Attention speeds up visual information processing: Selection for perception or Selection for action?

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Abstract. Attention speeds up information processing. Although this finding has a long history in experimental psychology, it has found less regard in computational models of visual attention. In psychological research, two frameworks explain the function of attention. *Selection for perception* emphasizes that perception- or consciousness-related processing presupposes selection of relevant information, whereas *selection for action* emphasizes that action constraints make selection necessary. In the present study, we ask whether or how far attention as measured by the speed-up of information processing is based on selection for perception or selection for action. The accelerating effect was primarily based on selection for perception, but there was also a substantial effect of selection for action.

Keywords: visuo-spatial attention, prior entry, selection for action, selection for perception

1 Introduction

Most theories of attention assume that attention is beneficial for information processing by yielding more accurate and detailed processing of information, see e.g. [4], [6], [9] and [13]. A wide body of empirical research demonstrated that attention is a pre-condition for complex object representations and awareness of these objects [15], [25], [30], [29]

Two interesting phenomena which support the assumption that attention is a pre-condition for awareness are *inattentional blindness* [11], [26] and *change blindness* [15] Simons and Chabris (1999) had observers watch a film of two teams playing basketball. They directed observers' attention by the experimental task to one of the teams: counting the ball passes of this team. During the basketball play, a person in a gorilla costume respectively a woman with an umbrella walked through the scene. Almost half of the observers were "inattentional" and overlooked these unexpected, but very prominent events. Studies on *change blindness* [15], [16] demonstrated that observers have difficulties to detect salient changes in static scenes if these changes co-occur with dynamic events such as eye blinks, saccades or flicker on the screen. Change blindness can, however, be attenuated by attention: If a cue directs observer's attention to the part of scene that will change, observers can detect the changes more quickly.

In this paper we focus on a less familiar, though not less important, consequence of attention on information processing: Attention accelerates information processing, e.g. it speeds up detection [14]. This acceleration means for example that, in comparison to an unattended stimulus, an attended stimulus is perceived earlier or as appearing earlier. Although this notion of "prior entry" of attended stimuli has been studied for more than 150 years in experimental psychology [25], [27], [28] it was little noticed by models and theories of attention.

Prior entry is especially interesting and valuable because it allows a direct and easily understandable quantification of the effect of attention on information processing. The speed-up is the temporal interval by which an attended stimulus can trail an unattended stimulus and still be perceived as simultaneous. Psychophysics allows to measure it with temporal order judgments.

In the present paper we use prior entry to distinguish between attention as selection for action and attention as selection for perception. Selection for perception is the more established framework, a sort of common sense, which has prevailed in psychology and modeling of attention. But the less known selection for action framework has some very interesting aspects, especially if attention is used in controlling autonomous agents.

The underlying idea of *selection for perception* is that attention is needed for coping with the information overload of the sensory system by *selecting* relevant information and rejecting irrelevant information for further processing, e.g [4], [10] for reviews see, Pashler (1998). Selection for perception focuses on the input-level of information processing and assumes attention-mediated selection as precondition for high-level-processing. This perspective is supported by a large body of research: Empirical findings for example indicate that visual attention speeds up detection [14] and finding of targets in an area of distractors, for an overview see [32]. Furthermore attention plays an important role for the integration of features represented in different visual modules into object files [29]. Ultimately, attention may lead to conscious perception. For example, the *asynchronous-updating model* [13] assumes that attention is a necessary but not a sufficient condition for conscious perception.

By contrast, *selection for action* [2] assumes attention as selection mechanism not on the input, but on the output level of information processing: Due to the constraints of effector systems - humans, for example, have only two arms and hands -, humans can direct an action only at one, at most at a few objects. Although humans can for example see many apples on the tree, at the same moment, they can pick up at most two apples at a given time. Therefore, relevant spatial parameters of the action target must be provided to the motor system by excluding effects of action-irrelevant distractors. This is selection for action, and attention is necessary to execute this selection.

. Selection for perception and selection for action were seen as alternative frameworks: A dissociation between perception and action is for example demonstrated by brain damage participants, which have selectively disrupted perception to visual stimuli but not disrupted action (or vice versa). Additionally some visual illusions are larger if measured by perceptual judgments than by actions e.g. [1]

But recently evidence for an interaction of selection for perception and for action arose, demonstrating that actions have immense influence on information processing, often on early processing stages. On the one hand, action-relations between objects (e.g. a bottle and a glass correctly positioned to action or not) affect selection for perception: Brain damage patients with *visual extinction* (difficulty of identifying objects on contralesional side, if they appear simultaneously with another object on the ipsilesional side) showed reduced extinction, if two objects were correctly positioned for action [17]. On the other hand perception is affected by actions: Deubel, Schneider and colleagues showed e.g [24] that identification of a stimulus is improved, if observers point at the location where the stimulus appears in comparison to pointing at another location nearby. Due to the described interaction between selection for perception and selection for action, it seems interesting to asses both mechanisms in the same experimental paradigm.

