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Reorienting the mind: The impact of novel sounds on go/no-go performance

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The present study explores the link between attentional reorienting and response inhibition. Recent behavioral and neuroscience work indicates that both might rely on similar cognitive and neural mechanisms. We tested two popular accounts of the overlap: The ‘circuit breaker’ account, which assumes that unexpected events produce global suppression of motor output, and the ‘stimulus detection’ account, which assumes that attention is reoriented to unexpected events. In Experiment 1, we presented standard and (unexpected) novel sounds in a go/no-go task. Consistent with the stimulus detection account, we found longer RTs on go trials and higher rates of commission errors on no-go trials when these were preceded by a novel sound compared with a standard sound. In Experiment 2, novel and standard sounds acted as no-go signals. In this experiment, the novel sounds produced an improvement on no-go trials. This further highlights the importance of stimulus detection for response inhibition. Combined, the two experiments support the idea that attention is oriented to novel or unexpected events, impairing no-go performance if these events are irrelevant but enhancing no-go performance when they are relevant. Our findings also indicate that the popular circuit breaker account of the overlap between response inhibition and attentional reorienting needs some revision.

Keywords: attention reorienting, response inhibition, cross-modal oddball, go/no-go, circuit breaker

Flexible behavior in a constantly changing environment requires a cognitive control system that allows people to reorient perceptual attention to important stimuli occurring outside the focus of attention and to cancel or replace actions when novel information requires it. In the present study we explored the link between attentional reorienting and response inhibition in a go/no-go task. Attentional reorienting and response inhibition are usually studied in different paradigms. However, recent behavioral and neuroscience work indicates that both might rely on similar cognitive and neural mechanisms, but it remains unclear how they are related (Levy & Wagner, 2011). We tested two accounts of this overlap: the ‘circuit breaker’ account, which proposes that attentional reorienting involves suppression of ongoing actions, and the ‘stimulus detection’ account proposing that response inhibition primarily depends on detection of the no-go or stop signal and which involves reorienting attention.

The ‘circuit breaker’ account was initially developed in the attentional reorienting literature, and proposes that reorienting attention towards unexpected but potentially behavioral relevant stimuli relies on a ventral frontoparietal network that interrupts ongoing actions (for reviews, see Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002). This right-lateralised reorienting network overlaps strongly with the network that is activated on no-go or stop-signal trials. This has led some researchers to propose that the attentional ‘circuit breaker’ activates a rapid inhibitory control mechanism that suppresses ongoing or planned responses (e.g. Arrington, Carr, Mayer, & Rao, 2000; Nobre, Coull, Frith, & Mesulam, 1999; Shulman et al., 2009). Not surprisingly, this view has also gained traction in the response-inhibition literature. For example, recent reviews on response inhibition speculate that attentional reorienting relies on the same inhibitory mechanisms as stopping in go/no-go and stop-signal tasks (e.g. Aron, 2011; Chambers, Garavan, & Bellgrove, 2009). Recently, this idea received support from computational (Wiecki & Frank, 2013) and empirical work (Wessel & Aron, 2013). In Wiecki and Frank’s model, the right ventrolateral prefrontal cortex, which is typically associated with response inhibition, is responsible for detecting salient events and subsequently engaging a stopping mechanism. Wessel and Aron (2013) found that unexpected events slowed latencies in a seemingly unrelated task (see also Escera, Alho, Winkler, & Näätänen, 1998; Parmentier, 2008; Parmentier, Elford, Escera, Andrés, & SanMiguel, 2008; Parmentier, Elsley, Andrés, & Barceló, 2011; Vachon, Hughes, & Jones, 2012). This slowing was associated with the activation of a neural network that was also activated on trials in which the presentation of a stop signal instructed subjects to cancel a planned response. Furthermore, corticospinal excitability was reduced when an unexpected stimulus occurred. Based on these findings, Wessel and Aron concluded that unexpected

events cause distraction via the global suppression of motor output. Aron, Robbins, and Poldrack (2014) went even further and concluded that ‘any stimulus that is salient/infrequent/unexpected will recruit [motor] inhibition’ (p.179).

