Cognition 168 (2017) 191–204

Contents lists available at ScienceDirect

Cognition

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

Original Articles

No arousal-biased competition in focused visuospatial attention

Árni Gunnar Ásgeirsson[a,b,*], Sander Nieuwenhuis[a,1]

[a] Cognitive Psychology Unit, Leiden University, The Netherlands
[b] University of Akureyri, Iceland

ARTICLE INFO

Article history:
Received 12 December 2016
Revised 3 July 2017
Accepted 4 July 2017
Available online 11 July 2017

Keywords:
Alerting
Emotion
Phasic arousal
Tonic arousal
Cognitive modeling
Bayesian statistics

ABSTRACT

Arousal sometimes enhances and sometimes impairs perception and memory. A recent theory attempts to reconcile these findings by proposing that arousal amplifies the competition between stimulus representations, strengthening already strong representations and weakening already weak representations. Here, we report a stringent test of this arousal-biased competition theory in the context of focused visuospatial attention. Participants were required to identify a briefly presented target in the context of multiple distractors, which varied in the degree to which they competed for representation with the target, as revealed by psychophysics. We manipulated arousal using emotionally arousing pictures (Experiment 1), alerting tones (Experiment 2) and white-noise stimulation (Experiment 3), and validated these manipulations with electroencephalography and pupillometry. In none of the experiments did we find evidence that arousal modulated the effect of distractor competition on the accuracy of target identification. Bayesian statistics revealed moderate to strong evidence against arousal-biased competition. Modeling of the psychophysical data based on Bundesen's (1990) theory of visual attention corroborated the conclusion that arousal does not bias competition in focused visuospatial attention.

1. Introduction

Arousal, the global state of activation of our central and autonomic nervous system, is one of the driving forces in human behavior. Recent years have seen a renewed interest in the effects of arousal on brain, mind and behavior (Cavanagh, Wiecki, Kochar, & Frank, 2014; Eldar, Cohen, & Niv, 2013; Lee, Baek, Lu, & Mather, 2014; Murphy, Vandekerckhove, & Nieuwenhuis, 2014; Nassar et al., 2012; Sørensen, Vangkilde, & Bundesen, 2015; Vinck, Batista-Brito, Knoblich, & Cardin, 2015; Warren et al., 2016). These studies have revealed that slow as well as second-to-second fluctuations in arousal have highly specific influences on neural activity and cognitive function. A common theme in this research is that arousal level modulates the impact of new observations on subsequent perceptual inferences, a finding that has led to detailed computational models in which arousal indexes specific forms of uncertainty and corresponding changes in gain or estimated precision (e.g., Allen et al., 2016; Murphy, Boonstra, & Nieuwenhuis, 2016; Nassar et al., 2012). A less well understood aspect of arousal is that it sometimes enhances and sometimes impairs perception and memory (reviewed in Hanoch & Vitouch, 2004; Mather, Clewett, Sakaki, & Harley, 2016; Mather & Sutherland, 2011). For example, the same arousal manipulation may enhance perceptual learning of a target among dissimilar distractors, while impairing perceptual learning of the same target among similar distractors (Lee, Itti, & Mather, 2012). Here, we examine this aspect of arousal by investigating how arousal shapes visual perception of targets and distractors in a focused-attention task.

An elegant theory that attempts to explain the somewhat contradictory effects of arousal on cognitive function is the arousal-biased competition theory (henceforth ABC theory; Mather & Sutherland, 2011). ABC theory is based on the idea of biased competition (e.g., Bundesen, 1990; Desimone & Duncan, 1995) which views visual attention as a competitive process, during which a processing capacity of a fixed size is divided asymmetrically among signals of varying interest (or priority). Because processing capacity is fixed, a processing advantage of one signal must come at the expense of processing other signals. Building on classic arousal studies (Bacon, 1974; Easterbrook, 1959; Hockey & Hamilton, 1970), ABC theory posits that the competitive advantages caused by biased competition are further exaggerated under arousal, leading to "winner-take-more/loser-take-less" dynamics (Mather & Sutherland, 2011). The priority of a given signal relative to other signals is what determines whether it will be amplified or

* Corresponding author at: University of Akureyri, Sólborg v/Nordurslod, IS-600 Akureyri, Iceland.

E-mail address: arnigunnar@unak.is (Á.G Ásgeirsson).

[1] Address: Cognitive Psychology Unit, Faculty of Social Sciences, Leiden University, The Netherlands.

http://dx.doi.org/10.1016/j.cognition.2017.07.001
0010-0277/

attenuated by arousal. When a signal is assigned high priority, either due to its salience (e.g., intensity) or goal relevance (Fecteau & Munoz, 2006), then arousal will amplify this signal, leading to a competitive advantage in biased competition. Conversely, when the salience or relevance of the signal is low, arousal will attenuate it, further impeding behavioral responses to that signal.

ABC theory has several virtues. First, the key principle of arousal-biased competition is consistent with a class of computational models in which the modulatory effects of catecholamine-mediated changes in arousal are implemented as a change in the responsivity or gain of task-processing units, and as a result produce the winner-take-more/loser-take-less effects that ABC theory attempts to explain (Eldar et al., 2013; Servan-Schreiber, Printz, & Cohen, 1990; Warren, Murphy, & Nieuwenhuis, 2016). Second, Mather and colleagues have proposed a biologically plausible account of how the winner-take-more/loser-take-less effects of arousal-biased competition are realized in the brain (Mather et al., 2016). A third major advantage of ABC theory is that it attempts to explain the effects of arousal on a wide range of cognitive processes, including perception, attention, and memory, and may even apply to higher-order cognition such as strategy use in decision-making (Wichary, Mata, & Rieskamp, 2015).

