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Attention capture is temporally stable: Evidence from mixed-model correlations

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ABSTRACT

Studies on domain-specific expertise in visual attention, on its cognitive enhancement, or its pathology require individually reliable measurement of visual attention. Yet, the reliability of the most widely used reaction time (RT) differences measuring visual attention is in doubt or unknown. Therefore, we used novel methods of analyses based on linear mixed models (LMMs) and tested the temporal stability, as one index of reliability, of three attentional RT effects in the popular additional-singleton research protocol: (1) bottom-up, (2) top-down, and (3) memory-driven (intertrial priming) influences on attention capture effects. Participants searched for a target having one specific color in most (Exp. 1) or all (Exp. 2) trials. Together with the target, in half (Exp. 1) or two thirds (Exp. 2) of the trials, a distractor was presented that stood out by the target's (Exp. 1) or a target-similar (Exp. 2) color, therefore matching a top-down search set, or by a different color, capturing attention in a bottom-up way. Also, matching distractors were primed or unprimed by the target color of the preceding trial. We analyzed all three attention capture effects in manual and target fixation RTs at two different times, separated by one (Exp. 1 and 2) or four weeks (only in Exp. 1). Random slope correlations of LMMs and standard correlation coefficients computed on individual participants' effect scores showed that RT capture effects were in general temporally stable for both time intervals and dependent variables. These results demonstrate the test-retest reliability necessary for looking at individual differences of attentional RT effects.

1. Introduction

Due to the importance of visual attention for a variety of everyday tasks, such as reading, vision-based learning, or vehicle control, recent years have seen an increasing interest in the inter-individual differences in visual attention capabilities for diverse research purposes, such as domain-specific expertise (e.g., Gegenfurtner, Lehtinen, & Säljö, 2011), pathological conditions (e.g., Ross, Harris, Olincy, & Radant, 2000), or cognitive enhancement (e.g., Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Green & Bavelier, 2003; Heitz & Engle, 2007). Although some methodology is available for this purpose, so far, research on inter-individual differences in visual attention rarely applies the experimental protocols that are most widely used in basic attention research. One reason for this state of affairs is that, in the domain of visual attention, many popular basic-research protocols rely on reaction time (RT) differences, but RT differences are of notoriously low reliability (Paap & Sawi, 2016). Yet, reliability is important for the study of inter-individual differences. Take the example of cognitive enhancement research. To demonstrate that an intervention increases the participants' top-down control of attention, it would be necessary to measure stable effects at least among the participants of a control group, without such intervention. Likewise, to link psychological pathologies with attentional functions, it needs to be shown that pathologies affect attentional capabilities in a stable manner for as long as the pathology in question continues.

The current study therefore tested once more if inter-individually varying but reliable (here: temporally stable) RT differences of attentional functions can be measured. So far, reliability of attentional RT differences has only been tested with traditional statistics, such as uncorrected RT differences between two conditions, one of which reflects more, the other of which less attentional selection. Such RT differences are sensitive to the accumulation of uncorrected errors of measurement (Miller & Ulrich, 2013). We therefore used novel analytical tools that have been tailored to control for such accumulation of errors–linear mixed models (LMMs; Pinheiro & Bates, 2000). An LMM counteracts the increased measurement error introduced by the computation of

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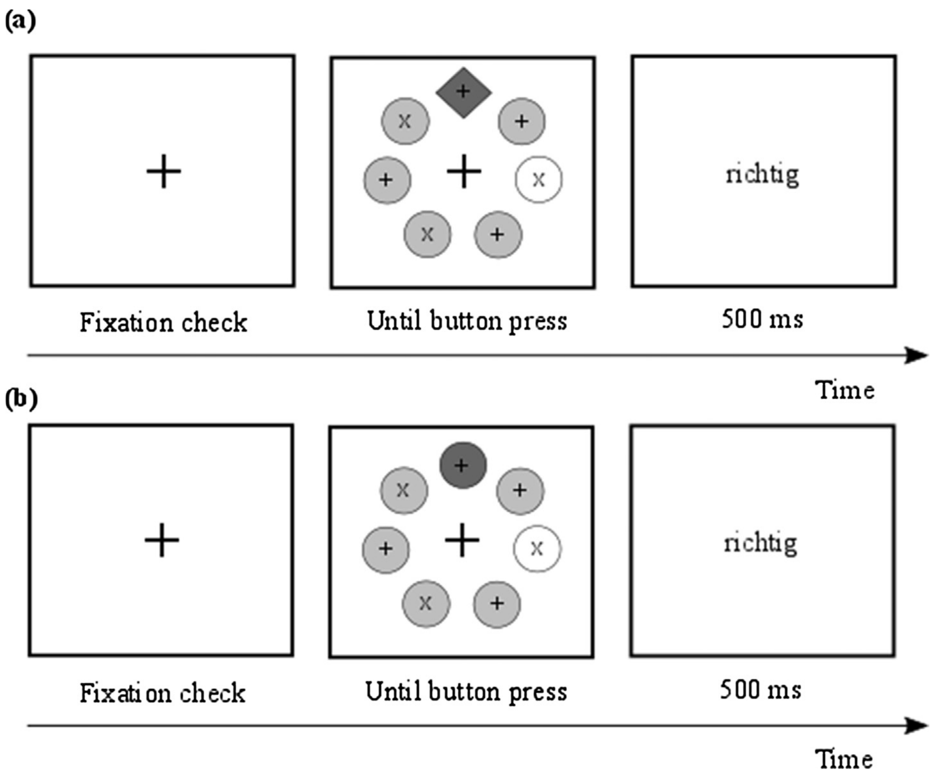

