Neuropsychologia 92 (2016) 142–146

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Inhibiting uncertainty: Priming inhibition promotes reduction of uncertainty

Eyal Kalanthroff[a,b,c,d,*,1], Omer Linkovski[c,d,1], Avishai Henik[c,d], Michael G. Wheaton[a,b,e], Gideon E. Anholt[c]

[a] Department of Psychiatry, Columbia University Medical Center, New York, NY, United States
[b] Anxiety Disorders Clinic and the Center for OCD and Related Disorders, New York State Psychiatric Institute, New York, NY, United States
[c] Department of Psychology Ben-Gurion University of the Negev, Beer Sheva, Israel
[d] Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Beer Sheva, Israel
[e] Ferkauf Graduate School, Yeshiva University, Bronx, NY, United States

ARTICLE INFO

Article history:
Received 7 July 2015
Received in revised form
20 November 2015
Accepted 24 November 2015
Available online 26 November 2015

Keywords:
Uncertainty
Executive control
Attention
Visual search
Obsessive-compulsive disorder (OCD)
Stop signal

ABSTRACT

Uncertainty affects performance in many cognitive tasks, including the visual-search task, and individual differences in the experience of uncertainty may contribute to several psychological disorders. Despite the importance of uncertainty, to date, no study has explained the basic mechanisms underlying individual differences in the experience of uncertainty. However, it has been suggested that inhibition, a cognitive mechanism aimed at suppressing unwanted thoughts or actions, may affect the development of uncertainty. In the current study, we investigated the relationship between inhibition and behavioral responses to uncertainty in the visual-search task. To accomplish this goal, forty six university students completed a novel combined visual-search and stop-signal task, in which we manipulated the degree to which the inhibitory control system was activated by varying the proportions of stop signals in separate blocks. We utilized target-absent trials in the visual-search task as a behavioral probe of responses to uncertainty. We found that activating higher levels of inhibitory control resulted in faster responses to target-absent visual-search trials, while not affecting target-present trials. These findings suggest that activation of inhibitory control may causally affect behavioral responses to uncertainty. Thus, individual differences in inhibitory control may influence the ability to rely on internal-ambiguous cues which are common in visual-search and other cognitive tasks. Clinical implications for obsessive-compulsive disorder (OCD) and other disorders involving deficient inhibitory control and difficulty with uncertainty are discussed.

1. Introduction

Increased uncertainty, a state of increased doubt, hesitancy or ambiguity, promotes checking behavior and commonly slows reaction times (RTs) on various tasks (Banca et al., 2014; Hodsoll and Humphreys, 2001; Najmi and Amir, 2010; Toffolo et al., 2013; Treisman and Gormican, 1988). For example, in the visual-search task performance is linked to uncertainty, as target-absent trials require responses based on internal criterion as there is no external target present (Toffolo et al., 2013). Moreover, it has been shown that increased uncertainty underlies several disorders such as panic disorder (Carleton et al., 2014), health anxiety (Fetzner et al., 2014), generalized anxiety disorder, and obsessive-compulsive disorder (OCD) (Aardema et al., 2009; Holaway et al., 2006). Furthermore, increased uncertainty may constitute a general risk factor in emotional disorders (Boswell et al., 2013). Specifically, difficulties with uncertainty has been suggested as a key factor that drives repeated-checking behaviors, a process underlying various psychopathologies (Dar, 2004; Van Uijen and Toffolo, 2015). For example, in OCD as well as in various anxiety disorders, uncertainty motivates repeated checking – a major symptom of these disorders. Therefore, reducing the experience of uncertainty, and its effects on behavior, is a key element in psychological treatment of these disorders (Belloch et al., 2011; Dugas et al., 2010). Despite the importance of uncertainty, to date, no study has examined the basic mechanisms underlying individual differences in proneness to uncertainty. However, it has been suggested that inhibition, a cognitive mechanism aimed at suppressing unwanted thoughts or actions (Logan, 1994; Logan et al., 1984), may affect the development of uncertainty (Linkovski et al., 2013, 2015). Thus, in the current study we used a novel task to investigate the influence

* Corresponding author at: Department of Psychiatry, Columbia University Medical Center, New York, NY, United States.
E-mail address: eyalkant@gmail.com (E. Kalanthroff).
[1] These researchers contributed equally to the current study.

http://dx.doi.org/10.1016/j.neuropsychologia.2015.11.020
0028-3932/

of inhibition on uncertainty.