In this study, we assess the contribution of both mechanisms to *prior entry*. We controlled visuo-spatial attention by peripheral *cues*. Peripheral cues are visual abrupt-onset stimuli appearing at a non-foveated location. Several studies showed that cues orient attention towards a specific location [14], [34] According to current accounts, this orientation is not “automatic”, “bottom-up”, but rather contingent on intentions of the observer [3],[7].

As in earlier studies e.g. [18], [19], [20], we used a cue which was not consciously perceivable because it was backward-masked by the target trailing at its location (for details concerning backwards masking see [23]). Directing attention by non-conscious cues has practical rather than theoretical reasons. Firstly, it is more cautious: If they do not perceive the cue, observers cannot confuse cue and target stimuli. Secondly, the control of attention by information which is itself not consciously available is a topic which is currently debated in psychology: Most interestingly, this control of attention is not automatic, like parallel information processing on saliency maps, but highly depends on current intentions of the observer [3],[7],[21].

2 Experiment

The present experiment explores the accelerating effect of attention by means of visual prior entry. We attempt to separate this acceleration into a part that is due to selection for perception and a part that is due to selection for action. Observers judged the temporal order of two visual stimuli: an attended target, preceded by a cue, and an unattended target. The two targets were presented with variable temporal intervals. The cue had either the shape of the attended target (*shape-congruent cueing*) or the shape of the unattended target, which appeared at a different location (*shape-incongruent cueing*). This manipulation allows separating the accelerating effect on information processing of selection for action from the effect which is due to selection for perception: Observers indicate which of the two targets appeared first (square and diamond) by pressing different buttons. Although the cue cannot be consciously perceived, it may specify a corresponding motor response, e. g. pressing the button for “square first” if it was a square. This direct specification of response parameters reflects selection for action.

With a shape-congruent cue, prior entry can either be caused by speeded perception or by the motor response specified by the cue (selection for action). With a shape-incongruent cue, by contrast, the motor response (selection for action) would indicate that the uncued (unattended) target, which has the same shape as the cue in the incongruent case, was perceived first. Any prior entry found in this condition must thus be a true effect of selection for perception. Attention as selection for action can be estimated as the difference between prior entry by shape-congruent cueing and prior entry by shape-incongruent cueing.

2.1 Participants, Apparatus, Stimuli, Procedure

Sixteen voluntary naïve participants with normal or corrected-to-normal visual acuity (10 female, mean age = 22.38) gave their informed consent and received € 6 or course credits.

Participants sat in a dimly lit room. Viewing distance was fixed at 57 cm by a chin rest. The centre of the monitor was at eye level. Stimuli were presented on a 17 in. colour monitor with a refresh rate of 60 Hz.

Targets were a square and diamond (edge length 2.1° of visual angle). Cues were smaller replicas of the targets which fitted into their inner contours (edge length 1.6°). In each trial, two targets appeared at two of four possible locations, either below or above a fixation cross, which was in the middle of the screen. The horizontal distance was 6.3° of visual angle from fixation. In half of the trials, a cue preceded one of the targets (attended or cued target). Target intervals (onset asynchronies between the two targets) were 68, 51, 34, 17 and 0 ms. The cue appeared, if presented, 68 ms before onset of the cued target. There were two experimental blocks. In one block, cueing was shape-congruent (cue and cued target had the same shape) in the other block, cueing was shape-incongruent (cue and uncued target had the same shape). Order of the blocks was balanced over participants. See Figure 1 for an example of a congruent and an incongruent cued trial. Targets and cues were deleted after 34 ms.

The participants fixated a central cross throughout each trial. They judged the temporal order of the targets by indicating which appeared first[1]. The instruction emphasized accuracy; there was no time pressure. Every 40 trials, a break was made automatically.

[1] Participants could also judge that both stimuli appeared simultaneously or that they were uncertain about temporal order, but these categories are not of interest for the present paper and therefore not analyzed here.

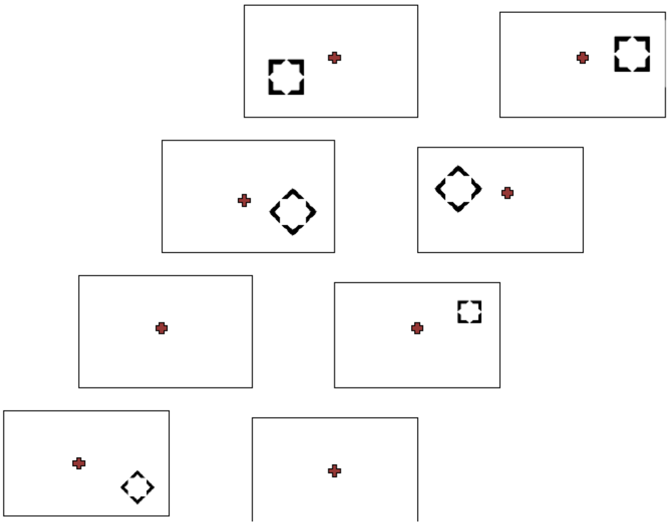

Fig. 1.shows an example of a congruent (left) and an incongruent cued trial (right). The trials started with the frames on the bottom of the figure.