Fig. 1. Depicted are example trials of the non-matching distractor condition of Experiment 1 (Panel a; cf. Becker et al., 2009) and Experiment 2 (Panel b). A major difference between the experiments was the shape of the target, here in dark gray; diamond for Experiment 1 and disc for Experiment 2. The white disc represents the non-matching distractor. "richtig" is German for "correct". Stimuli are not drawn to scale.

difference scores by more *shrinkage* of extreme effect values (i.e., based on more variable RTs) towards the estimated population mean (cf. Kliegl, Wei, Dambacher, Yan, & Zhou, 2011). We used one very popular experimental protocol of visual attention, the additional-singleton paradigm (cf. Theeuwes, 1991, 1992), with more attentional selection in conditions with than without a singleton, and tested if RT differences of attentional origin that are measured within this paradigm show sufficient reliability in the form of temporal stability when tested with LMMs. To compare LMM measures with traditional correlations, we also report Pearson and, where appropriate, Spearman correlation coefficients based on the individual participants' difference scores.

The additional-singleton paradigm is a popular protocol for studying visual attention. It requires visual search–that is, participants' searching for relevant visual targets among potentially distracting stimuli (Bundesen, 1990; Treisman & Gelade, 1980; Wolfe, 2007). In general, during visual search humans not only attend to relevant targets: Human attention is also often captured in a seemingly involuntary fashion by task-irrelevant distractors–that is, salient singletons that stand out by one of their features (e.g., their colors) among more feature-homogeneous non-singletons (Theeuwes, 1992, 1994).

The current study addresses an open question in this area: whether stable individual differences exist concerning three of the most common forms of attention capture, namely top-down contingent capture, bottom-up capture, and intertrial priming of capture (Awh, Belopolsky, & Theeuwes, 2012). Top-down contingent capture is an explanation for more capture by distractors similar to a target. These target-similar distractors may capture attention due to their match to top-down search settings directed at target features (Folk, Remington, & Johnston, 1992). Bottom-up capture accounts for the attraction of attention by more irrelevant and less task-related salient singleton distractors without much similarity to relevant targets (Theeuwes, 2010). A singleton distractor can be salient because of being different from its surrounding in a number of features, such as color, luminance, or orientation (Itti, Koch, & Niebur, 1998). Finally, priming of capture is demonstrated where a distractor attracts attention independently of the participant's current search goals because this distractor carries a feature similar to a previously attended-to target (often and also here: in the preceding trial, Kristjánsson, 2006; Maljkovic & Nakayama, 1994).

Importantly, the usage of measures of top-down, bottom-up, or primed attention capture for tests on individual differences requires benchmark tests of the reliability of these attention measures in normal healthy samples (e.g., Gordon & Mettelman, 1988), but these are missing (cf. Rodebaugh et al., 2016). The current study closes this gap. Besides traditional manual RT measures of visual search time, we also included the measurement of eye movements because these are tightly connected to attention (Deubel & Schneider, 1996; Itti et al., 1998; Zelinsky, 2008). Inclusion of eye movements also allows testing the spatial nature of attention capture (e.g., in the form of fixations directed to a distractor) and analyzing attention capture at points in time before search concludes (cf. Donk & van Zoest, 2008). In our study, bottom-up and top-down capture, as well as priming of capture were measured in the same single visual search task based on a protocol by Becker, Ansorge, and Horstmann (2009). This protocol was used because it allows measuring all three mentioned attention capture principles in a single task. This has the advantage of keeping method-specific variance at check, which otherwise might complicate the interpretation of correlations between different attention measures (cf. Roque, Wright, & Boot, 2016).

2. Experiment 1

Participants had a *compound visual search task*: They were instructed to look for one feature (a diamond-shaped target among six non-target discs) and to discriminate between another feature (crosses) inside the target (either an "x" or a "+"; see Fig. 1) by pressing alternative buttons.[2]

[2] On the basis of the findings by Becker et al. (2009), we expected that the participants incorporated the fixed target color into their top-down search set. The reason for this strategy of the participants is probably the facilitation of target search by looking for color rather than shape, an assumption that was also tested and confirmed in the present experiment by comparing search times