Vision Research 50 (2010) 1025–1034

Contents lists available at ScienceDirect

Vision Research

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

Temporal preparation influences the dynamics of information processing: Evidence for early onset of information accumulation

Karin M. Bausenhart *, Bettina Rolke, Verena C. Seibold, Rolf Ulrich

University of Tübingen, Psychologisches Institut, University of Tübingen, Friedrichstrasse 21, D-72072 Tübingen, Germany

ARTICLE INFO

Article history:
Received 27 March 2009
Received in revised form 3 September 2009

Keywords:
Temporal preparation
Attention
Speed-accuracy trade-off
Temporal information processing

ABSTRACT

When participants can temporally prepare for a visual target stimulus, responses to this stimulus are faster and more accurate. Recent accounts attribute these effects either to an earlier accumulation of stimulus information or to an increased rate of information sampling. The present study examines whether temporal preparation induces such changes in the dynamics of information processing by investigating speed-accuracy trade-off (SAT) functions. Shorter onsets and higher asymptotes of the estimated SAT functions were found for high temporal preparation conditions. These results provide evidence for an earlier onset of information accumulation in the visual system when temporal preparation is high.

1. Introduction

Temporal preparation describes preparatory activity that is directed to a certain moment in time. If this moment coincides with the presentation of a target stimulus, a variety of aspects of processing of this target stimulus are improved. For example, it is well-established that increasing the temporal predictability of a target stimulus shortens reaction time (Correa, Lupiáñez, Milliken, & Tudela, 2004; Karlin, 1959; Niemi & Näätänen, 1981; Sanders, 1980; Woodrow, 1914), and affects various correlates of motor processing, as for example, response force (Mattes & Ulrich, 1997), the contingent negative variation (Loveless, 1975; Trillenberg, Verleger, Wascher, Wauschkuhn, & Wessel, 2000), motor evoked potentials (Hasbroucq et al., 1999), and reflex amplitudes (Brunia, Scheirs, & Haagh, 1982; Requin, Bonnet, & Semjen, 1977). More recent research also indicates beneficial influences of temporal preparation on premotor (Bausenhart, Rolke, Hackley, & Ulrich, 2006; Hackley & Valle-Inclán, 1998, 1999; Müller-Gethmann, Ulrich, & Rinkenauer, 2003) and purely perceptual processing (Bausenhart, Rolke, & Ulrich, 2007; Correa, Lupiáñez, & Tudela, 2005; Klein & Kerr, 1974; Rolke & Hofmann, 2007). Electrophysiological evidence shows that these facilitating effects on perception are also reflected in an enhancement of the amplitudes of early event-related potentials (Correa, Lupiáñez, Madrid, & Tudela, 2006; Lange, Krämer, & Röder, 2006; Lange, Rösler, & Röder, 2003). All these results indicate that temporal preparation is a ubiquitous phenomenon of human information processing (for overviews, see Hackley, 2009; Müller-Gethmann et al., 2003; Niemi & Näätänen, 1981; Nobre, Correa, & Coull, 2007).

1.1. Temporal preparation and the dynamics of information accumulation

Although theoretical attempts have been made to account for temporal preparation effects on motor processing (Näätänen, 1971), relatively little progress has been achieved in shedding light on the mechanisms underlying temporal preparation effects on premotor processing. In order to unravel these mechanisms, it might be helpful to address the question about how temporal preparation alters the time course of information processing. For example, based on temporal preparation effects on accuracy in a spatial discrimination task, Rolke and Hofmann (2007) proposed that temporal preparation might affect perceptual stimulus processing by changing the dynamics of information accumulation.

To manipulate temporal preparation, Rolke and Hofmann (2007) employed the constant foreperiod paradigm, in which the time between a warning signal and the target stimulus (i.e., the foreperiod) is kept constant within a block of trials but is varied across blocks of trials. Thus, after a few trials of learning, participants know the foreperiod duration of the current block. However, even when participants know in advance when a target stimulus will occur, they often fail to adjust their preparatory activity precisely to this moment. This failure depends strongly on the duration of the foreperiod of the current block, because participants' predictions about when the target stimulus will occur get less precise with increasing foreperiod duration (Näätänen, Muranen, & Merisalo, 1974). Accordingly, preparation for the moment of target

---

* Corresponding author. Fax: +49 7071 29 2410.
E-mail address: karin.bausenhart@uni-tuebingen.de (K.M. Bausenhart).

0042-6989/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2010.03.011

presentation, and thus performance, deteriorates with increasing foreperiod duration in the constant foreperiod paradigm (e.g., Klemmer, 1956; Müller-Gethmann et al., 2003; Niemi & Näätänen, 1981).[1]

Rolke and Hofmann (2007) requested their participants to indicate whether a spatial gap in their target stimulus, a pattern masked Landolt square, was on the left or on the right side. They found reduced RT following short foreperiods compared to long foreperiods, and more important, also a higher accuracy of spatial discrimination following short foreperiods. To account for this finding, the authors proposed that temporal preparation influences the dynamics of information processing. More specifically, they base their account on a criterion model proposed by Grice (1968), according to which during stimulus processing external stimulus information is translated into internal activation. This activation is accumulated over time, and when it reaches a criterion level, a decision is made and a response is initiated. According to Rolke and Hofmann (2007), temporal preparation effects can be explained by the assumption that accumulation of perceptual evidence about a target stimulus starts earlier when participants are temporally well prepared for the onset of this stimulus. Therefore, under conditions that enable good temporal preparation, a higher level of accumulated activation would be reached by the time when stimulus processing becomes interrupted, for example, by a masking stimulus (Kahneman, 1968; Sperling, 1963). This so-called "early onset hypothesis" (Rolke, 2008) predicts that temporal preparation improves the accuracy of stimulus detection and discrimination, because post-perceptual decision processes are supplied with more relevant stimulus information under high levels of temporal preparation. In addition, shorter reaction time should be observed when participants are temporally well-prepared, as the criterion level would be reached earlier and thus, response selection and execution could start – and accordingly would be finished – earlier. Hence, this model can account for the results of various studies which have demonstrated that temporal preparation improves perceptual discrimination ability and shortens RT (e.g., Bausenhart et al., 2007; Correa et al., 2005; Klein & Kerr, 1974; Müller-Gethmann et al., 2003; Niemi & Näätänen, 1981).

