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Does temporal preparation facilitate visual processing in a selective manner? Evidence from attentional capture

Verena C. Seibold *, Bettina Rolke

Evolutionary Cognition, Department of Psychology, University of Tübingen, Schleichstraße 4, D-72076 Tübingen, Germany

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ABSTRACT

The present study addressed the question of whether temporal preparation influences perceptual stimulus processing in a selective manner. In three visual search experiments, we examined whether temporal preparation aids spatial selection and thus reduces distraction caused by the onset of a task-irrelevant item. In each trial, participants had to detect a target amongst five non-targets and report a basic feature of the target. In some trials, an additional task-irrelevant singleton item (abrupt onset) appeared on the screen which distracted attention away from the target. To manipulate the degree of distraction, we varied the spatial distance and the stimulus-onset asynchrony between target and singleton. Temporal preparation for the target varied by means of constant foreperiods of different lengths. Though we observed overall faster responding in the case of high temporal preparation in all three experiments, temporal preparation did not reduce spatial distraction by the abrupt onset, even when the spatial position of the target was predictable. In sum, this pattern of results does not provide support for an influence of temporal preparation on spatial selection. Instead, it indicates that temporal preparation affects early visual processing in a non-selective manner.

1. Introduction

At each moment while perceiving the world around us, our senses are faced with a bulk of information. One crucial cognitive function that enables us to manage this sensory overload is *attention*. Specifically, attention refers to a mediating cognitive function that serves to both prioritise and enhance processing of currently relevant information against information that may be irrelevant (Chun & Wolfe, 2001). These selection and sensory enhancement mechanisms have been shown to be very robust and flexible and can operate with different types of representations, ranging from basic sensory features like stimulus modality (e.g., Boulter, 1977; Spence, Shore, & Klein, 2001) to more complex feature-configurations (e.g., Moore, Yantis, & Vaughan, 1998; Vecera & Farah, 1997).

In vision, one especially highlighted dimension regarding the selective function of attention is *space* (e.g., Chun & Wolfe, 2001; Handy & Mangun, 2000; Theeuwes, 2010). Inspired by the notion of an attentional spotlight that can be flexibly moved within visual space (e.g., Posner, 1980), spatial attention has been regarded as the major means by which a portion of visual information will actually be selected. This selection process may be driven either *voluntarily*, that is, in accordance with a person's goals or expectations (e.g., Folk, Remington, & Johnston, 1992), or *involuntarily* (Posner, 1980; Theeuwes, 1991a, b), for example, driven by the relative saliency of a stimulus against its surroundings (e.g., Ruz & Lupiáñez, 2002). Regardless of the way attention is directed within visual space, those objects that fall into its beam will receive higher attentional weight and thus will be more likely subjected to further processing (Chun & Wolfe, 2001).

The involvement of spatial attention in visual selection has been documented in a wide range of studies (for reviews see Carrasco, 2011; Chun & Wolfe, 2001; Theeuwes, 2010). For example, spatial cuing studies have consistently revealed that a valid spatial cue, which correctly announces the position of an impending target, leads to a response benefit for the target whereas an invalid spatial cue leads to a response cost (e.g., Downing, 1988; Kingstone, 1996; Posner, 1980). Furthermore, psychophysical studies have shown that focusing attention on a specific location increases perceived stimulus contrast (Carrasco, Ling, & Read, 2004; Yeshurun & Carrasco, 1998), a finding that is directly in line with the idea that attended stimuli receive higher weights. Finally, maybe the most compelling evidence for space-based selection comes from studies on visual search, and specifically those involving the presentation of irrelevant singletons (for reviews see Chun & Wolfe, 2001; Theeuwes, 2010). In this kind of experimental paradigm, participants have to find one designated target object amongst multiple distractors. Importantly, in some portion of the trials, one of

* Corresponding author at: Evolutionary Cognition, Department of Psychology, University of Tübingen, Schleichstraße 4, 72076 Tübingen, Germany. Tel.: +49 7071 29 75641.
E-mail addresses: verena.seibold@uni-tuebingen.de (V.C. Seibold), bettina.rolke@uni-tuebingen.de (B. Rolke).

