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Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention

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ABSTRACT

Attention resources can be allocated in both space and time. Exogenous temporal attention can be driven by rhythmic events in our environment which automatically entrain periods of attention. Temporal expectancies can also be generated by the elapse of time, leading to foreperiod effects (the longer between a cue and imperative target, the faster the response). This study investigates temporal attention in touch and the influence of spatial orienting. In experiment 1, participants used bilateral tactile cues to orient endogenous spatial attention to the left or right hand where a unilateral tactile target was presented. This facilitated response times for attended over unattended targets. In experiment 2, the cue was unilateral and non-predictive of the target location resulting in inhibition of return. Importantly, the cue was rhythmic and targets were presented early, in synchrony or late in relation to the rhythmic cue. A foreperiod effect was observed in experiment 1 that was independent from any spatial attention effects. In experiment 2, in synchrony were slower compared to out of synchrony targets but only for cued and not uncued targets, suggesting the rhythm generates periods of exogenous inhibition. Taken together, temporal and spatial attention interact in touch, but only when both types of attention are exogenous. If the task requires endogenous spatial orienting, space and time are independent.

1. Introduction

Our sensory system is constantly exposed to vast amounts of information. To efficiently deal with this information, interact with the world and guide our behaviour, we need to select, predict and prioritize certain events and stimuli over others. This is collectively known as attention and can be directed in both space and time (Coull & Nobre, 1998). Spatial attention typically distinguishes between endogenous and exogenous orienting, the former being voluntary and the latter stimulus driven (Corbetta & Shulman, 2002; Posner, 1980). Endogenous attention to a spatial location has been shown to enhance perceptual processing (e.g., Mangun & Hillyard, 1990; Yeshurun & Carrasco, 1998) as well as facilitate behaviour for stimuli at attended compared to unattended locations (see Carrasco, 2014 for a review).

Interactions with events in our environment rely not only on *where* something happens but also on *when* an event occurs. The general terms used to describe expectations and associations of events based on timing is known as temporal attention. There are several different types of temporal structures which can guide temporal attention such as associations, hazard rates, sequences and rhythms (see Nobre and van Ede, 2018, for a recent review of temporal attention). Similar to spatial attention, these temporal structures can be stimulus driven and

automatic (exogenous temporal attention) or under voluntary control (endogenous temporal attention). Endogenous temporal attention has been investigated using temporal cueing tasks where temporal associations between stimuli are formed. In a Posner like cue-target paradigm, a symbolic temporal cue can be used to direct attention to a moment in time in anticipation of an upcoming target. To note is that the stimuli used in such paradigms are typically visual or auditory and little is known about the effects in touch; the modality of interest in the present study. Endogenous temporal attention has been shown to facilitate response times (RTs) (Griffin, Miniussi, & Nobre, 2001; Lange and Röder, 2006; Pomper, Keil, Foxe, & Senkowski, 2015), perceptual discrimination (Correa, Lupiáñez, & Tudela, 2005; Rohenkohl, Gould, Pessoa, & Nobre, 2014) and enhance neural processing at attended over unattended times (Buhusi & Meck, 2005; Correa, Lupiáñez, Madrid, & Tudela, 2006; Rohenkohl & Nobre, 2011; Zanto et al., 2011). Temporal attention can also be exogenous and driven by stimuli in our environment such as a rhythm (Rohenkohl, Coull, & Nobre, 2011; see Klein and Lawrence, 2012; and Lawrence & Klein 2013, for a review and framework for the allocation of temporal and spatial attention). Even in the absence of external stimuli and associations, temporal expectancies can be formed by the passage of time itself. The likelihood of an event occurring may vary over time. This automatic temporal expectation of