However, besides an early onset of information processing, there is an alternative explanation for these temporal preparation effects. According to this alternative, information accumulation would not start earlier when one is temporally well prepared, but the uptake of information about the stimulus would be faster, thus resulting in a higher rate of information accumulation. Similar to the early onset hypothesis, this account suggests that the criterion on which one bases his/her reactions would be reached sooner under conditions that enable good temporal preparation. A related idea has already been brought forward by studies of temporal resolution (Bausenhart et al., 2008; Correa, Sanabria, Spence, Tudela, & Lupiáñez, 2006). Specifically, these studies employed temporal order judgment tasks, in which two stimuli appear in close temporal succession, and participants have to indicate which of the stimuli appeared first. Both studies demonstrated that temporal preparation shortens the minimum time interval between the two stimuli that is needed for correct discrimination of temporal order. These results therefore indicate that temporal preparation improves the temporal resolution of perception. It was suggested that this finer temporal resolution might be the result of a mechanism that increases the speed of perceptual information sampling, when participants are temporally well prepared (Bausenhart et al., 2008; Correa, Sanabria, et al., 2006). As outlined above, such a higher speed of information sampling, in turn, might result in a higher rate of information accumulation and thus improve discrimination performance.

The two accounts outlined above (i.e., early onset vs. higher rate of information accumulation) assume that temporal preparation changes the dynamics of information processing. Enhanced perceptual discriminability might, however, also be explained by signal enhancement or a more effective suppression of external background noise. Such effects have already been well documented within the domain of spatial orienting. Specifically, it has repeatedly been shown that covert spatial attention increases spatial resolution (Carrasco, Williams, & Yeshurun, 2002; Montagna, Pestilli, & Carrasco, 2009; Morgan, Ward, & Castet, 1998; Shiu & Pashler, 1995), and enhances contrast sensitivity of the perceptual system (Cameron, Tai, & Carrasco, 2002; Carrasco, Penpeci-Talgar, & Eckstein, 2000; Ling & Carrasco, 2006; Reynolds, Pasternak, & Desimone, 2000). Such changes might as well be induced by temporal preparation, and they would improve the quality of the stimulus representations without necessarily changing the dynamics of stimulus processing.

1.2. The speed-accuracy trade-off function

So far, experimental research does not yield conclusive results about which of these proposed mechanisms (earlier start or higher rate of information accumulation, or enhanced discriminability) contribute to the perceptual effects of temporal preparation. Clearly, such a distinction cannot be accomplished on the basis of conventional RT experiments. However, important insights in these mechanisms might be gained by investigating the speed-accuracy trade-off (SAT) functions underlying performance. A SAT function reflects the relationship between processing time and accuracy and therefore incorporates measures of the dynamics of processing as well as discrimination performance (e.g., Carrasco & McElree, 2001; Dosher, 1976, 1981; Reed, 1973; Wickelgren, 1977).

Specifically, in a typical SAT experiment the time available for stimulus processing is manipulated, and the response accuracies corresponding to different processing times are registered. This can be accomplished, for example, with the response signal method (e.g., Carrasco, Giordano, & McElree, 2006; Miller, Sproesser, & Ulrich, 2008; Ratcliff, 2006; Wickelgren, 1977). In this method, and similar to conventional RT experiments, a target stimulus is presented to which participants have to make a two-alternative forced-choice decision. Unlike in RT experiments, however, participants are instructed to withhold their response until a response signal is presented. Importantly, the stimulus onset asynchrony (SOA) between the target stimulus and the response signal is varied from trial to trial. This procedure reveals a characteristic relationship between the SOA and the obtained level of accuracy. For very short SOAs, participants' performance is close to chance level. The more time is available for target processing (i.e., the longer SOA), the more accurate participants' responses will be. Clearly, if SOA is increased beyond a critical duration, no further gains in accuracy will be observed, as participants have already reached maximum accuracy for the requested decision (Fig. 1).

This relationship between processing time (t) and accuracy of performance can be described mathematically by an exponential approach to an asymptotic performance level (λ):

$$\text{Accuracy } (t) = \upsilon + (\lambda - \upsilon)(1 - e^{-\beta(t-\delta)}) \quad \text{for } t > \delta, \quad \text{else} \quad 0, \qquad (1)$$

where υ corresponds to the chance level of performance (e.g., in the present experiment, υ equals to 50% of correct responses, because a

---

[1] Besides temporal predictability, other sources may contribute to the size of the foreperiod effect in the constant foreperiod paradigm. For example, due to their longer overall duration, long foreperiod blocks may lead to a lower level of arousal or vigilance and thus, may increase the size of the foreperiod effect. However, when the overall trial duration is equated across foreperiod conditions, constant foreperiod effects are still present, arguing against the notion that arousal or vigilance is the sole cause underlying these effects (Bausenhart, Rolke, & Ulrich, 2008; Bausenhart et al., 2007). In order to minimize the potential contribution of differential states of arousal, we alternated foreperiod duration in the present experiment from block to block.