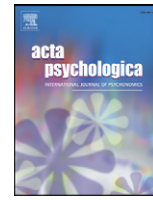
Acta Psychologica 139 (2012) 54–64

Contents lists available at SciVerse ScienceDirect

Acta Psychologica

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



At the mercy of prior entry: Prior entry induced by invisible primes is not susceptible to current intentions

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ARTICLE INFO

Article history:
Received 30 January 2011
Received in revised form 12 October 2011
Accepted 17 October 2011
Available online 17 November 2011

PsycINFO classification:
2323 Visual perception
2346 Attention

Keywords:
Prior entry
TOJ
Decision bias
Attention
Time perception
Intentions

ABSTRACT

If one of two events is attended to, it will be perceived earlier than a simultaneously occurring unattended event. Since 150 years, this effect has been ascribed to the facilitating influence of attention, also known as prior entry. Yet, the attentional origin of prior-entry effects[1] has been repeatedly doubted. One criticism is that prior-entry effects might be due to biased decision processes that would mimic a temporal advantage for attended stimuli. Although most obvious biases have already been excluded experimentally (e.g. judgment criteria, response compatibility) and prior-entry effects have shown to persist (Shore, Spence, & Klein, 2001), many other biases are conceivable, which makes it difficult to put the debate to an end. Thus, we approach this problem the other way around by asking whether prior-entry effects can be biased voluntarily. Observers were informed about prior entry and instructed to reduce it as far as possible. For this aim they received continuous feedback about the correctness of their temporal judgments. If elicited by invisible primes the effect could not be reduced at all and only by 12 ms if elicited by visible cues. This challenges decision biases as primary source of prior-entry effects — at least if attention is oriented exogenously.

1. Introduction

Imagine watching out at the night sky for shooting stars. Probably you will see a shooting star in an attended sky area earlier than a simultaneously appearing one in an unattended area. In other words, attended stimuli are perceived earlier than unattended stimuli. This *prior-entry* effect has been investigated in experimental psychology over the last 150 years (e.g. Boring, 1929; Scharlau, 2007b; Spence, Shore, & Klein, 2001; Stone, 1926; Titchener, 1908; for a recent review see Spence & Parise, 2010). During this time period, prior-entry effects have been demonstrated within and between several sensory modalities (e.g. visual modality: Scharlau, 2007b; Shore et al., 2001; Stelmach & Herdman, 1991; Weiß & Scharlau, 2011; auditory modality: Kanai, Ikeda, & Tayama, 2007; somatosensory modality: Yates & Nicholls, 2009, 2011; between modalities: Spence et al., 2001; Zampini et al., 2007; Zampini, Shore, & Spence, 2005).

As early as 1908, Edward B. Titchener assumed that "Unless, then I am unduly optimistic the negative displacement [that is, the prior-entry effect] need give psychologists no further trouble" (p. 259). Looking back, this statement was indeed unduly optimistic because the prior-entry effect has given psychologists some trouble. Especially one criticism was repeatedly raised: It was argued that the effect might be due to or might be enhanced by biases in decision or response criteria that would mimic an advantage in temporal perception for attended stimuli. But before we will explain this criticism in more detail, it is necessary to outline the basic experimental paradigm for assessing prior-entry effects.

1.1. Assessment of prior-entry effects

Usually prior-entry effects are assessed either by a temporal order judgment (TOJ) or a simultaneity judgment (SJ) task. Observers judge either which of two rapidly presented stimuli was presented first (TOJ) or whether both stimuli were presented simultaneously or not (SJ). In both tasks two factors are manipulated. First, the temporal delay between the two targets is varied. Second, attention is directed toward one of the targets. The expected perceptual advantage for attended stimuli, that is, the prior-entry effect, occurs as a shift in the so-called point of subjective simultaneity (PSS). In the TOJ task, this is the temporal delay at which the two possible order judgments are given equally often. In the SJ task, this is the temporal delay at which observers judge "simultaneous" most frequently. Usually the PSS is shifted toward a temporal delay at which objectively the

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[1] We will further use the term prior-entry effect to distinguish prior entry revealed by experimental paradigms from the attentional interpretation of prior entry, which we will call in the following prior entry only.

0001-6918/$ – see front matter
doi:10.1016/j.actpsy.2011.10.007

unattended stimulus leads the attended one. This shift's size quantifies the prior-entry effect.

For orienting attention in prior-entry studies several methods have been used; attention was oriented by instruction (e.g. Spence et al., 2001; Stelmach & Herdman, 1991; Yates & Nicholls, 2009) by peripheral location cues (e.g. Schneider & Bavelier, 2003, Experiment 1; Shore et al., 2001) or by central symbolic cues (e.g. Schneider & Bavelier, 2003, Experiment 2, Shore et al., 2001). Since the last decade Scharlau et al. (2002, 2004a,b,c, 2007a,b), Scharlau, Ansorge, and Horstmann (2006), Scharlau and Neumann (2003a,b) and Weiß and Scharlau (2011) used a special prior-entry paradigm termed *perceptual latency priming* (PLP) in which peripheral cues are masked. Since we will also use PLP in the present study we will describe it in more detail.

