

Letter to the editor

Voluntary attention reliably influences visual processing at the level of the C1 component: a commentary on Fu, Fedota, Greenwood, & Parasuram (2010)

Karsten Rauss¹, Gilles Pourtois², Patrik Vuilleumier^{3,4,5}, Sophie Schwartz^{3,4,5}

¹Institute of Medical Psychology and Behavioral Neurobiology, University of Tuebingen, Germany

²Department of Experimental Clinical and Health Psychology, Ghent University, Belgium

³Department of Neuroscience, University of Geneva, Switzerland

⁴Geneva Neuroscience Center, University of Geneva, Switzerland

⁵Swiss Center for Affective Sciences, University of Geneva, Switzerland

The load theory of selective attention (Lavie, 1995; Lavie, 2005; Lavie and Tsai, 1994) assumes an adaptive filtering mechanism that suppresses irrelevant perceptual information depending on the amount of attentional or perceptual resources used for task-related goals. In the wake of the original findings of Lavie and co-workers (Lavie, 1995; Lavie and Tsai, 1994), different types of load were identified. For example, it is now common to distinguish between perceptual load on the one hand and attentional load on the other. Perceptual load can be defined in terms of the amount of stimulus information that needs to be processed to perform a given task. It is typically assessed by comparing experimental conditions in which increasing numbers of stimuli are presented, leading to increased task difficulty (e.g. Barnhardt et al., 2008; Handy et al., 2001). By contrast, attentional load can be defined as differences in processing demands in the absence of physical stimulus differences (e.g. Bahrami et al., 2007). This is usually assessed using task instructions that lead to different processing demands for the same stimuli, such as the comparison between color detection and detection of conjunctions of color and shape during serial visual presentation of the same stimuli (Schwartz et al., 2005). For both perceptual and attentional load, increasing levels of load usually lead to reduced processing of task-irrelevant information such as distractor stimuli.

We previously demonstrated that attentional load modifies primary visual cortex (V1) responses to irrelevant stimuli, both as measured with fMRI (Schwartz et al., 2005) and as

indexed by the earliest component of the visual evoked potential (VEP), the so-called C1 (Rauss et al., in press; Rauss et al., 2009). While it has long been assumed that the earliest stages of processing in V1 are resistant to top-down influences exerted by attentional control mechanisms (Hillyard et al., 1998; Martinez et al., 1999), our results concur with other recent findings (Fu et al., 2010a; Fu et al., 2009; Karns and Knight, 2009; Kelly et al., 2008; Khoe et al., 2005; Poghosyan and Ioannides, 2008) to suggest otherwise.

In a paper published last year in this journal, Fu and colleagues (Fu et al., 2010b) report that attentional load does not affect C1 amplitudes. Their findings seemingly contrast with our results (Rauss et al., 2009). In this commentary, we argue that this apparent discrepancy is likely linked to methodological differences between the two studies. Specifically, we believe that the experimental manipulation used by Fu et al. (2010b) is not suitable for testing effects of attentional load and, accordingly, that their results cannot be used to challenge our findings. In addition, we clarify some issues regarding the interpretation of our work by Fu et al. (2010b). In so doing, we wish to underscore the compatibility of our results both with the load theory of selective attention and with recent fMRI and ERP evidence showing that attentional processes can exert early gain control influences in primary visual cortex that are reflected at the level of the C1.

Fu et al. (2010b) adapted an experimental paradigm previously used by their group to study effects of perceptual load on early VEP components (Fu et al., 2010a; Fu et al., 2009). Participants were shown an uninformative cue followed by a target display which varied in *perceptual* load on a trial-by-trial basis. Analyses focused on VEPs elicited by the cue stimuli, and *attentional* load was manipulated between experimental blocks by instructing participants to either watch the display passively (low attentional load) or to perform an orientation discrimination task on the target stimuli (high attentional load). It was found that VEPs elicited by the cue stimuli differed between low-load and high-load conditions at the level of the P1, but not at the level of the earlier C1 component. The authors concluded that attentional load has no effect on the C1.

We think that this conclusion is unwarranted for the following reasons. It is unclear whether effects of attentional load can be assessed with sufficient specificity by contrasting passive stimulation with active task-performance. While passive stimulation may be an interesting baseline condition of zero (or very low) attentional load, it does not control for spatial

orienting effects, nor does it provide any dependent measures that could relate electrophysiological changes to behavioral performance. This non-specificity of the passive-viewing condition, in combination with the non-informative nature of the cues employed by Fu et al. (2010b), complicates the interpretation of their results. Specifically, the behavioral data from their high-load condition indicate that cue stimuli affected the processing of subsequent targets. The authors explain this effect in terms of attention being involuntarily captured by the sudden onset of the cue. However, their claim that this process of involuntary attentional capture is comparable under conditions of passive viewing and active task-performance appears speculative in the absence of any behavioral data from the low-load condition that would corroborate this assumption. It thus remains unclear whether the observed modulation of P1 amplitudes elicited by the cue stimuli is unambiguously linked to attentional load or other, uncontrolled factors.