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elapsed time is continuously updated and has been used to explain the foreperiod effect whereby RTs are typically faster for longer compared to shorter foreperiods (Karlin, 1959; Niemi & Naatanen, 1981; Nobre, Correa, & Coull, 2007). In other words, the longer between a cue and imperative target, the faster you respond. This increase in expectation has been expressed as the ‘hazard function’ which is the likelihood of an imperative event increases with time, if it has not yet occurred (Janssen & Shadlen, 2005; Luce, 1986; Nobre et al., 2007). For example, the likelihood that the traffic light will turn green increases the longer you wait. The foreperiod effect is automatic but can be influenced and eliminated if the cue-target interval is fixed rather than variable (Coull, Cotti, & Vidal, 2016; Nobre & Rohenkohl, 2014). That is, if a cue is informative of when an upcoming target is likely to appear and thus endogenous temporal attention is allocated to a moment in time, the foreperiod effect is reduced or eliminated (Coull et al., 2016). The effects of endogenous temporal attention have not only been explored using a single symbolic cue, but also using rhythms. Rhythms themselves can be explicitly attended to and used as an endogenous temporal cue to speed up target detection (Doherty, Rao, Mesulam, & Nobre, 2005), but rhythms can also elicit exogenous temporal attention effects without the need to attend to the rhythmic events (Rohenkohl et al., 2011; Ball, Michels, Thiele, & Noesselt, 2018). In other words, rhythms can independently affect and facilitate performance regardless if they are relevant to the task or predictive of a target event (Breska & Deouell, 2014; Sanabria, Capizzi, & Correa, 2011).

The effects of rhythmic structures have been explained through the dynamic attending theory (DAT) which proposes that rhythms entrain periodic fluctuations of attention which modulate the gain of sensory input (Large & Jones, 1999). Jones, Moynihan, Mackenzie, & Puente (2002) conducted a seminal study providing empirical support for the DAT. Participants were asked to judge if two tones, one at the start and one at the end of the trial, were of the same pitch. Sandwiched between the first (standard) and last (comparison) tone was a stream of regularly presented tones forming a rhythm. Crucially, the comparison tone at the end of the trial could be presented in synchrony with the rhythm or slightly early or late. Jones and colleagues found that the pitch judgement accuracy followed an inverted U-shaped pattern whereby accuracy was best when comparison tones were presented on the beat and tailing off if appeared early or late. It is important to note that the rhythm was not task-relevant and did not explicitly help with performing the pitch judgement task. Presenting stimuli in synchrony with a rhythm has been shown to improve choice RTs (Martin et al., 2005), detection thresholds (Herrmann, Henry, Haegens, & Obleser, 2016; Lawrance, Harper, Cooke, & Schnupp, 2014) and perceptual discrimination (Rohenkohl, Cravo, Wyart, & Nobre, 2012).

In line with the DAT theory, research has observed that intrinsic neural oscillations can entrain to external rhythms by aligning the firing pattern of neurons with rhythms in our environment (Arnal & Giraud, 2012; Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008; for reviews see Calderone, Lakatos, Butler, & Castellanos, 2014; Henry and Herrmann, 2014). In other words, groups of neurons start to fire in synchrony with external rhythms. By locking onto these rhythms, the brain automatically creates time points where stimuli is thought to be better processed. Perception of near threshold stimuli has been shown to be influenced, depending on where in the phase of the oscillation the stimuli are presented (Busch, Dubois, & VanRullen, 2009; Henry & Obleser, 2012; see VanRullen, 2016; Haegens and Golumbic, 2018, for recent reviews). Many examples of rhythmic patterns in the environment, such as walking, running, speech, listening to or playing music, involve motor and somatosensory input. The motor system is imperative in generating temporal predictions which shape perception (Grahm & Rowe, 2013; Morillon, Hackett, Kajikawa, & Schroeder, 2015; Schubotz, 2007) and the somatosensory system is closely linked to the motor system (van Ede, Winner, & Maris, 2015; Zaghera, Casale, Sachdev, McGinley, & McCormick, 2013) and actively engaged in synchronized rhythmic movements (Todd & Lee, 2015). Yet, little is known about

how we process rhythms in touch (although see Dockstader, Cheyne, & Tannock, 2010; Giabbiconi, Dancer, Zopf, Gruber, & Müller, 2004) and how spatial orienting of attention influences the effects of rhythmic input, and vice versa. The current research addresses this.