However, behavioral distraction caused by unexpected events could also reflect a time penalty associated with the orientation to (and away from) the unexpected novel stimulus (Parmentier et al., 2008; Parmentier et al., 2011). Therefore, the ‘stimulus detection’ account proposes that the presentation of infrequent stimuli (in attentional reorienting paradigms) and no-go or stop signals (in response-inhibition paradigms) activate a similar neural network because both require the reorienting of attention and detection of novel and infrequent stimuli (e.g., Hampshire, 2015; Hampshire, Chamberlain, Monti, Duncan, & Owen, 2010; Schröger, 1996; Parmentier, 2014; Parmentier et al., 2008; Parmentier et al., 2011). Indeed, some have argued that successful response inhibition primarily depends on the rapid detection of infrequent or unexpected events (in this case, the stop or no-go signal; e.g. Boucher, Palmeri, Logan, & Schall, 2007; Salinas & Stanford, 2013; Verbruggen, Stevens, & Chambers, 2014). For example, we have demonstrated that visual distractors impaired stopping when a visual stop signal was presented in the periphery (Verbruggen, Stevens, et al., 2014). However, the distractors occurred frequently, and throughout the whole trial. Therefore, our previous study does not allow us to distinguish between the ‘circuit breaker’ and ‘stimulus detection’ accounts.

In Experiment 1, we contrasted both accounts by introducing novel (deviant) sounds in a go/no-go task. The main task was to respond to the location of the go stimulus but to withhold the response when a no-go stimulus was presented. Participants were told to ignore irrelevant sounds (novel or standards) presented before each go and no-go stimulus. The circuit breaker account predicts that presenting a rare novel sound should produce global suppression of motor output (e.g. Wessel & Aron, 2013), leading to an *impairment* on go trials (i.e. slower go responses) but an *improvement* on no-go trials (i.e. lower probability of responding), compared with presenting a standard sound. Thus, this accounts predicts that task-irrelevant processing (caused by the presentation of the novel sounds) should *enhance* inhibitory control in the primary go/no-go task (for a similar logic, see e.g. Verbruggen, Adams, & Chambers, 2012, who showed that response inhibition in a secondary task led to increased suppression of risky choice options in a primary decision-making task). In contrast, the ‘stimulus detection’ account predicts that both go and no-go performance should be impaired (i.e. slower go responses and higher probability of responding on no-go trials) by the presentation of novel sounds because attention would be oriented away from the

processing of the go/no-go signals.

Experiment 1

Method

Participants

Twenty (15 females) undergraduate students from the University of Exeter (Mean age = 20.45, $SD = 4.21$) participated for course credit.

Apparatus and stimuli

The experiment was run on a 21.5-inch iMac using Psychtoolbox (Brainard, 1997). The stimuli in the go/no-go task were the white letters 'W' and 'M' (0.8 cm x 0.8 cm), presented against a black background (Figure 1). Go/no-go mapping (e.g. 'W' = go; 'M' = no-go) was counterbalanced. The letter appeared on the left or on the right (distance: 3 cm) of a central white cross (size: 0.8 cm x 0.8 cm). Participants responded to the location of the go stimulus by pressing the right or left arrow keys on a computer keyboard using the left and right index finger, respectively.

On each trial, a sound preceded the go/no-go stimulus. There were two types of sounds. The standard sound was a 150 ms sinewave tone (frequency = 600 Hz). Novel sounds were short clips of environmental sounds (e.g., drill, hammer, rain, door, telephone ring, etc.), selected from a list of 60 sounds files (adapted from Escera et al., 1998), each with a duration of 150 ms. Sounds were selected randomly, with the constraint that 'novel' sounds were not immediately repeated. The sounds were presented binaurally via headphones.

Procedure

Participants were instructed to respond as quickly and accurately as possible to the location of the go stimulus, but to withhold their response when a no-go stimulus appeared. They were told to ignore irrelevant sounds presented before each letter. They were also told not to move their eyes or blink between the presentation of the fixation cross and the execution of their response¹.

Each trial started with the presentation of a fixation cross (Figure 1). After 300 ms, the sound was presented. On 80% of the trials, this was the standard sound; on the remaining

¹ We plan to use this task in EEG experiments. In such experiments, participants are instructed not to blink or move their eyes to reduce EEG artifacts. To allow a direct comparison between experiments, we used the same instructions here.

trials, a novel sound was presented. Fifty ms after the irrelevant sound's offset, a go or no-go stimulus appeared on the left or right side of the fixation cross. On two thirds of the trials, a go stimulus appeared, requiring a left or right response. On the remaining trials, a no-go stimulus appeared, instructing participants to withhold their response.

