Acta Psychologica 171 (2016) 93–98

Contents lists available at ScienceDirect

Acta Psychologica

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

Automated symbolic orienting is not modulated by explicit temporal attention

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ARTICLE INFO

Article history:
Received 1 March 2016
Received in revised form 29 September 2016
Accepted 6 October 2016
Available online 13 October 2016

Keywords:
Automated symbolic orienting
Temporal attention
Spatial attention

ABSTRACT

Recent studies show that spatial attention is uniquely engaged by the selection history of a stimulus. One example of this process is Automated Symbolic Orienting, which is thought to reflect overlearned spatial links between a behaviorally relevant stimulus and a target event. However, since automated symbolic effects have been found to vary with temporal expectancies about when a target might occur, it is possible that this spatial effect may also depend on processing resources associated with voluntary temporal attention. To test this idea, here we elicited automated symbolic orienting and voluntary temporal attention in isolation and in combination. Across all conditions, both types of orienting remained typical without interacting. Thus, typical automated symbolic orienting is not modulated by participants' explicit utilization of temporal information; however, and as we have shown previously, typical ASO does appear to require the presence of an implicit temporal structure within a task.

1. Introduction

Recent studies (Awh, Belopolsky, & Theeuwes, 2012; Hayward & Ristic, 2013b; Ristic & Kingstone, 2012) indicate that a prominent dichotomy between bottom-up or reflexive attention and top-down or voluntary attention (Jonides, 1981; Posner, Snyder, & Davidson, 1980) does not fully capture the richness of attentional processes occurring in real life. In addition to stimulus properties and individual goals, attention has been found to be independently driven by events that hold motivational value (e.g., Anderson, Laurent, & Yantis, 2011) and the history of stimulus selection (Awh et al., 2012). One example of this novel type of attentional control is Automated Symbolic Orienting (ASO; Ristic & Kingstone, 2012), in which overlearning the meaning of useful everyday symbols such as arrows leads to faster responses for targets that are congruent with the cue's direction relative to events that occur elsewhere (Ristic & Kingstone, 2012; Ristic, Landry, & Kingstone, 2012). ASO effects emerge quickly by 100 ms post cue and persist until about 1000 ms (Brignani, Guzzon, Marzi, & Miniussi, 2009; Ristic, Friesen, & Kingstone, 2002; Ristic & Kingstone, 2006, 2012). ASO effects occur when the cue is spatially uninformative (i.e., points equally often towards and away from the target, Ristic et al., 2002; Tipples, 2002), proceed in parallel with reflexive and voluntary spatial orienting (Ristic & Kingstone, 2012; Ristic et al., 2012), and facilitate both the speed of target processing, as reflected by target detection measures, as well as its perceptual analysis, as reflected by target discrimination measures (Ristic et al., 2012).

It was recently proposed however that these typical ASO effects may depend on participants anticipating *when* in time a response target might occur (Hayward & Ristic, 2015). We (Hayward & Ristic, 2015) measured ASO under conditions in which the implicit structure of cue-target events within the task did and did not provide temporal information about the target's occurrence. We found typical early and prolonged ASO when the cue-target temporal sequence was implicitly predictable, however when the implicit temporal link between the cue and the target was unpredictable, automated symbolic orienting was delayed in its onset until 900 ms. This opens up the possibility that while ASO may occur in parallel with reflexive and voluntary *spatial* orienting (Ristic & Kingstone, 2012; Ristic et al., 2012), it may nevertheless share processing resources with *temporal* attention, which modulates expectancies about the timing of target events (e.g., Nobre, 2001). To address this question, here we assessed whether spatial automated symbolic orienting was affected by voluntary temporal attention.

A large number of investigations (Griffin, Miniussi, & Nobre, 2002; Los, 2004; MacKay & Juola, 2007; Milliken, Lupiáñez, Roberts, & Stevanovski, 2003; Miniussi, Wilding, Coull, & Nobre, 1999; Weinbach, Shofty, Gabay, & Henik, 2015) suggest that while spatial and temporal orienting may share some processing resources, the two types of attention serve different purposes, and involve several different underlying neural mechanisms (cf. Doherty, Rao, Mesulam, & Nobre, 2005; Rohenkohl, Gould, Pessoa, & Nobre, 2014). This dissociation was first demonstrated by Coull and Nobre (1998; see also Miniussi et al.,

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http://dx.doi.org/10.1016/j.actpsy.2016.10.004
0001-6918/

1999; Nobre, 2001; Nobre, Correa, & Coull, 2007). In their study, the authors used a modified cuing paradigm in which participants were presented with a spatially predictive cue, a temporally predictive cue, or a spatially and temporally predictive cue. Behavioral data indicated reliable orienting for both spatial and temporal cues in isolation and in conjunction with no interactions. That is, like the informative spatial cue, participants were also able to use an informative temporal cue to respond faster when the target appeared at the expected time point as compared to when the target appeared at an unexpected time point. The analyses of brain activity further revealed that while spatial orienting preferentially engaged the right inferior parietal lobe, temporal orienting preferentially engaged the left inferior parietal lobe and left premotor areas. Based on these results, it was argued that orienting in the spatial and temporal domains was additive because the two attentional systems differentially affected the underlying sensory and cognitive processes.