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the distractors contains a salient but task-irrelevant feature like, for example, a unique colour or shape (e.g., Theeuwes, 1991a, 1991b). Experimental research conducted within this paradigm has demonstrated that the mere presence of this salient feature disrupts search performance (e.g., Theeuwes, 1991a, 1991b; Yantis & Jonides, 1996). For example, Theeuwes (1991b) showed that reaction time (RT) to a target was prolonged when a task-irrelevant salient feature was presented in one of the distractor positions. Theoretically, this observation is explained in terms of an involuntary shift of spatial attention towards the salient event, also known as *attentional capture*. Importantly, attentional capture can be counteracted by voluntary guidance of attention. For example, attentional capture is reduced or even eliminated by giving advance information about the target's spatial location (Theeuwes, 1991b; Yantis & Jonides, 1990). Furthermore, the degree of capture depends on the spatial proximity of the target and the irrelevant item (e.g., Theeuwes, 1995), which also underlines that it is a spatial phenomenon. Altogether, spatial attention is thus an important determinant of visual selection and can be guided in both a bottom-up and top-down manner.

In addition to space, *time* is another dimension which has not received that much attention yet, but may also play a role in selective processing of visual information. Specifically, just like attention can be guided to specific locations in visual space, it can also be guided towards specific moments in time and, in this way, facilitate stimulus processing. This phenomenon, commonly referred to as *temporal preparation* (e.g., Müller-Gethmann, Ulrich, & Rinkenauer, 2003; Rolke & Ulrich, 2010), can develop through internal expectations (e.g., Coull & Nobre, 1998; Kingstone, 1996; Los & Van den Heuvel, 2001) or the perception of temporal regularities in the environment (e.g., Olson & Chun, 2001). For example, in the *constant foreperiod paradigm*, temporal preparation for an impending target is induced by the presentation of a warning signal (e.g., a sine tone) which precedes the target by either a short (e.g., 800 ms) or a rather long interval (e.g., 2400 ms). Crucially, this interval, referred to as the *foreperiod*, is kept constant within blocks of trials, but changes across blocks of trials. As a consequence, participants learn the duration of the foreperiod within the trials and can thus predict and prepare for the moment of stimulus presentation. These preparatory attempts, however, are less effective for longer foreperiods, due to the increased difficulty in estimating longer time intervals and maintaining an attentive, preparatory state. On the behavioural level, the decline in temporal preparation for longer foreperiods is mirrored in an increase in RTs (e.g., Klemmer, 1956; Müller-Gethmann et al., 2003; Niemi & Näätänen, 1981; Woodrow, 1914). Importantly, temporal preparation, like spatial attention, leads to a reliable perceptual benefit, as shown in a bulk of experimental studies (for a review see, e.g., Rolke & Ulrich, 2010; see also Correa, Lupiáñez, Madrid, & Tudela, 2006). For example, behavioural studies have revealed benefits due to temporal preparation in signal detection (e.g., Klein & Kerr, 1974), temporal order judgement (e.g., Correa, Sanabria, Spence, Tudela, & Lupiáñez, 2006), and discrimination of masked stimuli (e.g., Rolke & Hofmann, 2007). Furthermore, electrophysiological studies have shown that temporal preparation modulates sensory components of the event-related potential (Correa, Lupiáñez, Madrid, & Tudela, 2006; Lange & Röder, 2006; Sanders & Astheimer, 2008; Seibold & Rolke, 2014). Finally, recent modelling studies have revealed that temporal preparation accelerates the speed of sensory processing (e.g., Vangkilde, Coull, & Bundesen, 2012) and may also enhance stimulus contrast (Bausenhart, Rolke, Seibold, & Ulrich, 2010).