The response deadline was adjusted using a 3-down/1-up tracking procedure. After every three correct go responses the deadline decreased by 50 ms, pushing participants to respond faster; when they failed to respond in time the deadline was increased again by 50 ms. The deadline was not adjusted after a no-go trial. We used separate tracking procedures for standard-sound and novel-sound trials.

At the end of each trial, participants received feedback in the center of the screen for 1000 ms. On go trials, "correct" appeared when they responded correctly to the location of the letter, "incorrect" when they pressed the wrong key, and "too slow" when they did not respond in time. On no-go trials, "correct" appeared when they withheld their response and "do not respond" when they responded.

Participants performed 15 blocks of 60 trials. At the end of each block, we presented the mean RT, number of incorrect and missed go responses, and the percentage of correctly stopped responses. Participants had to pause for 15 seconds before they could start the next block. The total duration of the experimental session was approximately 45 minutes.

Analyses

Data were processed and analysed using R (R Development Core Team, 2014). For estimations of effect sizes, we used Hedges' g_{av} (Lakens, 2013). All data files and R scripts used for the analyses are deposited in Dropbox (<https://www.dropbox.com/sh/02zw0vjlx9onlw9/AADphSYhRPGYC6faCfrtYGgFa?dl=0>)².

The probability of a correct go response was at ceiling (Table 1), so we did not analyse it further. The probability of a missed go response was close to .20, indicating that the tracking procedure worked well.

Results and Discussion

Descriptive statistics appear in Table 1. Go RTs were significantly longer for novel-sound trials (318 ms) than for standard-sound trials (313 ms), $t(19) = 2.40$, $p = .03$, $g_{av} = .21$. Figure 2 shows that the whole RT distribution was shifted to the right for novel-sound trials. Furthermore, the probability of responding on no-go trials was higher for novel-sound trials

² If this paper is accepted, the data files and R scripts will be deposited on the Open Research Exeter data repository.

(.402) than for standard-sound trials (.362), $t(19) = 2.63$, $p = .02$, $g_{av} = .28$. These findings are inconsistent with the ‘circuit breaker’ account. Instead, they provide support for the ‘stimulus detection’ account: attention was orientated to the unexpected novel stimulus; this interfered with detection of the go and no-go stimuli, producing impairment for both trial types.

Experiment 2

We propose that the results of Experiment 1 are inconsistent with the circuit breaker account. However, salient events may not directly suppress motor output but ‘reset’ controlled processing in the primary task (Corbetta, Patel, & Shulman, 2008). Because not going requires a decision (Gomez, Ratcliff, & Perea, 2007; Verbruggen, McLaren, & Chambers, 2014), this ‘reset signal’ could lead to the automatic execution of a prepotent response on no-go trials. Therefore, in Experiment 2 sounds acted as the no-go signal. The ‘stimulus detection’ account predicts that no-go performance should improve if the novel sound is the actual no-go signal, whereas the ‘reset’ version of the circuit breaker account predicts a performance cost.

Method

Participants

Twenty-four (20 females) undergraduate students from the University of Exeter (Mean age = 18.75, $SD = .79$) participated for course credit.

Apparatus, stimuli, procedure, and analyses

These were the same as in Experiment 1, except for the following: sounds were presented at the same moment as the visual stimuli and acted as the no-go signal. Participants were instructed to respond to the location of the go stimulus. The letter ‘M’ was used for half of the participants; the letter ‘W’ for the others. On one third of the trials, a sound was presented at the same time as the visual stimulus, instructing participants to withhold their response. The no-go stimulus was either the standard sound (80% of the no-go trials) or a novel sound (20% of the no-go trials). No sounds occurred on go trials.

Results and Discussion

Descriptive statistics for go and no-go trials appear in Table 1. Here we focus on no-go trials only (i.e. no sounds were presented on go trials). Consistent with the ‘stimulus detection’ account, probability of responding was *lower* for novel-sound no-go trials (.178) than for

standard-sound trials (.325), $t(23) = 7.86$, $p < .001$, $g_{av} = 1.28$. Again, this pattern is consistent with the stimulus detection account.

General discussion

This study explored the link between attentional reorienting and response inhibition in a go/no-go task. Results of Experiment 1 showed that novel sounds presented before the primary-task stimulus impaired performance on both go and no-go trials. This is consistent with the finding that visual ‘noise’ or distractors can impair the detection of visual stop signals (Verbruggen, Stevens, et al., 2014), and provides further support for the ‘stimulus detection’ account. Furthermore, Experiment 2 showed that novel sounds did produce an improvement on no-go trials when they represented the no-go signal. Thus, novelty impairs no-go performance when the sounds are task-irrelevant, but it enhances no-go performance when the sounds are task-relevant.