Spatial and temporal attention have been independently explored in the tactile domain, and in a similar manner to visual spatial attention research, variations of the Posner cue-target paradigm have been used (Posner, 1980). In an endogenous version of this paradigm a cue, for example a visual arrow or informative vibration, indicates to which hand an upcoming tactile target (e.g. a tap to the finger) will appear (Haegens, Handel, & Jensen, 2011). Endogenously attending to a location on the body has been shown to facilitate RTs (Jones & Forster, 2014; Spence & Gallace, 2007) and enhances early ERP components (e.g. P100) linked to somatosensory analysis (Sambo & Forster, 2011). In an exogenous version, the cue is non-informative (e.g., a tap to the left or right hand) and a target is presented to the same or opposite hand. This typically leads to inhibition of return (IOR; Klein, 2000) with slower RTs for cued compared to uncued targets and has been observed in both detection (Jones & Forster, 2012; Lloyd, Bolanowski, Howard, & McGlone, 1999) and discrimination tasks (Brown, Danquah, Miles, Holmes, & Poliakoff, 2010). When endogenous and exogenous spatial attention have been contrasted, independent RT effects have been observed suggesting these are separate mechanisms, at least under low task demands (Jones & Forster, 2013, 2014; see also Berger, Henik, & Rafal, 2005 for similar results in visual orienting). The effects of tactile temporal attention have been less explored but with a few exceptions. van Ede, de Lange, Jensen, & Maris (2011) presented participants with a spatially informative auditory cue indicating to which hand an upcoming tactile target would be presented. The target was then presented after one of three different time intervals. van Ede and colleagues observed faster RTs for longer intervals between cue and target, consistent with the hazard function (Janssen & Shadlen, 2005; Luce, 1986).

The aim of the current study is to investigate how the effects of exogenous temporal attention in touch are affected by endogenous and exogenous spatial attention. In this article, the term temporal attention will refer to predictive temporal structures which are used to prioritize and select relevant items to guide behaviour (Nobre and van Ede, 2018). Moreover, and in line with Nobre and van Ede’s (2018) definition, temporal expectation refers to the neural or cognitive state of predicted timing of an event and with no implications concerning volition, awareness or conscious deliberation. Endogenous temporal attention in the present article refers to voluntarily anticipating moments in time (the present study did not explicitly manipulate endogenous temporal attention). Exogenous temporal attention includes both the effects of the rhythmic temporal structure, which can automatically generate predictions about the timing of an event, and also foreperiod effects which are automatically driven by the passage of time. The current study, comprised of two independent experiments, uses a novel version of a Posner cue-target paradigm, manipulating spatial and temporal attention in a single trial. Instead of the cue being for example, an arrow or single tap, the cue itself forms a rhythm of tactile events. In the endogenous spatial attention tasks (experiment 1), the rhythmic cue is bilateral and informs whether to attend to the left or right hand. In the exogenous task (experiment 2), the rhythmic cue is unilateral and non-informative as to which hand the upcoming target will appear. A target then appears early, in synchrony or late in relation to the rhythmic cue. Importantly, whether the target appears in synchrony with the rhythm is not task-relevant. The first objective was to investigate exogenous temporal attention in touch which could lead to two possible outcomes, both of which might be observed. First, rhythmic tactile stimuli are automatically entrained and observed effects follow the DAT theory with faster RTs to in synchrony targets compared to early and late targets. Second, RTs are influenced by the probability of target events over time and follow the foreperiod effect with faster RTs for late, compared to in synchrony and then slowest RTs

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