The observation that temporal preparation leads to a general perceptual benefit and may involve mechanisms similar to those proposed for spatial attention (i.e., contrast enhancement; Bausenhart et al., 2010) evidently raises the question of whether this effect may be stimulus-specific. Stated differently, does temporal preparation enhance perceptual processing only in a *non-selective* manner – by enhancing sensory processing in general – or in a *selective* manner — by selecting which stimuli are subjected to further processing? So far, empirical evidence in this regard is scarce since the majority of earlier studies were focused on measuring the isolated effect of temporal preparation on perceptual processing of single stimuli without any competing event (see also Correa, Cappucci, Nobre, & Lupiáñez, 2010).

Some indirect hints for such a selective effect arise from studies addressing the impact of temporal context variations on the exogenous spatial cueing effect (Lamy, 2005; Milliken, Lupiáñez, Roberts, & Stevanovski, 2003). The exogenous spatial cueing effect refers to the observation that responses to a target are faster when the target is preceded by a cue appearing in the same spatial location in contrast to a different location. In a first study addressing temporal context effects on exogenous spatial cueing, Milliken et al. (2003) showed that biasing participants' expectation towards one of three cue-target stimulus onset asynchronies (SOAs) magnified the exogenous cueing effect. Furthermore, in another study on this topic, Lamy (2005) compared exogenous spatial cueing effects in variable and regular temporal contexts by means of variable and fixed cue-target SOAs. In contrast to Milliken et al. (2003), however, she observed that cueing effects were not enhanced by a regular temporal context (i.e., the fixed cue-target SOAs), but instead were completely eliminated. On the grounds of the notion that exogenous spatial cues cause an involuntary shift of spatial attention towards their location, Lamy argued that temporal preparation may allow for faster recovery from this involuntary attention shift. Finally, besides these indirect hints from exogenous spatial cueing studies, supportive indication for a selective effect emerges from a study by Correa et al. (2010) who addressed the idea of a selective effect within various conflict tasks. Most importantly, they observed that temporal preparation reduced perceptual conflict in a Spatial Stroop task (Experiment 2 of Correa et al., 2010), which is in line with the idea that temporal preparation may facilitate stimulus selection. These authors reasoned that temporal preparation may selectively pre-activate processing of task-relevant features and thus reduce perceptual conflict.

In summary, several studies suggest an involvement of temporal preparation in the selection of sensory information. However, the results reported in the exogenous cueing studies are quite inconsistent – pointing towards either reduced or magnified selectivity – and also seem to be confined to particular experimental conditions. Specifically, the enhanced cueing effect in the study of Milliken et al. (2003) was observed only for the shortest SOAs, but did not occur when biasing participants towards the two longer SOAs. Furthermore, the SOAs used in exogenous spatial cueing studies were rather short (i.e., 125, 300, and 425 ms in the study by Lamy) as compared to typical foreperiods used in temporal preparation research (i.e., at least about 400 to 600 ms; see Correa, Lupiáñez, Madrid, & Tudela, 2006; Rolke, 2008). This is especially important as RT benefits from brief foreperiods were partially attributed to an increase in arousal which operates in addition to temporal expectancy (Hackley & Valle-Inclán, 1998; see also Steinborn, Rolke, Bratzke, & Ulrich, 2008). It is therefore difficult to explain the above-mentioned findings exclusively in terms of voluntary temporal preparation. Instead, they may have resulted from an intermittent increase in arousal triggered by the exogenous cue. Finally, the conclusions that can be drawn from the Spatial Stroop study by Correa et al. (2010) are limited in that sense that it only showed that temporal preparation aids selection amongst different features situated within one object at one spatial location. However, this study was uninformative regarding a possible selective effect of temporal preparation in situations in which task-relevant information and task-irrelevant information were part of different objects at different spatial locations, and thus selection, in the first instance, takes place between objects.

The present study was conducted to fill in this gap. Specifically, we investigated whether temporal preparation modulates spatial selection amongst competing task-relevant and task-irrelevant objects. To this end, we conducted three visual search experiments in which we examined whether temporal preparation influences attentional capture.