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Inhibition of return and attentional facilitation: Numbers can be counted in, letters tell a different story

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ABSTRACT

Prior research has provided strong evidence for spatial–numerical associations. Single digits can for instance act as attentional cues, orienting visuo-spatial attention to the left or right hemifield depending on the digit's magnitude, thus facilitating target detection in the cued hemifield (left/right hemifield after small/large digits, respectively). Studies using other types of behaviourally or biologically relevant central cues known to elicit automated symbolic attention orienting effects such as arrows or gaze have shown that the initial facilitation of cued target detection can turn into inhibition at longer stimulus onset asynchronies (SOAs). However, no studies so far investigated whether inhibition of return (IOR) is also observed using digits as uninformative central cues. To address this issue we designed an attentional cueing paradigm using SOAs ranging from 500 ms to 1650 ms. As expected, the results showed a facilitation effect at the relatively short 650 ms SOA, replicating previous findings. At the long 1650 ms SOA, however, participants were faster to detect targets in the uncued hemifield compared to the cued hemifield, showing an IOR effect. A control experiment with letters showed no such congruency effects at any SOA. These findings provide the first evidence that digits not only produce facilitation effects at shorter intervals, but also induce inhibitory effects at longer intervals, confirming that Arabic digits engage automated symbolic orienting of attention.

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1. Introduction

Numbers are omnipresent in our daily lives. We use them for instance to express the value of a given item, to indicate time, dates and locations, to evaluate distances, quantities and order. Behavioural studies have shown a strong link between number and space representations (for a review, see de Hevia, Vallar, & Girelli, 2008; Fias & Fischer, 2005; Hubbard, Piazza, Pinel, & Dehaene, 2005). A popular hypothesis states that the representation of numerical magnitude is mapped onto a spatial mental number line (Dehaene, 1992; Moyer & Landauer, 1967; Restle, 1970) oriented from left to right — at least in western cultures (Dehaene, Bossini, & Giraux, 1993). Whereas most people are unaware of this association of numerical and spatial representations, approximately 12% of individuals (Tang, Ward, & Butterworth, 2008) experience this number–space link consciously: number–form synaesthetes (Galton, 1880; Hubbard, Ranzini, Piazza, & Dehaene, 2009; Jarick, Dixon, Maxwell, Nicholls, & Smilek, 2009; see Price & Mattingley, 2013 for a review).

The best-documented demonstration of the association of numbers and space is the so-called SNARC effect (Spatial–Numerical Association of Response Codes), first described by Dehaene et al. in 1993 (for a review see Fias & Fischer, 2005). The SNARC effect refers to the observation that in a magnitude irrelevant binary classification task on centrally presented digits, participants are typically faster to respond to a small number with the hand in their left side of space, and to a large number with the hand in the right side of space. These findings were interpreted as reflecting the specific orientation characteristics of the mental number line representation stored in long-term memory (for a meta-analysis see Wood & Fischer, 2008). Alternatively, the effect has been proposed to reflect the direction of serial order processing in working memory (van Dijck & Fias, 2011; van Dijck, Abrahamse, Acar, Ketels, & Fias, 2014; van Dijck, Abrahamse, Majerus, & Fias, 2013).

The association between numbers and space has been confirmed by behavioural evidence that numbers can shift visuo-spatial attention when they are presented as uninformative cues in the context of a target detection task (Fischer, Castel, Dodd, & Pratt, 2003). Fischer and colleagues reported that participants were faster to detect a left-sided target when it was preceded by a small digit, whereas

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right-sided targets were detected faster when preceded by a large digit; even though the digit was presented centrally and was completely irrelevant to the successful completion of the target detection task. These findings are referred to as "attentional SNARC effect" (e.g. Dodd, van der Stigchel, Adil Leghari, Fung, & Kingstone, 2008; van Dijck et al., 2014). More recently, neuroscientific studies have extended the attentional SNARC effect to modulations of neural activity using functional magnetic resonance imaging (fMRI) (Goffaux, Martin, Dormal, Goebel, & Schiltz, 2012) and event-related potential (ERP) techniques (Ranzini, Dehaene, Piazza, & Hubbard, 2009; Salillas, El Yagoubi, & Semenza, 2008; Schuller, Hoffmann, Goffaux, & Schiltz, 2014). Since in the original paradigm, digit cues were task-irrelevant and non-predictive of target location it has been suggested that visuo-spatial attention shifts induced by numbers are obligatory.

However several more recent reports (Galfano, Rusconi, & Umilta, 2006; Ristic, Wright, & Kingstone, 2006) indicate that the observed visuo-spatial attention shifts induced by numbers are influenced by the participant's mental set, and thus question the automaticity of attentional shifts elicited by digits. As a matter of fact, it was reported that number-induced attentional shifts can be abolished by simply adding vertical target locations. The attention effect is even reversed when asking participants to imagine a mental number line running from right to left or a clock face (Ristic et al., 2006) or when instructing participants to orient their attention to the left after large numbers and to the right after small numbers (Galfano et al., 2006; for a detailed discussion about the issue of automaticity of visuo-spatial cueing by numerals see Galfano et al., 2006 and Ristic et al., 2006). Contrary to the above-mentioned hypothesis of obligatory attentional shifts, these findings suggest that activation of the mental number line is influenced by top-down control (see also Zanolie & Pecher, 2014 for a failure to replicate the original study and the related comment by Fischer & Knops, 2014).