In a recent study that investigated behavioral manifestations of uncertainty Toffolo et al. (2013) used a version of the visual-search task, in which participants were asked to decide whether a target stimulus was present or absent in an array of stimuli. In this task, which is commonly used to assess spatial attention, performance is also affected by a non-spatial aspect of attention—ambiguity and uncertainty. Target-absent trials involve a degree of ambiguity, as participants must decide that no target is present while also considering the possibility that they might have overlooked the target in their visual search. Thus, it is difficult to be completely confident about one's decision in these trials. Indeed, surveys of participants show significantly more uncertainty in target-absent than in target-present trials (Toffolo et al., 2014). An important distinction between target-absent and target-present trials is whether the decision is made based on an internal or external cue. On target-present trials, the target itself provides an external visual cue that allows participants to respond with a high degree of confidence (as the target remains on the screen until the response is made), high accuracy, and little uncertainty (Toffolo et al., 2013, 2014). In contrast, decisions about a target's absence involve internal ambiguous cues (an internal representation of the target that was not found). Previous work suggests that decisions based on internal-ambiguous cues induce uncertainty (e.g., Lazarov et al., 2012). In addition, target absent trials also map nicely onto some conceptualizations of OCD symptoms, in which doubts and uncertainty motivate symptoms. Toffolo et al. (2013) found that only in target-absent trials participants with elevated OCD symptoms (sub-clinical) searched longer and used more eye fixations compared to participants with low OCD tendencies (whereas these groups did not differ in target-present trials). The finding that individuals with difficulty tolerating uncertainty (i.e., participants with high OCD symptoms) take longer to respond to target-absent (but not to target-present) trials, along with participants' self-reports that they were less certain about their responses in the target-absent trials, strengthen the notion that target-absent trials induce uncertainty and highlights the usefulness of this cognitive task as a tool to study OCD symptoms. Although Toffolo et al.'s study found differences in responses to uncertainty between the two groups, its correlational design precludes conclusions about the origin of this difference. Because OCD patients are known to exhibit deficient inhibition (e.g., Chamberlain et al., 2006; De Wit, 2012; Penadés et al., 2007), results in that study may involve differences in the efficiency of inhibitory control systems between the two groups (Linkovski et al., 2013). In a recent study, efficient inhibition was suggested to prevent the development of uncertainty (Linkovski et al., 2013). This study replicated the paradoxical effect of repeated checking on uncertainty–the more one checks, the more uncertain one becomes (Boschen and Vuksanovic, 2007; Linkovski et al., in press; Van den Hout et al., 2008; Van den Hout and Kindt, 2003). However, effects of repeated-checking on uncertainty were moderated by inhibition levels such that participants with high levels of inhibitory control were unaffected by repeated checking (Linkovski et al., 2013).

To investigate the causal effects of inhibition on uncertainty we used a novel task that combined the visual-search task and the stop-signal task. The classic stop-signal task (Logan and Cowan, 1984) examines the ability to suppress an already initiated action that is no longer appropriate (for a review see Verbruggen and Logan (2008)). In the classic task, participants are asked to respond to a visual stimulus (go signal) with a motor response as fast as possible, knowing that in some trials an auditory stimulus (stop signal) will follow the visual go signal. Participants are instructed to inhibit their motor response when they hear the stop signal. Recently, Verbruggen et al. (2012) demonstrated that this task can be used to manipulate, rather than to measure, inhibition. Verbruggen and colleagues showed that integrating stop signals in a gambling task activates inhibitory control and reduces risky decision-making (see also: Verbruggen et al., 2013). Guerrieri et al. (2012) showed that the degree to which the inhibitory system is activated can be manipulated by changing the proportions of stop trials within the stop-signal task. These researchers found that the group that completed a block with higher proportion of stop trials had significantly lower caloric intake (i.e., were more inhibited in eating) during a subsequent taste test compared to participants in the "low proportion stop-signal" group.

In the current study we employed two blocks of a novel combined visual-search and stop-signal task that differed in the proportions (high vs. low) of stop trials. This task allowed us to manipulate the degree to which the inhibitory system is activated, with the aim of investigating its effects on the behavioral manifestation of uncertainty (i.e., visual-search target-absent trials). We predicted that in the high inhibitory demand condition (i.e., greater proportion of stop trials), participants would exhibit less uncertainty (i.e., faster response) compared with the low inhibitory demand condition. For target-absent trials, we predicted that (RTs) would be significantly shorter in the high inhibitory demand condition as compared to low inhibitory demand condition. For target-present trials, in which there is no ambiguity about the presence of a cue, we predicted no effect of inhibitory demand.