To date, the clearest evidence for the ABC theory is seen in memory research. For example, Sakaki, Fryer, and Mather (2014; see also Clewett, Sakaki, Nielsen, Petzinger, & Mather, 2017) presented a serial stream of pictures of which one was an oddball (signified by a black frame), and asked half of the participants to prioritize the oddball itself, and the other half to prioritize the picture preceding it (oddball-1). The researchers found that the arousal induced by the oddball picture affected memory for the oddball-1 picture in a way that depended on whether subjects prioritized that item. The arousing picture facilitated memory of the preceding neutral picture in the group of participants that prioritized those oddball-1 pictures, while it impaired memory of the oddball-1 picture in the group that prioritized the oddballs rather than the preceding neutral items. This data pattern can be accounted for in terms of arousal-biased competition by positing that arousal enhanced memory consolidation of the prioritized signal representations at the expense of other, lower-priority signal representations.

In this article we focus on the potential of ABC theory to account for effects of arousal on another cognitive process: visual attention. Sutherland and Mather (2012) conducted a direct test of arousal-biased competition principles in visual attention. They presented participants with unpleasant and neutral sounds before flashing eight target letters on the screen. Of the eight targets, three were high-contrast letters, while the other five were of low contrast. This manipulation was assumed to force asymmetric bottom-up prioritization of letters, in that the strong, high-contrast signals would naturally be prioritized above the weaker, low-contrast signals. Participants were instructed to report as many of the letters as possible, but were not asked to value one letter type over the other. The authors found that high-contrast letters were more likely to be reported, but also that this bias was amplified following arousing sounds. The opposite was true for low-contrast letters, which were reported less often under arousal. Another divided-attention study found that increases in temporal attention, which are accompanied by increased arousal, enhance the efficiency of selecting targets rather than distractors (Sørensen et al., 2015). This pattern of findings provides some promising first evidence that arousal increases competition in divided visual attention, amplifying the effects of prioritization based on (bottom-up) salience or (top-down) task-relevance.

In the current study, we assessed whether the principles of arousal-biased competition also apply in the context of focused rather than divided visuospatial attention. Specifically, our participants were forced to exert a high degree of attentional control to select a target from irrelevant distractors of differing intensity. We present the results of three main experiments (Experiments 1A, 2 and 3A) and two control experiments (Experiments 1B and 3B) using this focused-attention task in which we employed three different, well-established arousal manipulations to examine whether arousal modulates the competition for perceptual representation of stimuli differing in both top-down (task relevance) and bottom-up (salience) priority.

The specific task that we used was a singleton letter identification task, in which we briefly presented a red target letter, either (1) alone (target alone condition; Fig. 1.3), (2) flanked by five blue distractor letters (homogeneous distractor condition; Fig. 1.4), or (3) flanked by four blue and a single yellow distractor letter (salient distractor condition; Fig. 1.5).

By manipulating levels of distraction we were able to gauge perceptual performance when there was no, medium, and hard competition for limited attentional resources.

In Experiments 1A and 1B arousal was manipulated by presentation of pleasant, unpleasant and neutral pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). The IAPS picture set has been used successfully to induce emotional arousal in a large number of studies on visual cognition (e.g., Kristjánsson, Óladóttir, & Most, 2012; Lee et al., 2012). Compared to the International Affective Digital Sounds (IADS) stimulus set used by Sutherland and Mather (2012), the IAPS is a much larger set of stimuli and supports category formations (e.g., pleasant, unpleasant and neutral) with a sharper distinction between arousal and valence ratings. Therefore, we reasoned that – if anything – arousal effects should be increased by using IAPS pictures, relative to IADS sounds.

In Experiment 2 we used auditory alerting tones to induce arousal in participants, and compared task performance to a no-tone condition. A loud tone often induces a reflexive phasic arousal response (Hackley & Valle-Inclán, 2003; Tona, Murphy, Brown, & Nieuwenhuis, 2016), and can serve as a temporal cue for the participant to concentrate their efforts in a narrow interval of time.

Finally, in Experiments 3A and 3B we examined the effects of a tonic arousal manipulation on focused visuospatial attention. We presented ongoing loud white noise to participants while they performed the singleton letter identification task, and compared performance to blocks without auditory stimulation. Although most of the support for ABC theory is based on phasic arousal manipulations, Mather and Sutherland (2011, p. 120) mention an experiment by Hockey (1970), who found that ongoing loud auditory noise facilitated responses to higher-probability centrally presented stimuli while impairing responses to lower-probability peripherally presented stimuli. This effect of loud noise on selectivity was not found when central and peripheral stimuli were presented with equal likelihood. Although Hockey manipulated expectations rather than bottom-up or top-down attention, his result has been interpreted as a narrowing of attention under arousal (noise), in line with Easterbrook's (1959) cue-utilization theory of arousal (see Kahneman, 1973, pp. 37–42, for a short review). Note that according to ABC theory, the result reflects an arousal-induced attentional bias towards high-priority (here: high-probability) stimuli, not necessarily a narrowing of attentional focus.

In all three experiments we tested the prediction, derived from ABC theory, that arousal would modulate the effects of competition (level of distraction) on task performance. The prediction of an interaction between arousal and level of distraction was statistically evaluated using repeated-measures ANOVAs as well as their Bayesian counterparts (Rouder, Morey, Verhagen, Swagman, & Wagenmakers, in press), from which we obtained quantitative evidence for each of three models that might plausibly explain the data (see *General Method – Bayesian Analysis*). Furthermore, to get