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Trial-to-trial carryover effects on spatial attentional bias☆,☆☆

Thomas E. Gladwin[a,*], Bernd Figner[b,c]

[a] Department of Psychology & Counselling, University of Chichester, Chichester, United Kingdom
[b] Behavioral Science Institute, Radboud University, Nijmegen, the Netherlands
[c] Donders Institute for Brain, Cognition and Behaviour, Radboud University, Nijmegen, the Netherlands

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ABSTRACT

Visual Probe Tasks (VPTs) have been extensively used to measure spatial attentional biases, but as usually analysed, VPTs do not consider trial-to-trial carryover effects of probe location: Does responding to a probe on, e.g., the location of a threat cue affect the bias on the subsequent trial? The aim of the current study was to confirm whether this kind of carryover exists, using a novel task version, the diagonalized VPT, designed to focus on such trial-to-trial interactions. Two versions of the task were performed by a sample of college students. In one version cues were coloured squares; in the other, cues were threat-related and neutral images. Both versions included partially random positive or negative response feedback and varying Cue-Probe Intervals (200 or 600 ms). Carryover effects were found in both versions. Responding to a probe at the location of a cue of a given colour induced an attentional bias on the subsequent trial in the direction of that colour. Responding to a threat-related cue induced an attentional bias towards threat on the subsequent trial. The results provide evidence that trial-to-trial carryover effects on spatial attentional bias indeed exist. A methodological implication is that previous probe location could be considered in analyses or re-analyses of spatial visual attention tasks.

1. Introduction

The ability to select relevant information for further processing and response selection is essential for efficient, adaptive behaviour. Visual spatial attention is an important form of this ability, in which information is selected from regions of the visual field. This process involves bottom-up or intrinsic visual features versus top-down or task-dependent signals, together creating a spatial map of saliency (Soltani & Koch, 2010). Saliency maps are also affected by attentional biases involving emotional or motivational stimuli (Mogg & Bradley, 2016). Such biases involve effects on selection or inhibition that are not due to intrinsic visual features, but that are nevertheless automatic rather than controlled and in that sense bottom-up. Attentional biases are commonly studied using dot-probe or visual probe tasks (VPTs) (MacLeod, Mathews, & Tata, 1986). In these tasks, emotional cue stimuli are presented on screen, and their appearance affects the saliency map as measured by responses to probe stimuli appearing at their location versus away from their location (Cisler & Koster, 2010; Mogg & Bradley, 2016; Notebaert, Crombez, Van Damme, De Houwer, & Theeuwes, 2011) or predicted location (Gladwin, Möbius, Mcloughlin, & Tyndall, 2019). Attentional approach versus avoidance of emotional cues is inferred from faster versus slower responses to probes at their location, relative to responses to probes at the location of non-emotional cues. Attentional biases, in terms of both attentional approach and avoidance, have been connected to a wide range of clinical disorders, including anxiety (for review, see Mogg & Bradley, 2016), aggression (e.g., Kimonis, Frick, Fazekas, & Loney, 2006) and post-traumatic stress disorder (for review, see Aupperle, Melrose, Stein, & Paulus, 2012).

VPTs may however also contain information in the trial-to-trial variability that would long have been considered noise. That is: the bias towards or away from a certain stimulus category could change from one trial to the next, or over relatively brief periods of time within a task session. This variability of the attentional bias to and from salient stimuli over trials has received recent research interest, although questions have been raised about the interpretation of most measures of attentional bias variability (Kruijt et al., 2016). Nevertheless, attentional bias variability has been related to, e.g., trauma (Iacoviello et al., 2014), anxiety (Zvielli, Bernstein, & Koster, 2014), and conflicting positive and negative alcohol-related associations (Gladwin & Vink, 2018).

One as yet rarely explored source of attentional bias variability could be trial-to-trial *carryover effects* (Gladwin, 2017; Hill & Duval,

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* Corresponding author at: Department of Psychology and Counselling, University of Chichester, College Lane, Chichester PO19 6PE, United Kingdom.
E-mail address: thomas.gladwin@gmail.com (T.E. Gladwin).