2. Method

2.1. Participants

Forty-nine participants (recruited via the university's online experiments system) participated for course credit or a small monetary reward. The study was approved by University's Institutional Research Board and all participants signed an informed consent form prior to participating in this study. All participants had normal or corrected-to-normal vision, had no self-reported history of attention deficit hyperactivity disorder (ADHD) or dyslexia, and all were naive as to the purpose of the experiment. In addition, in order to ensure participants' engagement, accuracy of 0.75 in the visual-search task was set as the threshold for inclusion. Three participants were excluded based on this criterion; thus the analyzed sample comprised 46 participants (29 females and 17 males; average age = 24.13 years, SD = 1.95).

2.2. Stimuli

The target line in the visual-search task was a 1.4 cm long green line, at a 45° incline. Non-target lines differed in either color (pink, gray) or orientation (vertical, 135° incline), so that all lines shared one feature with the target (i.e., orientation or color). The auditory stop signal was a brief tone (750 Hz, 85 dB, 50 ms; see Fig. 1)

2.3. Procedure

Participants completed the novel combined visual-search task with stop signals (see Fig. 1). On stop trials participants were instructed to inhibit their responses and wait for the following trial. The portion of the trials on which a stop signal appeared was manipulated to create high and low inhibitory demand conditions. In the high demand condition stop signals were presented on 30% of trials. In the low demand condition stop signals were presented on 10% of trials. Blocks of trials were administered, in a counter balanced order, to induce differential activation of the inhibitory system.

Prior to beginning the task, a target stimulus (a unique combination of color and angle) was introduced and participants were

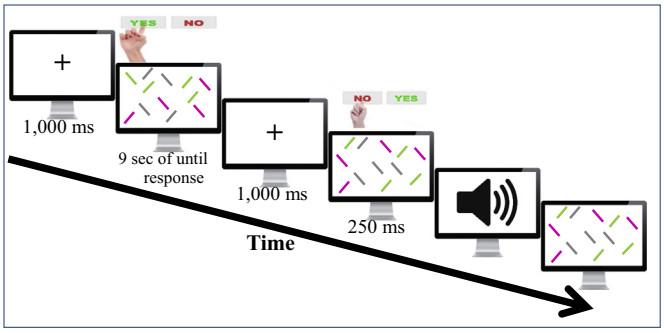

Fig. 1. Example of a target-present trial followed by a target-absent stop-signal trial. The target was a 1.4 cm long green line, slanted at 45°. The auditory stop signal was a brief tone. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

asked to hold it in mind and remember it. Each trial started with a 1000 ms fixation cross (i.e., a white cross at the center of the screen), followed by an array of a varied number of colored-lines (16, 18, or 20) appearing in different angels on a black background. Participants were instructed to indicate, as quickly and accurately as possible, whether the target line was present or absent in the current array. Responses were made using the "/" and "z" keys on the keyboard for target-absent and target-present trials – stimulus-response mapping was counterbalanced.[2] The array remained on screen for nine seconds or until a key press. The auditory stop signal was presented 650 ms following the presentation of the visual-search array. The stop signal signaled participants to cease searching and wait for the next trial without responding. Each block included 200 trials. The high inhibitory demand block featured 60 stop trials and 140 no-stop trials, of which 112 featured a target (e.g., target-present) and 28 trials did not (e.g., target-absent). The low inhibitory demand block featured 20 stop trials and 180 no-stop trials of which 144 featured a target and 36 did not. The ratio between target-present trials and target-absent trials was kept constant in both stop and no-stop trials and in both blocks. Each block started with 27 training trials which were identical to the upcoming block and in the same proportions of the different conditions, and which included feedback for accuracy and RT. Responses on practice trials were not included in our analyses.

2.4. Data analyses

Performance on the stop-signal task was evaluated by the proportion of erroneous responses (i.e., responses made despite the appearance the stop-signal) out of all stop trials. A paired-sample *t-test* was applied to compare the performance on the stop-signal task in the high vs. low inhibitory demand blocks. To analyze performance on the visual-search task we calculated RT for correct responses, on trials without a stop-signal, as a function of trial type (target-present vs. target-absent) and inhibitory demand condition (high vs. low). Accuracy was calculated as the proportion of correct responses from all responses (for no-stop trials only). One-way ANOVAs with repeated measures were conducted to compare RT and accuracy data between trial type and inhibitory demand condition. In order to investigate the interaction between trial type and inhibitory demand condition, a two-way ANOVA with repeated measures was applied to RT and accuracy data (separately), with trial type and inhibitory demand condition as within-subjects factors. To further investigate this two-way interaction we conducted planned comparisons (one-way ANOVAs with repeated measures) to compare the performance on high vs. low inhibitory demand conditions, in the target-absent and target-present conditions separately. Alpha was set at $p < .05$ (two-tailed).