Since this pioneering study, the relationship between spatial and temporal orienting has been described as both additive and synergistic, with spatial and temporal attention each linked with facilitating the target's sensory analysis (Correa, Lupiàñez, & Tudela, 2005; Cravo, Rohenkohl, Wyart, & Nobre, 2013; Rohenkohl et al., 2014). However, temporal attention has been specifically linked with furnishing the preparation and timing of responses (Nobre, 2001) and more recently with accelerating the perceptual processing of the target (Seibold & Rolke, 2014a, 2014b; Vangkilde, Coull, & Bundesen, 2012). These ideas were supported by EEG investigations. Miniussi et al. (1999) reported that modulations in spatial target expectancies affected the early event-related components associated with early sensory processing (e.g., P1, N1; Hillyard, Hink, Schwent, & Picton, 1973; Mangun, 1995; Van Voorhis & Hillyard, 1977), while modulations in temporal target expectancies affected the later event-related components associated with response execution and expectancy formation (e.g., the CNV and P300). More recently, Seibold and Rolke (2014b) found that latencies of the early sensory event-related components (i.e., the N2pc) also became shorter when the task included a predictable temporal sequence. Thus, one distinctive function of temporal attention relates to the temporal fine-tuning of responses for expected targets, which in turn contributes to the acceleration of a target's sensory processing (Griffin, Miniussi, & Nobre, 2001; Griffin et al., 2002; Miniussi et al., 1999; Seibold & Rolke, 2014a, 2014b; cf. Correa, Lupiàñez, Milliken, & Tudela, 2004; Vangkilde et al., 2012).

Our recent result showing delays in ASO's onset under conditions in which the implicit temporal links between the cue and the target were reduced dovetails with this proposed role of temporal attention. That is, the absence of early ASO under reduced temporal predictability (Hayward & Ristic, 2015) suggests that ASO's rapid onset may be contingent on the presence of a reliable temporal structure between cues and targets. Generally, temporal expectancies can be either explicit or implicit (Coull & Nobre, 2008). Explicit temporal expectancies involve the deliberate use of temporal information. Experimentally, this is achieved by presenting cues that indicate a likely time at which a target may appear. Participants are instructed to utilize this contingency to maximize their performance. Implicit temporal expectancies, on the other hand, involve participants' non-deliberate utilization of the more subtle temporal regularities present within the task sequence. Experimentally, this is often achieved by presenting the cues and targets within a rhythmical sequence of cue-target intervals, in which the probability of target occurrence within a trial increases with the lengthening of cue-target time (i.e., an aging distribution of trials; Gabay & Henik, 2008; Näätänen, 1970). And although participants are typically not informed about this regularity, their performance is facilitated by such task conditions. A classic example of implicit temporal performance facilitation is the foreperiod effect (e.g., Bertelson, 1967; Gabay & Henik, 2008; Hayward & Ristic, 2013a), which is indexed by an overall speeding up of responses with increases in the time delay between the cue and the target, when the cue-target intervals are presented in an intermixed fashion.

In our previous study (Hayward & Ristic, 2015), we manipulated implicit temporal expectancies within a cuing task by modulating the presence and absence of a foreperiod effect (i.e., by using aging and non-aging distributions of cue-target intervals; see also Gabay & Henik, 2008; Hayward & Ristic, 2013a). In contrast to the aging distribution, in which the presentation of an equal number of targets at each cue-target interval contributes to the increased probability of target occurrence at longer cue-target times, the non-aging distribution keeps the probability of target occurrence equal by halving the number of targets presented at each successive cue-target time (Gabay & Henik, 2008; Näätänen, 1970). Our data (e.g., Hayward & Ristic, 2015) indicated that the rapid ASO effects were contingent on the presence of the tasks' implicit temporal structure, as early ASO emerged only when the task involved an aging distribution of trials, and not when the task involved a non-aging distribution of trials. While in general this implicates temporal predictability in the development of early spatial symbolic orienting, it does not specifically reveal whether participants utilized the task's temporal structure in a deliberate manner. In other words, it remains unknown if typical ASO depends on the implicit or explicit utilization of available temporal information. To address this question, here we assessed if ASO was influenced by the formation of explicit temporal expectancies about when a target might occur.

To do so, we manipulated and measured spatial automated symbolic orienting and explicit voluntary temporal orienting alone in isolation, and simultaneously in combination. If ASO did not require explicit voluntary temporal attention, we expected to observe the two processes in their typical forms across all conditions (Coull & Nobre, 1998; Miniussi et al., 1999). More specifically, we expected to find no interactions between spatial and temporal orienting when the two processes were elicited simultaneously.

2. Methods

2.1. Participants

Thirty-two (32) undergraduate students (5 males, mean age 19.9 ± 1.4 years) participated in the experiment.

2.2. Stimuli & Apparatus

The stimuli are shown in Fig. 1A. They were rendered in black and presented against a white background. Stimuli included a large circle (8.0°), a small circle (0.3°), and an arrow, which was comprised of a horizontal line (2.9° long), an arrowhead (0.6°), and a vertical stop line (0.8°). A capital letter 'X' (1°) served as the response target, appearing with an eccentricity of 7.1° from central fixation along the horizontal meridian. The stimuli were presented on a 16-in CRT monitor at an approximate viewing distance of 57 cm.

2.3. Design

Four possible Trial types were distributed across 552 target-present trials: (*i*) *No Cue trials*, in which neither a Space nor a Time cue occurred; (*ii*) *Space only trials*, in which an arrow pointing to the left or to the right served as a spatial cue; (*iii*) *Time only trials*, in which the brightening (from 1 to 5 points) of either the large or the small circle served as a temporal cue; and (*iv*) *Space and Time trials*, in which both the Space cue and the Time cue occurred simultaneously. In this last condition, Space and Time cues could converge onto the same target (i.e., *Both valid; Both invalid*) or be committed in a divergent fashion to the processing of two different targets (i.e., *Space valid*/*Time invalid* or *Time*