We recently proposed that response inhibition and other forms of action control require both attentional and response selection (Verbruggen, McLaren, et al., 2014). Biased competition accounts of visual attention assume that attentional selection is a competitive process: the stronger the response to a particular object, the weaker the response to other objects (e.g. Beck & Kastner, 2009; Bundesen, 1990; Desimone & Duncan, 1995; Duncan, 2006; Kastner & Ungerleider, 2000). This competition has also been observed across modalities (Duncan, 2006). Thus, when novel and possibly important stimuli are presented, processing of other stimuli will be suppressed. This leads to a performance cost when the novel stimuli are task-irrelevant (Experiment 1), and leads to a performance benefit when they are task-relevant (Experiment 2).

The results of Experiment 1 are inconsistent with the ‘circuit breaker’ account as it stands, which claims that responding is suppressed when unexpected or potentially relevant stimuli are presented (Aron et al., 2014; Corbetta et al., 2008; Corbetta & Shulman, 2002; Wessel & Aron, 2013; Wieck & Frank, 2013). Wessel and Aron (2013) found that corticospinal excitability was temporarily reduced when an unexpected stimulus occurred. However, in Experiment 1 we found increased responding on novel-sound no-go trials, which is inconsistent with the idea that unexpected events inhibit motor activity. Recent computational work can help to reconcile these findings. Traditionally, researchers assume that responses are stopped via direct inhibition of response units (e.g. Boucher, et al., 2007). However, Logan, Yamaguchi, Schall, and Palmeri (2015) showed that blocking the input to these go units could also stop responses. Deviant sounds direct attention away from the main

task; this could temporarily block the sensory input to the motor system on go trials and subsequently reduce go activity. In other words, the blocked-input account predicts decreased go activity on novel-sound trials, but this is achieved by removing go input rather than by direct suppression of motor activation (cf. Logan et al., 2015). Note that on no-go trials, blocking of input would lead to increased responding because the decision not to go is impaired. Future computational work could compare the block-input and the motor-suppression versions of the circuit breaker account, and whether there are situations in which both mechanisms might be in play.

In conclusion, we tested two accounts, which describe the interplay of reorienting attention and response inhibition. Our results are consistent with the ‘stimulus detection’ account, underlining the importance of reorienting our attention in order to detect the unexpected signals and consequently cancel or replace our actions.

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Table 1. Probability of correct responses on go trials [$p(\text{correct})$], probability of missed go responses [$p(\text{miss})$], average reaction time (RT) for correct go responses and probability of responding on a no-go trial [$p(\text{resp}|\text{no-go})$] as a function of trial type in Experiments 1 and 2. Consistent with our previous work (Verbruggen & Logan, 2009), $p(\text{correct})$ is the ratio of the number of correct responses to the number of correct and incorrect responses: $p(\text{correct}) = \text{correct}/(\text{correct} + \text{incorrect})$. $P(\text{miss})$ is the ratio of the number of omitted responses to the total number of no-stop-signal trials: $p(\text{miss}) = \text{missed}/(\text{correct} + \text{incorrect} + \text{missed})$. M = mean; SD = standard deviation.

	Experiment 1						Experiment 2			
	Novel		Standard		No sound		Novel		Standard	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
$p(\text{correct})$	.995	.007	.990	.010	.964	.029				
$p(\text{miss})$	.197	.009	.210	.004	.210	.004				
RT	318	21	313	22	306	38				
$p(\text{resp} \text{no-go})$	.402	.137	.362	.140			.178	.105	.325	.121

Figure 1. Schematic illustration of the tasks. Experiment 1: on every trial, participants responded to the location of the go stimulus (e.g., W), but tried to withhold their response when a no-go stimulus appeared (e.g., M). Irrelevant sounds (80% standard, 20% novel) were presented before each letter, and participants were told to ignore them. Experiment 2: the task was the same as in Experiment 1, but the sounds (80% standard, 20% novel) and visual stimuli were presented together. The sounds acted as no-go signals. Two trials of every experiment are illustrated.

Figure 2. Distribution of response times in the standard and deviant conditions of Experiment

1.