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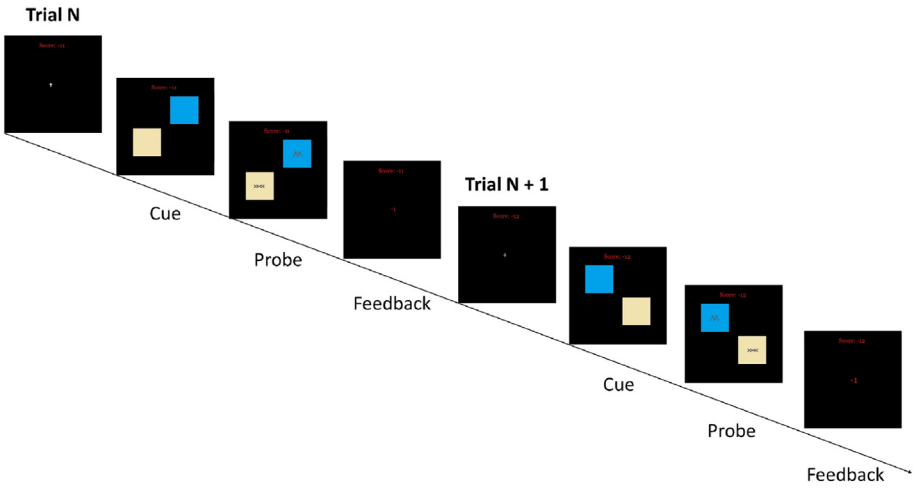

Fig. 1. Illustration of the diagonalized Visual Probe Task.
Trials consisted of a cue, which remained on screen for 200 or 600 ms. In the Colour version of the task, cue stimuli were a yellow and a blue box. In the Threat version of the task, a neutral and a threatening picture were used. A probe stimulus then appeared requiring a button press indicating the location of a target stimulus. Correct responses were followed by random positive or negative feedback. Incorrect responses were always followed by negative feedback only. The diagonal on which the two elements of the cue appeared alternated over trials so that spatial location and response button were never repeated. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
RTs per condition.

A. Colour variant

	Blue				Yellow			
	Neg		Pos		Neg		Pos	
	200	600	200	600	200	600	200	600
Blue	563 (121)	540 (124)	562 (126)	553 (142)	567 (114)	561 (118)	582 (118)	563 (124)
Yellow	576 (122)	563 (130)	572 (114)	563 (128)	550 (115)	535 (127)	552 (110)	544 (142)

B. Threat variant

	Neutral				Threat			
	Neg		Pos		Neg		Pos	
	200	600	200	600	200	600	200	600
Neutral	582 (95)	529 (99)	584 (93)	526 (87)	592 (102)	531 (89)	593 (94)	533 (102)
Threat	588 (93)	528 (88)	588 (85)	524 (83)	588 (101)	525 (88)	583 (79.7)	532 (109)

Note. The Table shows the mean RT per condition, with standard deviations in brackets, of the Colour and Threat variants of the dVPT. Standard deviations are given for the between-subject data, i.e., without removal of the subject means. Rows show the probe locations on the current trial. Columns show the probe location on the previous trial, feedback on the previous trial (Negative or Positive), and Cue-Probe interval (200 or 600 ms). The overall accuracy was 0.96 in the Colour task and 0.96 in the Threat task.