[2] For the first 28 participants, the response keys were such that the "/" was for target-absent and the "z" was for target-present. In an effort to counterbalance response mappings to reduce any effect of participant handedness we subsequently ran 21 participants with the response keys reversed.

3. Results

On the stop-signal task p(r|s) (i.e., proportion of erroneous responses on stop signal trials) was not significantly affected by level of inhibitory demand ($M = 35\%$ for both high and low inhibition conditions), $t(45) = 1.17$, $p = .247$. On the visual-search task we found faster RT and higher accuracy in target-present trials compared with target-absent trials (RT: 1471 ms vs. 2784 ms, $F(1, 45) = 245.14$, $p < .001$, $\eta_p^2 = .85$; Accuracy: 0.92 vs. 0.77, $F(1, 45) = 159.59$, $p < .001$, $\eta_p^2 = .78$). There were no significant differences in RT or accuracy between the two inhibitory demand conditions (RT: 1715 ms vs. 1669 ms for low vs. high inhibition respectively, $F(1, 45) = 1.41$, $p = .24$; Accuracy: 0.88 vs. 0.89 for low vs. high inhibition respectively, $F(1, 45) = 1.38$, $p = .25$).

There was a significant interaction of RTs between trial type and inhibitory demand condition, $F(1, 45) = 4.90$, $p < .03$, $\eta_p^2 = .10$ (see Fig. 2). A similar interaction for accuracy rate was not evident, $F(1, 45) = 2.31$, $p = .14$.[3] Planned comparisons revealed significantly faster RT in the high inhibitory demand condition compared with the low inhibitory demand condition in the target-absent condition (126 ms difference), $F(1, 45) = 5.39$, $p < .03$, $\eta_p^2 = .11$, but not in the target-present condition (26ms difference), $F(1, 45) = .44$, $p = .51$[4] (see Fig. 2).

4. Discussion

In the current study we investigated the effect of activation of the inhibition system on behavioral responses to uncertainty. To do so, we used a novel paradigm in which we combined a visual-search task (previously validated as a reliable tool to study uncertainty in the lab), with stop-signal trials, which activate the inhibitory control system. By using different proportions of stop signal trials, we manipulated the degree of inhibitory activation (Guerrieri et al., 2012; Verbruggen et al., 2013). We found that only

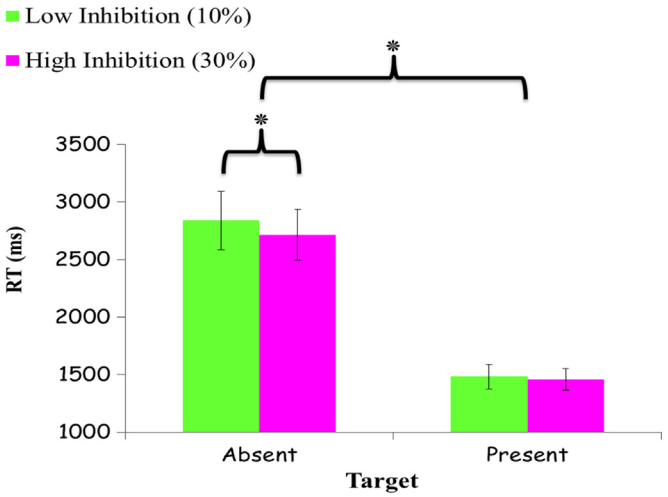

Fig. 2. Mean RT in the different inhibition conditions for the visual-search task in target-absent vs. target-present trials. *Significant at $p < .05$ levels. Error bars represent 95% confidence intervals.

in the high uncertainty condition (target-absent trials), where decisions must be made based on ambiguous cues, greater engagement of the inhibitory system resulted in shorter RTs – a behavioral manifestation associated with reduced uncertainty. Importantly, on the target-present trials, on which a decision can be made based on clear external cues (which do not involve uncertainty), there was no effect for degree of inhibitory activation, indicating that the effect of inhibition is specific to ambiguous trials (hence uncertainty) rather than a global effect on cognitive processes. These results also highlight the interaction between spatial and non-spatial factors (i.e., uncertainty and inhibition) on visual attention and target identification tasks.

