interacting effects and operate in concert to focus spatial attention.

The fact that the high impulsivity group performed comparably to the low impulsivity group in the blocked condition may suggest that in less cognitively complex tasks, high impulsivity participants will not necessarily exhibit impairments in goal-directed behavior. However, when cognitive demands increase, such as in the mixed condition, in which attention switching is required between trials, high compared to low impulsivity participants would be expected to show a greater deficit, with "instruction-driven"/top-down processing strategies modulating "stimulus-driven"/bottom-up processing strategies less effectively.

The possibility that there is greater cognitive load in the mixed condition, affecting the high impulsivity group, is further supported by the absence of ear differences for word processing as measured by the LI, which applies to correct responses (hits). Analysis of the LI results revealed elimination of the REA (i.e., LH dominance) for word processing in the mixed but not in the blocked condition in the high impulsivity group, alongside a REA in both conditions in the low impulsivity group. This elimination of the REA was also demonstrated in the negative correlation between BIS score and LI in the mixed condition only. Indeed, DL studies using forced attention paradigms (but not necessarily the same task and paradigm) in normal participants have shown that attention can dramatically affect ear advantages for words, reducing the differences between the ears (Bryden et al. 1983; Hugdahl et al. 2000, 2009; Leshem 2013). It can therefore be argued that high compared to low impulsivity participants were better able to shift their attention from one ear to another in order to perform the task. This means that attentional factors, specifically when attentional switching is involved, can override the basic REA asymmetry for word processing, providing evidence for modulation a bottom-up/stimulus-driven effect by top-down instructions. However, if this was indeed the case here, then the absence in difference between the ears should have been reflected in the blocked condition as well. Thus, it is more likely that the elimination of the REA in the mixed condition in the high impulsivity group was due to a greater load on cognitive control, which burdened the common pool of limited resources within the hemispheres (Pollmann 2010). When task complexity increases to the point that the resources of a single hemisphere are overly taxed, other cognitive processes come into play (Banich and Brown 2000), resulting in bilateral involvement. Yet, under some conditions, it is advantageous to process information in a single hemisphere, preventing interhemispheric interference. Interference among tasks that are unrelated will be minimized when they are each performed by functionally distant cerebral regions (Daselaar and Cabeza 2005). In the current paradigm, however, the stimulus encompassed verbal and emotional features at the same time and the perceptual and cognitive functions required were less differentiated between the two hemispheres. Thus, some form of interhemispheric conflict during stimulus processing may have occurred, limiting the ability to control responses and resulting in more errors. It can be argued that the involvement of the two hemispheres increased hemispheric interference and was not cost-effective in the mixed condition, presumably because processing can occur within the specialized LH. In the low impulsivity group, there was indeed a REA (LH dominance) in the mixed condition.

The reduced laterality together with the higher error rate in the high impulsivity group indicate that the mixed condition was more difficult for high impulsivity than for low impulsivity participants and that the ability to inhibit response and resolve a conflict was most affected by attentional switching. This also supports the assertion of the load model that while increasing perceptual load is expected to reduce distractor interference, increasing cognitive control load is expected to increase distractor interference (Lavie et al. 2004).

Continuing in this line, the ability to detect the target word correctly, as measured by hits index, was not affected by impulsivity level in both the mixed and the blocked conditions. In addition, contrary to the prediction that greater ear differences would be found in high impulsivity participants, there was no effect or interaction for ear and impulsivity. These findings suggest that the differences between high and low impulsivity participants in this study did not necessarily stem from impairments in perception (detecting the target word) or attention abilities (the ability to maintain response performance). Rather, differences may lie at the cognitive level required by task demands. Specifically, it seems that the effect of impulsivity may be more pronounced when processing random and unexpected stimuli than expected stimuli, such that cognitive control processes are weakened while bottom-up processes are strengthened, affecting the ability to inhibit dominant response sets and shifts in the allocation of attentional resources. This is reinforced by the positive correlations between the intrusion index and total BIS, MI (involved acting without thinking) and NP (involved perseveration, self-control, and cognitive complexity(subscale scores (Haden and Shiva 2008; Stanford et al. 2009) that were found only in the mixed condition, indicating that as the BIS score increases, it is increasingly difficult to implement the top-down cognitive control processes required to ignore and inhibit responses when the target word is presented. The dominance of bottom-up processes over cognitive control processes is particularly expressed in increased FAs and intrusions, which are heavily dependent on cognitive functions, as well as in high scores on the BIS, which examines components of cognitive control, response inhibition, and cognitive resolution (Patton et al. 1995).