2016). This refers to effects caused by the probe appearing on the emotional versus non-emotional location that are observed on the subsequent trial. Say, for instance, that on trial N the probe appears at the location of the emotional cue. The question is whether the attentional bias on trial N + 1 is different from if the probe had appeared at the location of the non-emotional cue on trial N. Analogous effects have been found to affect non-spatial attentional biases in the emotional Stroop task (Cane, Sharma, & Albery, 2009; Clarke, Sharma, & Salter, 2014; Waters, Sayette, Franken, & Schwartz, 2005; Wilson, Sayette, Fiez, & Brough, 2007) and spatial attentional biases carrying over between different tasks (Thompson & Crundall, 2011). The rationale for translating the carryover concept to trial-to-trial effects in spatial visual probe tasks is that responding to probes at the location of the emotional versus non-emotional cue could cause a state that affects attentional bias on the subsequent trial. Such a state could be described using a generalized concept of binding (Roelfsema, Engel, König, & Singer, 1997; Treisman & Gelade, 1980) in which the stimulus feature "threat" is bound to an attentional function. If this binding remains active on the subsequent trial, it would cause an attentional bias towards the location of the cue corresponding to the previous probe's location. Some evidence for carryover effects has been found for threat VPTs (Gladwin, 2017): Responding to probes at the location of threat cues caused lower overall accuracy on the subsequent trial (but no change in bias towards or away from threat), and subclinical post-traumatic stress disorder symptoms were associated with this effect. Further, symptoms appeared to be associated with a time-dependent carryover effect on bias, in which responding to threat on a trial induced a bias towards threat on the next trial, expressed by increased errors when the probe appeared on the neutral cue location. Such effects would be missed without considering previous trial cue location as a factor in analyses. However, it remains to be firmly established that trial-to-trial carryover exists as a phenomenon in spatial attentional bias tasks.

The aim of the current study was therefore to confirm the hypothesis that trial-to-trial carryover effects exist in visual probe tasks. We used a variant of the VPT, the diagonalized VPT (dVPT), optimized to study such effects. This task is designed in such a way as to reduce trial-to-trial interference other than the type of carryover effect of interest. Essentially, neither response keys nor stimulus locations were ever repeated. In task version 1 (the Colour task), the cues concern a basic visual feature (the colour of cues), while in task version 2 (the Threat task), the cues concern an emotional-motivational feature (threatening versus non-threatening scenes). An additional, more exploratory