1.2. Perceptual latency priming

In the PLP paradigm, attention is directed by peripheral *primes*. These primes are peripheral cues which are metacontrast-masked by the target following at the same location. As a consequence, they are invisible or barely visible to the observer (e.g. Breitmeyer & Ögmen, 2006). Despite this strongly reduced visibility, primes in the PLP paradigm are effective in directing attention toward the target (e.g. Scharlau, 2004a), like cues in other prior-entry paradigms. This attention-directing property is suggested by several empirical findings. First and most importantly, the time course of PLP mirrors that typically reported for exogenous attention. With priming intervals below the duration of an exogenous attention shift −100–200 ms (Nakayama & Mackeben, 1989; Suzuki & Cavanagh, 1997) PLP increases constantly; its peak is located between 100 and 300 ms, with longer priming intervals PLP decreases (e.g. Scharlau et al., 2006; Scharlau & Neumann, 2003b, for an overview about PLP see Scharlau, 2007a). Second, PLP does not seem to be due to *sensory priming*. Since prime and primed target are presented at the same location, PLP can partially or totally reflect an acceleration of the targets' sensory processing due to pre-activation of sensory receptors by the prime. In this case PLP's size should depend on prime–target similarity. But as Scharlau and Neumann (2003a, Experiment 4) demonstrated using a binary TOJ-task PLP has the same size for prime–target pairs with different degrees of similarity (shape and color). Third, PLP is not due to an averaging between prime and target onset since target leading primes but not target trailing primes cause PLP. Fourth, that PLP is due to confusion between prime and target onset is unlikely since the size of PLP remains the same for congruent and incongruent primes. Confusion should lead to a reduction in PLP for incongruent primes since in this case the prime specifies a response favoring the unattended target. Taken together, these properties of PLP argue for its attentional origin, thus making it a useful paradigm for studying prior-entry effects. So far we spared the question how a response bias could account for PLP since we will discuss this question in the next paragraph along with other prior-entry paradigms.

1.3. How response biases could account for the prior-entry effect

There are several ways imaginable in which a response bias[2] could account for a given prior-entry effect. First of all it is important to note that judging the temporal order of two stimuli occurring in very rapid succession is a difficult task. Therefore observers might be inclined to use other than temporal information for solving this task. For instance, if uncertain about the temporal properties of the stimulus sequence, observers could report the stimulus appearing at the attended location or sharing the attended property as the first. Here, the PSS-shift would be due to a *judgment bias* and not to attentional prioritization. In a more sophisticated form of a response bias, observers might actually ascribe the judgment criterion to any salient stimulus property, which would include the feature of being the attended one (cf. Frey, 1990; Pashler, 1998; Schneider & Bavelier, 2003). These so-called "second-order biases" or criterion biases are very difficult to avoid and cannot easily be distinguished from attention-based prior-entry effects.

Many studies (e.g. Kanai et al., 2007; Lester, Hecht, & Vecera, 2009; Roberts & Humphreys, 2010; Scharlau, 2004a; Shore et al., 2001; Yates & Nicholls, 2009) took precautions against such second-order biases by varying the judgment criterion of the TOJ task. Observers judged either which stimulus was presented first or which stimulus was presented second. If they assigned any judgment criterion to the attended stimulus, the judgment "which first?" should lead to the usual prior-entry effect, but the judgment "which second?" should reveal an opposite advantage for the unattended stimulus. Half of the difference between the apparent temporal advantages derived from the two judgment criteria is an estimate of decision bias (Shore et al.). Using this method in a PLP-paradigm, Scharlau (2004a) found virtually no bias whereas Shore et al. found a bias of 13 ms with a prior-entry effect of 61 ms with visible peripheral cues. This finding is in accordance with the higher difficulty to distinguish between "attended" and "non-attended target" in a PLP-paradigm where attention is oriented with invisible primes. This makes a decision bias favoring the attended target less likely in PLP. Although these results can be counted as evidence against a prominent role of decision bias in prior-entry effects, not all researchers are convinced by this. For instance Schneider and Komlos (2008) argued that observers could use the same judgment criterion for both judgments and then invert their response in one of the conditions. Thus, the possible contribution of a decision bias to prior-entry effects seems a question very difficult to settle.

Apart from post-perceptual decision processes a response bias might also arise on the level of sensory or motor processing. With respect to motor processing, if the required response is compatible with allocation of attention – e.g. attention is directed to the left or right and the observers have to judge whether the stimulus on the right or left appeared first – motor priming might facilitate judgments in favor of the attended target. Other response-relevant features of the attention-grabbing prime can also elicit responses which might mimic prior entry, for example if the prime has the same shape as the primed target (Scharlau & Neumann, 2003a, Experiment 1). This type of motor priming can be excluded either by primes with irrelevant features (Scharlau & Neumann, 2003a, Experiments 3 and 4) or by using primes which share their response-relevant features with the unprimed target (e.g. Weiß & Scharlau, 2011).

Another possible bias in prior-entry paradigms using peripheral primes or cues is a *sensory bias*. Primes that are presented close to the primed target might pre-activate sensory receptors concerned with target processing. Acceleration of the target is then caused by faster sensory processing. As mentioned above a large contribution of sensory priming to PLP is unlikely since PLP's size is not dependent on prime–target similarity.

So far, we have only spoken about how response biases could account for prior-entry effects in TOJs. Usually smaller prior-entry effects are found with the SJ task (e.g. Schneider & Bavelier, 2003; Van der Burg, Olivers, Bronkhorst, & Theeuwes, 2008; Yates & Nicholls, 2011). This led some authors to assume that SJs provide a more exact, bias free measure of prior-entry effects. In SJs a tendency favoring one of the judgments would affect the frequency of "simultaneous" judgments and thereby the width and the height of their bell-shaped distribution but importantly not their peak, that is the PSS. Additionally, the SJ task is less prone to sensorimotor biases since a judgment about simultaneity or succession is neither compatible with attentional allocation nor can it be specified by a prime. Although it seems very convincing at first glance that the SJ task is

[2] Note that we chose the term response bias as an umbrella term for all sorts of biases which could possibly occur in a prior-entry experiment.