In a previous study we found that participants with less efficient inhibitory control are prone to uncertainty-driven behaviors following a repeated checking manipulation (Linkovski et al., 2013). The current study results suggest one possible causal relationship—that a basic cognitive process (activation of inhibitory control) influences behavioral responses to ambiguous cues, which can involve higher order emotional processes, such as the experience of uncertainty. This possibility is in line with the model presented by Noël et al. (2013) in which neuropsychological executive factors, such as activation of inhibitory systems, might reduce the influence of emotionally driven processes that affect behavior (such as uncertainty). Similarly, Kalanthroff et al. (2013) have shown that the effect of negative emotional cues is attenuated when inhibitory control is activated (for a similar suggestion see also (Cohen et al., 2011)). Hence, the current study results might be better understood as a specific and unique example for the interaction between executive functions and emotional operations. We suggest that this specific relationship between uncertainty and inhibitory control has particular implications for the visual-search task, where uncertainty plays a key role in performance in target-absent trials.

As mentioned earlier, increased uncertainty underlies several psychopathologies (e.g., Boswell et al., 2013; Carleton et al., 2014; Fetzner et al., 2014) with OCD being the most pronounced (e.g., Aardema et al., 2009; Holaway et al., 2006; Lambrecq et al., 2013). Szechtman and Woody (2004) suggested that OCD patients experience difficulties in their ability to generate the normal "feeling of knowing" and Lazarov et al. (2012) found that decisions that are not based on clear unambiguous cues were difficult for OCD patients. More specifically, using a similar version of the visual-search task, Toffolo et al. (2013) reported that subclinical-OCD participants exhibited behavioral responses consistent with heightened uncertainty in target-absent trials. OCD has also been associated with inhibitory deficits, which have been suggested to be a core factor in the etiology and maintenance of the disorder (Bannon et al., 2002; Chamberlain et al., 2005; de Wit et al., 2012; Kalanthroff et al., 2014; Morein-Zamir et al., 2010; Penadés et al., 2007). Interestingly, although both problems with uncertainty and inhibitory deficits have been studied extensively with respect to OCD, the interaction between these two factors was not previously investigated. Therefore, a model based on the interplay between inhibition and uncertainty might improve upon models that focus on only one factor. Additionally, by establishing a potential causal relationship, the current study supports the view of deficient inhibitory control as a contributing factor, rather than an epiphenomenon, of OCD (Anholt et al., 2012; Chamberlain et al., 2005; Robbins et al., 2012). Future studies are required in order to determine the psychological and neurological mechanisms that underlie the interaction between uncertainty and inhibition. An attractive hypothesis would be that individuals with good inhibitory control might be able to inhibit/suppress intrusive doubts and thoughts about uncertainty. Thus, good inhibitory control might serve as a protective factor from disorders characterized by pathological doubts, including OCD.

The mechanism that was probed in the current study reveals an important aspect of human behavior that we believe might also have clinical implications, specifically to OCD. However, there are several limitations to the current study that should be noted. First, the relevance of our results to clinical disorders should be interpreted with caution since the current study involved non-clinical participants. A more specific investigation of this mechanism in clinical samples awaits future studies. A second limitation stems from the design that consisted of only one aspect of executive functioning – response inhibition. Inhibition has been suggested to be a hallmark of the executive system (Verbruggen and Logan, 2008), however, the design of the current study does not allow us to draw specific conclusions about inhibition per-se. It is possible that a similar effect would be obtained following triggering of other executive functions (e.g., conflict monitoring).

To conclude, we found that greater activation of inhibitory control reduces behavioral manifestations of uncertainty. Our results demonstrate the existence of a potential causal pathway between inhibitory operations and the experience of uncertainty. These results suggest that individual differences in inhibitory control should be taken into consideration in a wide variety of cognitive tasks that induce uncertainty. Moreover, the current results underscore an effect of non-spatial factors (uncertainty and inhibition) on performance in a spatial visual-search task. This suggests that performance on visual attention tasks involves an interaction between spatial and non-spatial aspects of visual attention. This interaction might have specific implications for clinical patients. In addition, the causal effect of inhibition on uncertainty that was demonstrated in the current study may underlie a pathway that is of specific importance to OCD and perhaps other psychopathologies that are characterized by difficulties with tolerating uncertainty and deficits in response inhibition. Understanding this pathway might improve our understanding of the way goal-directed behaviors are executed in general, and particularly in OCD. This suggestion might also inspire novel treatment targets (see: Belloch et al., 2011; Dugas et al., 2010).