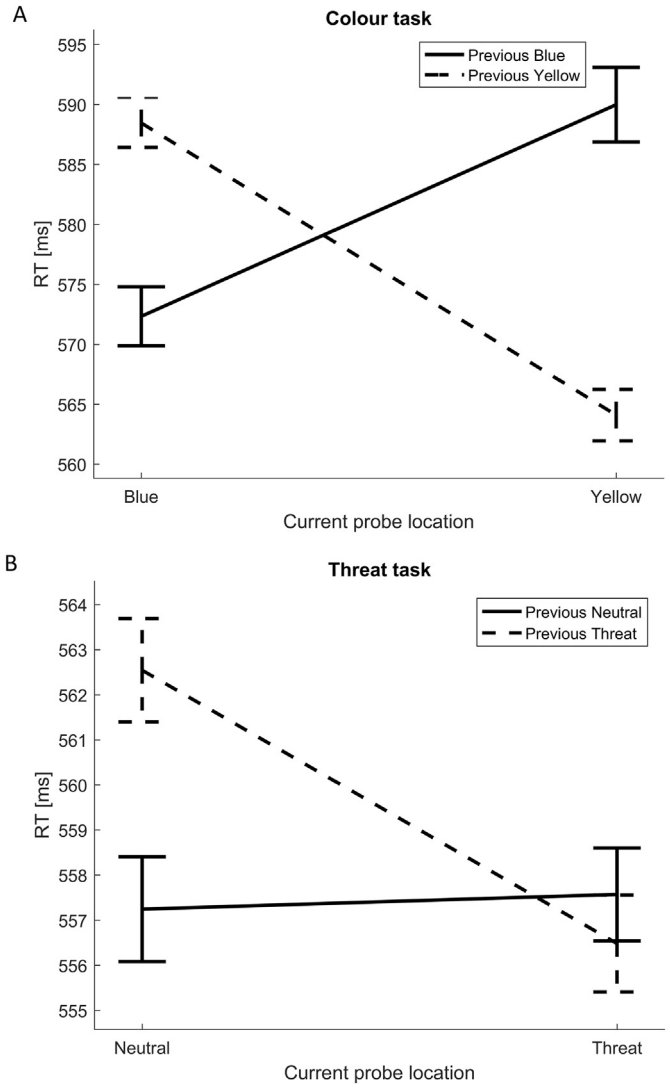

Fig. 2. Carryover effects.
The figures illustrate the main findings involving carryover. The x-axis represents the location of the probe on the current trial. The lines are separated based on the location of the probe on the previous trial. The error bars are +1/−1 standard errors based on the data after removal of the subject means, as effects concerned within-subject factors (Cousineau, 2005; O'Brien & Cousineau, 2016). In both task versions, attentional bias was affected by the probe location on the previous trial. In the Colour task (A), an attentional bias was induced in the direction of the cue associated with probe location on the previous trial. In the Threat task (B), an attentional bias to threat, expressed as slower responses when the probe appeared away from the threat cue, was found only following trials when the probe appeared at the location of the threat cue.

question involved the use of random feedback on responses. This was based on the theoretical perspective that the adaptive activation of cognitive responses to stimuli must depend on prior reinforcement processes (de Wit & Dickinson, 2009; Gladwin & Figner, 2014; Hazy, Frank, & O'Reilly, 2007). Just as how motor responses are learned and subsequently selected, likely involving dopaminergic signals in the basal ganglia, cognitive responses and even executive functions are determined by whether they were previously reinforced (Bunge, 2004; Lanciego, Luquin, & Obeso, 2012). We therefore hypothesized that trial-to-trial carryover would depend on whether positive or negative feedback occurred on the previous trial, even if this feedback was task-independent. If positive versus negative feedback occurred, carryover was expected to be stronger, as positive feedback would reinforce the most recently performed cognitive action (i.e., attending to a location associate with a given cue category). Finally, the Cue-Probe Interval (CPI), the duration of the interval between the cues (the stimuli expected to induce an attentional shift) and the probe (the stimulus requiring a response), was manipulated, as temporal dynamics are known to play an important role in attentional biases (Mogg, Bradley, Miles, & Dixon, 2004). There was no specific a priori hypothesis concerning CPI and variability, but using multiple CPIs allows potential time-dependent effects to be detected.

2. Methods

2.1. Participants

Participants were students who enrolled for participation credits (N = 163, analytical sample of 144 after removing subjects who showed low overall accuracy (below 0.8) or incomplete data; 119 female and 25 male, mean age 20, SD = 4).

2.2. Diagonalized visual probe task

Two versions of the dVPT were used (Fig. 1). In both versions, trials started with the presentation of two cue stimuli. In the Colour version of the task, the cues were a yellow and a blue square. In the Threat version of the task, the cues were neutral and threatening pictures drawn from a subset of 14 images from the International Affective Pictures Set (Lang, Bradley, & Cuthbert, 2008). Threatening pictures included attacking animals and scenes with physical violence such as a pointed gun. Neutral pictures included non-threatening animals and sports scenes. Pictures never repeated from one trial to the next. The positioning of the two cue stimuli changed per trial, alternating between the diagonals of locations on a two by two grid. That is, they either appeared at the top-left and bottom-right locations, or at the bottom-left and top-right locations. The cues remained on-screen for a CPI of either 200 or 600 ms, with equal probability. During cue presentation and throughout the trial, the current score was shown in white (if the score was non-negative) or red (if the score was negative) digits at the top of the screen. Following the CPI, the probe stimulus appeared. The probe consisted of two symbols: The target symbol ≫≪ which replaced one of the two cues, and a non-target symbol ⋁⋁ or ⋀⋀ on the other location. The task was to press the button corresponding to the location of the target. The keyboard response buttons were R, F, J, and I; note that these had a strong stimulus-response compatibility in terms of spatial locations (e.g., “upper-left”, “lower-left”, etc.). The task continued after a response was given. Following an incorrect response, a red “-1” was presented as negative feedback, and the score was decreased. Following a correct response, a red “−1” or a green “+1” could appear, with equal probability, while the score was in the range −2 to +2. Outside this range, there was a tendency for the score to be pushed back towards zero. If the score was lower than −2 and the initial random feedback was negative, there was a 0.4 chance for the random feedback to become positive. If the score was higher than +2 and the initial random feedback was positive, there was a 0.4 chance for the random feedback to become negative. The score was updated according to the feedback. Participants were instructed that the feedback was random, but that incorrect responses were always followed by negative feedback. It was therefore still optimal to provide correct responses. The intertrial interval was 250 ms.