Classically the visuo-spatial attention field distinguished "exogenous" attentional processes, following salient peripheral cues controlled exclusively by the external events themselves, from "endogenous" ones, induced by internal expectations following central and predictive cues (James, 1890; Jonides, 1981; Posner, 1980; Posner & Cohen, 1984; Yantis & Jonides, 1984). Exogenous cues typically induce a facilitation effect (i.e. shorter RTs for cued targets than uncued targets) followed by inhibition of return (IOR) (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985) at longer cue-target intervals at the cued location. IOR refers to the fact that cued targets are processed slower than uncued targets at long cue-target intervals since after the initial attentional shift, attention is subsequently disengaged from that location in order to facilitate visual search (see Klein, 2000 for a review). With endogenous (predictive) cues, initial facilitation is in comparison slow to emerge and long lasting — typically without being followed by an IOR effect (Taylor & Klein, 2000; but see Lupiáñez, Martín-Arévalo, & Chica, 2013 for a report of IOR using an endogenous cueing paradigm). IOR is thought to arise because people tend not to revisit recently attended locations (Posner et al., 1985; Posner & Cohen, 1984 in Mathôt & Theeuwes, 2010). It was also proposed that IOR might be related to oculo-motor response preparation (e.g. Rafal, Calabresi, Brennan, & Sciolto, 1989; but see also Chica, Klein, Rafal, & Hopfinger, 2010) and sensory adaptation processes (e.g. Berlucchi, 2006; Posner & Cohen, 1984).

In the last decade, this overly simple sub-categorisation into endogenous vs. exogenous attention effects has been revisited (Chica & Lupiáñez, 2009; Chica, Lupiáñez, & Bartolomeo, 2006; Hommel, Pratt, Colzato, & Godijn, 2001; Lupiáñez et al., 2004; Pratt & Hommel, 2003; Ristic & Kingstone, 2006, 2009, 2012; Ristic, Landry, & Kingstone, 2012; Ristic, Wright, & Kingstone, 2007; see also Gibson & Kingstone, 2006). A more descriptive and balanced classification of attentional cues has been elaborated by focusing (a) on the informational content of the cue (predictive vs. non-predictive) and (b) on its spatial position with respect to visual fixation (central vs. peripheral). Amongst others, the traditional focus on central predictive cues was balanced by using also *central non-predictive* cues that convey spatial information.[1] Accordingly Ristic and Kingstone (2012) recently extended the prevailing framework by suggesting a third form of attentional orienting processes to account for attentional effects induced by central uninformative but behaviourally relevant cues. In their study, the authors demonstrate that overlearned behaviourally relevant stimuli engage attentional orienting processes that operate independently of, and in parallel with, endogenous and exogenous spatial attention. Ristic and Kingstone refer to these processes as automated symbolic orienting as they reflect an "involuntary attentional response that has become automated as a function of repeated exposure to environmental contingencies", with the term "automated" reflecting the learning aspect of this automatic effect. Consequently, the automaticity of the effect may vary as a function of central cue (Ristic & Kingstone, 2012). The attentional response is described as being involuntary or unintentional as opposed to endogenous orienting, which is based on intentional resource allocation and exogenous orienting which occurs without intention but as a function of simple sensory stimulation. Automated symbolic orienting arises without intention but as a function of the overlearning of the cue's contingency over time (Dodd & Wilson, 2009). In the cue category eliciting automated symbolic orienting, Ristic and Kingstone distinguish between social biologically relevant cues such as gaze (Driver et al., 1999; Langton & Bruce, 1999) and finger pointing (Langton & Bruce, 2000) and nonsocial behaviourally relevant cues such as arrows (Hommel et al., 2001; Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). Pertinent to the present study, former research has indicated that the facilitation effects produced by this type of cues can be followed by IOR. With gaze cues IOR has been observed when using particularly long stimulus onset asynchronies (SOAs) (Frischen & Tipper, 2004; Frischen, Bayliss, & Tipper, 2007; Frischen, Smilek, & Tipper, 2007; Jingling, Lin, Tsai, & Lin, 2015; Marotta et al., 2013), whereas central arrows have been shown to lead to IOR in the context of saccade preparations (Rafal et al., 1989, but see Chica et al., 2010) or for specific response modalities (manual versus saccadic, see Taylor & Klein, 2000).

As mentioned above, several studies have also shown that digits orient visuo-spatial attention when they are presented as central non-predictive cues in lateral target detection paradigms (Fischer et al., 2003; Galfano et al., 2006; Ristic et al., 2006). However, so far none of these studies investigated potential IOR effects expected at longer SOAs for this nonsocial behaviourally relevant type of central non-predictive cue as has been done with social biologically relevant cues (see Frischen & Tipper, 2004; Frischen, Bayliss, et al., 2007; Frischen, Smilek, et al., 2007; Jingling et al., 2015; Marotta et al., 2013). The current study fills this gap by investigating attentional SNARC effects at short and long SOAs, thus exploring the time course of attentional orienting effects induced by central non-informative digits. Since IOR has been observed with social biologically relevant eye-gaze cues and nonsocial behaviourally relevant arrow cues, we might also expect IOR after non-predictive centrally presented digit cues when using appropriately long SOAs. The present design thus provides important information on the automated nature of attention shifts associated with digits, originating from the category of non-social behaviourally relevant cues. Our findings will critically help define this central non-predictive cue type that has been reported to elicit less automatic effects than for instance gaze cues (Galfano et al., 2006).

Our control condition consisted of the same paradigm using letters of the alphabet as central non-predictive cues. It has been shown that other ordered series such as letters are associated to space (Gevers,

[1] In addition to the classically used uninformative peripheral cues, Lupiañez and colleagues also introduced *informative peripheral* cues and found facilitation followed by IOR for predictive as well as non-predictive peripheral cues. This finding indicates that expectations based on cue predictiveness do not influence involuntary attention shifts induced by peripheral cues (Chica & Lupiáñez, 2009; Lupiáñez et al., 2004, 2013).

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