[3] d′ for the high inhibitory demand condition was 2.17 whereas d′ was 2.11 for the low inhibitory demand condition. Taken together with the lack of differences in accuracy rates between the high and low inhibitory demand conditions, these analyses indicate that there was not a substantial criterion shift in the high vs. low inhibitory demand conditions.

[4] In order to rule out an artifact of differences in general RTs (i.e., shorter RTs in target-present compared with target-absent trials) we conducted two additional analyses: (a) a sensitivity analysis in which we re-conducted the two-ways ANOVA (and the planned comparisons) using only the fastest quarter of the trials in the target-absent condition and the slowest quarter of the trials in the target-present condition; and (b) a proportion analyses in which we have calculated the proportions between high and low inhibition conditions in target-absent and target-present trials separately, and then compared them using a t-test. In both analyses, the same pattern of results was obtained (i.e., the effect of inhibition condition was larger in the target-absent condition), indicating that the results could not be explained by differences in the measurement scale.

Acknowledgment

We thank Ms. Lee Shem-Tov for her assistance in collecting the data. Dr. Kalanthroff is supported by the Rothschild Caesarea Foundation, the Molberger Scholar Award, and The Israel Science Foundation (Grant no. 79/15).

References

Aardema, F., O'Connor, K.P., Pélissier, M.C., Lavoie, M.E., 2009. The quantification of doubt in obsessive-compulsive disorder. Int. J. Cogn. Ther. 2 (2), 188–205. http://dx.doi.org/10.1521/ijct.2009.2.2.188.

Anholt, G.E., Linkovski, O., Kalanthroff, E., Henik, A., 2012. If I do it, it must be important: integrating basic cognitive research findings with cognitive behavior theory. Psicoter. Cogn. E Comport. 18 (1), 69–77.

Banca, P., Vestergaard, M.D., Rankov, V., Baek, K., Mitchell, S., Lapa, T., Voon, V., 2014. Evidence accumulation in obsessive-compulsive disorder: the role of uncertainty and monetary reward on perceptual decision-making thresholds. Neuropsychopharmacology 40 (5), 1192–1202. http://dx.doi.org/10.1038/npp.2014.303.

Bannon, S., Gonsalvez, C.J., Croft, R.J., Boyce, P.M., 2002. Response inhibition deficits in Obsessive-Compulsive Disorder. Psychiatry Res. 110, 165–174.

Belloch, A., Cabedo, E., Carrió, C., Fernández-Alvarez, H., García, F., Larsson, C., 2011. Group versus individual cognitive treatment for Obsessive-Compulsive Disorder: changes in non-OCD symptoms and cognitions at post-treatment and one-year follow-up. Psychiatry Res. 187 (1–2), 174–179. http://dx.doi.org/10.1016/j.psychres.2010.10.015.

Boschen, M.J., Vuksanovic, D., 2007. Deteriorating memory confidence, responsibility perceptions and repeated checking: Comparisons in OCD and control samples. Behav. Res. Ther. 45, 2098–2109.

Boswell, J.F., Thompson-hollands, J., Farchione, T.J., Barlow, D.H., 2013. Intolerance of uncertainty: a common factor in the treatment of emotional disorders. J. Clin. Psychol. 69 (6), 630–645. http://dx.doi.org/10.1002/jclp.21965.

Carleton, R.N., Duranceau, S., Freeston, M.H., Boelen, P.A., McCabe, R.E., Antony, M. M., 2014. "But it might be a heart attack": intolerance of uncertainty and panic disorder symptoms. J. Anxiety Disord. 28 (5), 463–470. http://dx.doi.org/10.1016/j.janxdis.2014.04.006.

Chamberlain, S.R., Blackwell, A.D., Fineberg, N.A., Robbins, T.W., Sahakian, B.J., 2005. The neuropsychology of obsessive compulsive disorder: the importance of failures in cognitive and behavioural inhibition as candidate endophenotypic markers. Neurosci. Biobehav. Rev. 29 (3), 399–419. http://dx.doi.org/10.1016/j.neubiorev.2004.11.006.

Chamberlain, S.R., Fineberg, N.A., Blackwell, A.D., Robbins, T.W., Sahakian, B.J., 2006. Motor inhibition and cognitive flexibility in obsessive-compulsive disorder and trichotillomania. Am. J. Psychiatry 163 (7), 1282–1284.