The Colour dVPT consisted of 9 blocks of 35 trials per block. The Threat dVPT consisted of 16 blocks of 35 trials per block. The difference in block numbers was due to the expectation that fewer trials would be needed to detect effects involving the simple Colour cues due to the simpler categories and the lack of variation of cues per category.

Importantly for the current study, by using the diagonalized locations and these response keys, neither stimulus locations nor response keys were repeated from one trial to the next. This removed these sources of trial-to-trial influence.

2.3. Procedure

The study was performed online. Participants received information via a webpage, clicked on a clearly marked button to indicate informed consent, and then received an invitation by email with a link to participate. Participants performed the Colour and Threat versions of the dVPT, always starting with the Colour version. Participants also filled in questionnaires and performed other tasks and subsequent sessions unrelated to the current study.

2.4. Data pre-processing and statistical analyses

Analyses were performed in Matlab (The Mathworks, 2015). The first four trials of the task, the first trial of each block, trials with incorrect responses and trials following incorrect responses and trials with RTs above 3000 ms were removed as being likely noisy. Further pre-processing concerned the removal of trial data that was logged more than once (due to a feature of the software that re-logged data when the connection was slow, to avoid data loss) and the removal of data of task performance that was repeated or restarted. Repeated measures ANOVA was used to test effects of the within-subject factors of Current Probe Location (Blue or Yellow for the Colour version; Threat or Neutral for the Threat version), Previous Probe Location (Probe Location on the previous trial), CPI (200 versus 600 ms), and Previous Feedback (Negative or Positive). Higher-order interactions were explored using post-hoc tests which performed lower-order interactions per level of one of the variables of the higher-order interaction. The dependent variable was median RT, as this removes effects of outliers and the need to set arbitrary RT criteria for defining outliers.

Data and scripts are available on request.

3. Results

Descriptive statistics are provided in Table 1. Overall accuracy was good, 0.96 for the Colour task and 0.96 for the Threat task. Fig. 2 illustrates the main findings. For the Colour version, the primary test—the interaction between Current Probe Location and Previous Probe Location—was significant, $F(1, 143) = 91$, $p < .0001$, $\eta_p^2 = 0.39$: On the trials following a response to a probe at the location of a blue cue, responses were faster for probes on blue than on yellow cue locations, $t(143) = -3.44$, $p = .00076$, $d = 0.29$. On the trials following a response to a probe at the location of a yellow cue, responses were slower for probes on blue than on yellow cue locations, $t(143) = 7.66$, $p < .0001$, $d = -0.64$. This interaction was not further moderated by CPI or Previous Feedback. There were also effects of Previous Probe Location (responses were faster following responses to yellow than to blue locations: $t(143) = -2.22$, $p = .028$, $d = -0.18$), and of CPI (responses were faster following the longer (600 ms) than the shorter (200 ms) CPI: $t(143) = -5.54$, $p < .0001$, $d = -0.46$).

For the Threat version, the interaction between Current Probe Location and Previous Probe Location was also significant, $F(1, 143) = 8.5$, $p = .0042$, $\eta_p^2 = 0.056$. On trials following respond-to-threat trials, responses to the threat location were faster than responses to the non-threat location, $t(143) = -2.92$, $p = .0041$, $d = -0.24$. On trials following respond-to-non-threat trials, there was no significant difference between probes at the threat versus non-threat location, $t(143) = -0.63$, $p = .53$, $d = 0.0027$. There was no further moderation of the interaction. There was a main effect of CPI, with faster responses following the longer than the shorter CPI, $t(143) = -27.89$, $p < .0001$, $d = -2.32$; and an effect of Previous Probe Location, with slower responses following probes at the threat versus non-threat location, $t(143) = 2.00$, $p = .048$, $d = 0.17$.