2.2 Results and Discussion

Acceleration values (prior entry values) were calculated separately for shape-congruent and shape-incongruent cues (for details see [19], [20] and [31]). As expected, both cueing conditions revealed a speed-up by attention. This acceleration is, as to be expected from earlier studies, primarily due to selection for perception, but in a smaller amount due to selection for action.

Acceleration was 45 ms in the shape-congruent condition and 38 ms in the shape-incongruent condition. Note that these values are relative to an upper value: Since the cue preceded the target by only 68 ms, the maximum speed-up by attention is this same value of 68 ms. Of course, with larger intervals between cue and cued target, attention has more time to operate and the respective gains might be much larger.[22]

The difference of 7 ms between congruent and incongruent cueing can be seen as quantitative estimate of selection for action. Prior entry for incongruent cueing can be seen as a rather pure (but also conservative) estimate of the acceleration of perception by the cue (selection for perception). See Figure 2 for an illustration of prior entry effects. Thus, we find a very strong effect of attention which is most easily interpreted as selection for perception, but a much smaller effect of selection for action.

In statistical terms, there was a temporal advantage for cued stimuli (shape-congruent-cueing: $t(15) = 15.5$, $p < .001$, $d = 4.14$; shape-incongruent cueing = $t(15) = 13.64$, $p < .001$, $d = 3.65$). Furthermore, as assumed prior entry was larger for *shape-congruent cueing* (45 ms) than for *shape-incongruent-cueing* (38ms; $t(15) = 2.76$, $p < .01$, $d = 0.73$, one-tailed).

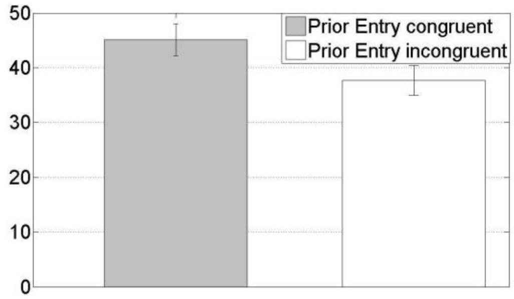

Fig. 2. shows Prior Entry effects for both cueing conditions (congruent vs. incongruent) in ms. Errorbars indicate the standard error of the mean.

3 General Discussion

As demonstrated in the large body of literature on prior entry [25], [28], [27],[33] we found that perception of an attended (visual) stimulus is accelerated in comparison to unattended stimulus. The main purpose of the present paper was to provide a quantification of selection for action and selection for perception in prior entry: To this aim, we tested whether the cue draws attention to its location in a perceptual manner or whether this effect is related to the motor relevance of the cue. We found a substantial accelerating of perception by 38 ms (selection for perception), and a smaller effect for specification of motor responses by the cue of 7 ms (selection for action).

Prior entry, the accelerating effect of attention on perception, is well documented in experimental psychology. Such a speed-up possibly is an important part of prioritized processing of attended information: Information is transferred faster to higher levels such as internal models or consciousness [12]. To our knowledge, it is only rarely entailed in computational models of visual attention. One computational model which incorporates prior entry is the *systems-model of visual attention* by Fred Hamker which can explain prior entry by masked peripheral cues with the help of early top-down influences [8] Bröckelmann et al. showed, for example, that target-like cues attracted attention more effectively than distractor-like, and thus irrelevant, cues. Reentrant processing from attentional task sets: Converging support from magnetoencephalography and computational modeling.

It is worth noticing that we found that attention was differentially controlled by stimuli of different shape. Squares and diamonds, such as we used them here, are *complex* features which are not represented on feature maps. Still, they were able to influence attention-mediated information processing, quickly. This finding is in accordance with current theories on early reentrant influences by target templates or intentions in visual processing [8]

Finally, we want to draw attention towards a possible confound in our experiment. Although we interpret the difference between congruent and incongruent cueing as a difference in specification of motor responses by the cue, that is, selection for action, there is an alternative explanation, which cannot be excluded by the present experiment. Shape-congruent cues and targets have a larger overlap of sensory features than shape-incongruent cues and targets. It is therefore possible that difference between prior entry resulting from congruent and incongruent cueing, represents, at least partially, *sensory priming* (sensory detectors which are relevant for detecting the cued target were pre-activated by the cue) This question should be investigated in further experiments by varying feature overlap between cues and targets and task implications of the cues more independently.

To summarize, attention which is controlled by non-conscious information accelerates information processing. This acceleration is due to selection for perception *and* selection for action. This finding emphasizes the relevance of action for information processing: to modulate attention-mediated specification of motor-responses (selection for action) seems especially interesting for research on the control of autonomous agents.

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