From a neuropsychological perspective, top-down control systems in the PFC play an important role in impulsivity (Bechara et al. 2000b; Beeli et al. 2008). Functional neuroimaging studies have provided direct evidence for the relationship between the BIS and neuropsychological measures that have demonstrated sensitivity to the prefrontal area, which is considered central to the cognitive functions associated with the DL task. For example, in an fMRI study using the BIS, Gansler et al. (2011) found that the left PFC and the orbitofrontal cortex accounted for significant variance in attentional aspects of impulsivity, such as attentional control and behavioral inhibition. Another fMRI study (Asahi et al. 2004) found a negative correlation between the BIS and response inhibition using a go/no-go task in non-clinical impulsive participants. In this study, no-go responses were related to right dorsolateral prefrontal activation. Horn et al. (2003) also found neural correlates of response inhibition and BIS during a go/no-go task in the right lateral orbital prefrontal cortex. Similarly, electrophysiological studies have shown BIS scores to be associated with prefrontal activity in response inhibition and other cognitive tasks (Chen et al. 2007; Martin and Potts 2009).

In the current study, the mixed condition required more effortful cognitive investment, due to an endogenous, executive control process that was necessary for reconfiguring the cognitive system to implement the relevant task set for task instruction alternations (Rogers and Monsell 1995). Highly impulsive participants were especially influenced by attention switching, presumably because they had particular difficulty in focusing their attention on the relevant stimulus and ignoring the irrelevant one when cognitive load was high. In contrast, in the blocked condition, when cognitive load was relatively low, highly impulsive participants were able to perform the task at a comparable level to low impulsivity participants. This is in line with Dickman's (1985, 1990) suggestion that the consequences of impulsivity are not negative when the experimental task is very simple, such that the rapid responses of highly impulsive individuals have little cost in terms of errors. Furthermore, the lack of difference in correct responses between the high and low impulsivity groups may suggest that impulsivity-related performance differences lie in error-prone information processing, as reflected by intrusions, FAs, and d' indices. This is in accordance with the claim that impulsivity is characterized by a tendency to engage in rapid, error-prone information processing (i.e., to act with relatively little forethought) (Daruna and Barnes 1993; De Pascalis et al. 2009; Dickman 1990).

The paradigm used in this study makes it possible to examine the effect of attention switching on inhibition response and conflict resolution in non-clinical impulsive participants. The significant interactions involving impulsivity and attention conditions indicate that apparently small variations in impulsivity scores are sufficient to discriminate between the effects of attentional manipulation. In this respect, it would be valuable to use additional measures examining attention and perception components of impulsivity in future studies, while increasing sample sizes to solidify the evidence for this effect.

The present study shows that inhibition and conflict resolution are affected by trait impulsivity in healthy participants under specific attentional conditions as determined by manipulation at the cognitive level (i.e., top-down control processes driven by the active deployment of different cognitive resources). Further studies are warranted regarding the possible effects of task perceptual load on cognitive control abilities in relation to impulsivity. A study by Forster and Lavie (2007) examined the effects of perceptual load on the ability to focus attention (or conversely, distractibility). They found that high perceptual load reduced distractor interference for all participants (high and low scores on the Cognitive Failures Questionnaire), eliminating any individual differences in distractibility. Hence, in the context of differences in impulsivity, if a distractor influences target processing during a task with low perceptual load but not at all or less so during a task with high perceptual load, then distractor processing is dependent on capacity-limited resources. Conversely, if distractors consistently influence performance despite variations in the perceptual load of the target task, then (to the extent tested by the manipulation) distractor processing is independent of capacity-limited resources.

The evidence from the current study showing that impulsive individuals may be less prone to attentional difficulties when cognitive load is relatively low is important to advancing our understanding of how they operate in the real world, which involves a range of loads. The findings may be particularly valuable in building educational programs and teaching methods targeting children that exhibit impulsive behavior.

In conclusion, the study suggests that trait impulsivity is associated with deficits in response inhibition and conflict when attentional switching is involved in low-level auditory processing. This indicates that impulsivity-related performance differences depend on the nature of the task and on the level of cognitive load it requires.

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