4. Discussion

The results confirmed the primary hypothesis: Carryover effects were found in both task variants. In the Colour task, responses were faster on probes appearing at the location of the same Colour-cue as where the previous trial's probe had appeared, versus on probes appearing at the location of the other cue. In the Threat task, an attentional bias to threat was only found following a trial with a response to a probe on the threat location. This was previously interpreted in terms of a kind of binding (Roelfsema et al., 1997; Singer et al., 1996) between the function of attentional selection and the stimulus category associated with the position to which attention is shifted (Gladwin, 2017). Questions clearly remain on the precise processes underlying carryover effects. Whether effects occur at the level of the saliency map or involve later processing involving response selection cannot yet be determined. However, the current carryover effects fit the binding interpretation, or stated somewhat differently the model of a task set (Monsell, 2003) of stimulus – response mappings, with cue categories as imperative stimuli and attentional shifting as the responses to which the stimuli are mapped. That is, it appears that by responding to a probe at the location of a given cue, a mapping is established between that cue category and the covert cognitive response of shifting attention to that cue's location (or potentially, away from the non-attended location's cue).

We note that while the carryover effect was found in both tasks, it was stronger in the Colour than in the Threat task. The effect size of the interaction was greater in the Colour task, and the effect in Threat task was limited to trials following a probe-on-threat trial. There are a number of reasons that could have played a role in this. First, the colour cues were highly visually salient and there was no variation between cues. In contrast, threat versus non-threat stimuli were complex and varied, requiring more visual processing to determine the categories and presumably also varying in how threatening different exemplars were. This would be expected to lead to more noise in the Threat task. Further, the limitation of the effect to post-threat trials may be a true effect: perhaps responding to neutral trials does not induce a bias in the way that attending to threat trials does. Speculatively, this would make evolutionary sense, in that becoming attuned to threat and down-regulating unthreatening information could aid survival.

A limitation of the current study is that the results concern a novel task variant, specifically designed to answer the theoretical question of whether carryover effects exist in spatial attentional bias. While it appears difficult to explain these effects in a different way than an attentional bias, whether similar effects can be found in classical dot-probe tasks remains to be determined by future research. Some current task-variations involving feedback, such as the changing colour of the score, may be unnecessary or suboptimal for future work. Less abstract positive and negative feedback could yet prove to influence carryover, for instance angry faces or electric shock. A second limitation is the use of true randomization per trial rather than precisely counterbalanced trials. However, analyses of trial numbers showed the expected averaging to very similar numbers for comparable conditions; there did not seem to be any likely way random variations in trial numbers could result in systematic RT differences. Nevertheless, future work could consider controlling the trial numbers per condition, per participant. Third, the possibility was raised during review of a different kind of carryover, namely of CPI – could effects involve differences involving the same versus different CPI being used on consecutive trials? We note that there was no systematic relationship between CPI-carryover and the type of carryover, Category-carryover, that was the focus of the current study. However, future work could restrict the design to a single CPI to remove any effect of this type of carryover. Fourth, the stimulus categories of threat versus non-threat could be further decomposed, in particular in terms of being negative and arousing. In the current study, threat stimuli would be both more negative and more arousing than the control stimuli. Future work could determine whether carryover effects are also found while controlling for either dimension. Fifth, the order of the Colour and the Threat tasks was not counterbalanced, so that comparisons between the tasks are confounded by order and time on

task.

In conclusion, trial-to-trial carryover effects were found in spatial attentional bias tasks involving colour and threat cues. Including previous probe location as a factor in future analyses may contribute to the understanding of trial-to-trial variability and reveal previously undetected effects and relationships.

Declarations of interest

None.

Compliance with ethical standards

The authors declare no conflict of interest. The study was approved by the institutional ethical review board (Ethics Committee of the Radboud University Nijmegen, application ECSW2016-1710-422). Participants provided informed consent before performing the experiment.

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