Cohen, N., Henik, A., Mor, N., 2011. Can emotion modulate attention? Evidence for reciprocal links in the attentional network test. Exp. Psychol. 58 (3), 171–179. http://dx.doi.org/10.1027/1618-3169/a000083.

Dar, R., 2004. Elucidating the mechanism of uncertainty and doubt in obsessive-compulsive checkers. J. Behav. Ther. Exp. Psychiatry 35 (2), 153–163. http://dx.doi.org/10.1016/j.jbtep.2004.04.006.

de Wit, S.J., de Vries, F.E., van der Werf, Y.D., Cath, D.C., Heslenfeld, D.J., Veltman, E. M., van den Heuvel, O.A., 2012. Presupplementary motor area hyperactivity during response inhibition: a candidate endophenotype of obsessive-compulsive disorder. Am. J. Psychiatry 169, 1100–1108.

Dugas, M.J., Brillon, P., Savard, P., Turcotte, J., Gaudet, A., Ladouceur, R., Gervais, N.J., 2010. A randomized clinical trial of cognitive-behavioral therapy and applied relaxation for adults with generalized anxiety disorder. Behav. Ther. 41 (1), 46–58. http://dx.doi.org/10.1016/j.beth.2008.12.004.

Fetzner, M.G., Asmundson, G.J.G., Carey, C., Thibodeau, M.A., Brandt, C., Zvolensky, M.J., Carleton, R.N., 2014. How do elements of a reduced capacity to withstand uncertainty relate to the severity of health anxiety? Cogn. Behav. Ther. 43 (3), 262–274. http://dx.doi.org/10.1080/16506073.2014.929170.

Guerrieri, R., Nederkoorn, C., Jansen, A., 2012. Disinhibition is easier learned than inhibition. The effects of (dis)inhibition training on food intake. Appetite 59 (1), 96–99. http://dx.doi.org/10.1016/j.appet.2012.04.006.

Hodsoll, J., Humphreys, G.W., 2001. Driving attention with the top down: the relative contribution of target templates to the linear separability effect in the size dimension. Percept. Psychophys. 63 (5), 918–926. http://dx.doi.org/10.3758/BF03194447.

Holaway, R.M., Heimberg, R.G., Coles, M.E., 2006. A comparison of intolerance of uncertainty in analogue obsessive-compulsive disorder and generalized anxiety disorder. J. Anxiety Disord. 20 (2), 158–174. http://dx.doi.org/10.1016/j.janxdis.2005.01.002.

Kalanthroff, E., Cohen, N., Henik, A., 2013. Stop feeling: inhibition of emotional interference following stop-signal trials. Front. Hum. Neurosci. 7, 78. http://dx.doi.org/10.3389/fnhum.2013.00078, March.

Kalanthroff, E., Anholt, G.E., Henik, A., 2014. Always on guard: test of high vs. low control conditions in obsessive-compulsive disorder patients. Psychiatry Res. 219 (2), 322–328. http://dx.doi.org/10.1016/j.psychres.2014.05.050.

Lambrecq, V., Rotge, J.Y., Jaafari, N., Aouizerate, B., Langbour, N., Bioulac, B., Guehl, D., 2013. Differential role of visuospatial working memory in the propensity toward uncertainty in patients with obsessive-compulsive disorder and in healthy subjects. Psychol. Med. 44, 1–12. http://dx.doi.org/10.1017/S0033291713002730.

Lazarov, A., Dar, R., Liberman, N., Oded, Y., 2012. Obsessive-compulsive tendencies and undermined confidence are related to reliance on proxies for internal states in a false feedback paradigm. J. Behav. Ther. Exp. Psychiatry 43 (1), 556–564. http://dx.doi.org/10.1016/j.jbtep.2011.07.007.

Linkovski, O., Kalanthroff, E., Henik, A., Anholt, G.E., 2013. Did I turn off the stove? Good inhibitory control can protect from influences of repeated checking. J. Behav. Ther. Exp. Psychiatry 44 (1), 30–36. http://dx.doi.org/10.1016/j.jbtep.2012.07.002.

Linkovski, O., Kalanthroff, E., Henik, A., Anholt, G.E., 2015. Stop checking: repeated checking and its effects on response inhibition and doubt. J. Behav. Ther. Exp. Psychiatry, in press.

Logan, G.D., Cowan, W.B., 1984. On the ability to inhibit thought and action: a theory of an act of control. Psychol. Rev. 91 (3), 295.

Logan, G.D. (1994). On the ability to inhibit thought and action: A users' guide to the stop signal paradigm.

Logan, G.D., Cowan, W.B., Davis, K.A., 1984. On the ability to inhibit simple and choice reaction time responses: a model and a method. J. Exp. Psychol. Hum. Percept. Perform. 10 (2), 276–291.

Morein-Zamir, S., Fineberg, N.A., Robbins, T.W., Sahakian, B.J., 2010. Inhibition of thoughts and actions in obsessive-compulsive disorder: extending the endophenotype? Psychol. Med. 40 (2), 263–272. http://dx.doi.org/10.1017/S003329170999033X.

Najmi, S., Amir, N., 2010. The effect of attention training on a behavioral test of contamination fears in individuals with subclinical Obsessive-Compulsive Symptoms. J. Abnorm. Psychol. 119 (1), 136–142. http://dx.doi.org/10.1037/a0017549.

Noël, X., Brevers, D., Bechara, A., 2013. A triadic neurocognitive approach to addiction for clinical interventions. Front. Psychiatry 4, 1–14. http://dx.doi.org/10.3389/fpsyt.2013.00179 (DEC).

Penadés, R., Catalán, R., Rubia, K., Andrés, S., Salamero, M., Gastó, C., 2007. Impaired response inhibition in obsessive compulsive disorder. Eur. Psychiatry: J. Assoc. Eur. Psychiatr. 22 (6), 404–410. http://dx.doi.org/10.1016/j.eurpsy.2006.05.001.

Robbins, T., Gillan, C., Smith, D., 2012. Neurocognitive endophenotypes of impulsivity and compulsivity: towards dimensional psychiatry. Trends Cogn. 16 (1), 81–91. http://dx.doi.org/10.1016/j.tics.2011.11.009.

Szechtman, H., Woody, E., 2004. Obsessive-Compulsive Disorder as a disturbance of security motivation. Psychol. Rev. 111 (1), 111–127. http://dx.doi.org/10.1037/0033-295X.111.1.111.

Toffolo, M.B.J., van den Hout, M.A., Hooge, I.T.C., Engelhard, I.M., Cath, D.C., 2013. Mild uncertainty promotes checking behavior in subclinical Obsessive-Compulsive Disorder. Clin. Psychol. Sci. 1 (2), 103–109. http://dx.doi.org/10.1177/2167702612472487.

Toffolo, M.B.J., van den Hout, M.A., Engelhard, I.M., Hooge, I.T.C., Cath, D.C., 2014. Uncertainty, checking, and intolerance of uncertainty in subclinical obsessive compulsive disorder: an extended replication. J. Obsessive Compuls. Relat. Disord. 3 (4), 338–344. http://dx.doi.org/10.1016/j.jocrd.2014.08.004.

Treisman, A., Gormican, S., 1988. Feature analysis in early vision: evidence from search asymmetries. Psychol. Rev. 95 (1), 15–48. http://dx.doi.org/10.1037/0033-295X.95.1.15.

Van den Hout, M., Kindt, M., 2003. Repeated checking causes memory distrust. Behav. Res. Ther. 41 (3), 301–316. http://dx.doi.org/10.1016/S0005-7967(02)00012-8.

Van den Hout, M.A., Engelhard, I.M., de Boer, C., du Bois, A., Dek, E., 2008. Perseverative and compulsive-like staring causes uncertainty about perception. Behav. Res. Ther. 46 (12), 1300–1304. http://dx.doi.org/10.1016/j.brat.2008.09.002.

Van Uijen, S.L., Toffolo, M.B.J., 2015. Safety behavior increases obsession-related cognitions about the severity of threat. Behav. Ther. 46, 521–531. http://dx.doi.org/10.1016/j.beth.2015.04.001.

Verbruggen, F., Logan, G.D., 2008. Response inhibition in the stop-signal paradigm. Trends Cogn. Sci. 12 (11), 418–424. http://dx.doi.org/10.1016/j.tics.2008.07.005.

Verbruggen, F., Adams, R., Chambers, C.D., 2012. Proactive motor control reduces monetary risk taking in gambling. Psychol. Sci. 23 (7), 805–815. http://dx.doi.org/10.1177/0956797611434538.

Verbruggen, F., Adams, R.C., van't Wout, F., Stevens, T., McLaren, I.P.L., Chambers, C. D., 2013. Are the Effects of Response Inhibition on Gambling Long-Lasting? PLoS ONE 8 (7), e70155. http://dx.doi.org/10.1371/journal.pone.0070155.