In our opinion, the effects reported by Fu et al. (2010b), rather than resulting from differences in attentional load, likely reflect involuntary attentional processes acting differentially in the context of passive stimulation vs. active task-performance. We refer to involuntary attention as the bottom-up selection of a stimulus due to some distinguishing characteristics (e.g. pop-out of a single red dot from a field of blue dots). Voluntary attention, on the other hand, designates an internally driven process of top-down selection related to the current goals of the subject. The concept of attentional load is intimately related to voluntary control of attention, as exemplified in our study by participants' compliance with the instruction to attend to either a single feature or a conjunction of features (Rauss et al., 2009).

It has been shown that voluntary attention can interact with involuntary attentional processes in a task-specific manner (Bacon and Egeth, 1994; Lamy et al., 2003). In this context, we believe that there is a high probability for the cues employed by Fu et al. (2010b) to engage involuntary attention to a higher degree during active task-performance than in the passive-viewing condition, chiefly because the cues appear in the same location as the target stimuli. This could explain why ERP modulations were selectively seen at the level of the P1 component, which has previously been linked to involuntary attention (Hopfinger and West, 2006). Voluntary attention, on the other hand, has been associated with systematic changes in the amplitude of the N1 component, but less consistently of the P1 component (Talsma et al., 2007; Vogel and Luck, 2000). Stronger engagement of

involuntary attention during active task-performance could also explain why P1 amplitudes were increased in this condition. In contrast, voluntary attention would be expected to suppress cue-elicited neural activity because the cues are completely non-informative, and this should result in reduced rather than augmented component amplitudes. Thus, inasmuch as it is linked to voluntary attention, attentional load is unlikely to explain the effects reported by Fu and colleagues. We conclude that due to theoretical and methodological limitations associated with the study of Fu et al. (2010b), their results cannot be taken as evidence against recent findings of C1 modulations by attentional load (Rauss et al., in press; Rauss et al., 2009).

In addition to these issues, we feel that Fu et al. (2010b) in some cases misrepresent our findings. In our study (Rauss et al., 2009) a task at fixation ensured that attention remained focused at the same location while the same distractors were presented in the peripheral visual field across two levels of attentional load. Behavioral results indicated successful manipulation of attentional load, and C1 amplitudes were found to be smaller under high compared to low attentional load when stimuli were presented in the upper visual field. Fu et al. (2010b) claim that these observations reflect enhanced C1 amplitudes under low load due to attentional spill-over from the fixation task. This interpretation appears unlikely, given that the presentation of central task-relevant stimuli was completely decoupled from the presentation of peripheral distractors in our study via a jitter between the offset of the central stimulus and the onset of the peripheral distractor. Moreover, this interpretation does not explain why any spill-over effect would selectively influence the C1 component. Instead, previous fMRI findings by our group on retinotopic surround suppression effects under increased attentional load (Schwartz et al., 2005), combined with the known electrophysiological properties of the C1 (Jeffreys and Axford, 1972) and the basic tenets of load theory (Lavie, 2005), suggest increased filtering of peripherally presented stimuli under high load as the most likely explanation for the observed results.

We also disagree with the statement of Fu and colleagues that their attentional manipulation was “direct”, whereas our assessment of VEPs elicited by task-irrelevant peripheral stimuli under different levels of attentional load at fixation was “indirect”. From their use of these terms, the authors’ argument seems to rest on the fact that they presented target stimuli at the same locations as the preceding cues. However, considering the temporal structure of their task, it appears unlikely that the cue stimuli were directly

affected by the attentional manipulation, as the latter would be expected to primarily apply to the processing of subsequent target stimuli, and because attention may act in a temporally specific fashion (Nobre et al., 2007; Rauss et al., in press).

Finally, Fu and colleagues explain the discrepancy between their results and ours by suggesting that attentional load is not the relevant variable explaining the modulation of C1 amplitudes reported in Rauss et al. (2009). The authors argue that non-specific factors such as arousal may instead be the source of the effects observed. While we cannot completely exclude such influences, we strongly believe that the experimental variables were properly controlled in our studies and represented a genuine manipulation of attentional load. Arguably, the same cannot be said of the experimental protocol used by Fu et al. (2010b), making their ERP results difficult to interpret within the framework of the load theory of selective attention. Consequently, we think that the results of Fu et al. (2010b) do not challenge recent evidence that the C1 component is modulated by attentional load.

References

- Bacon, W.F., Egeth, H.E., 1994. Overriding stimulus-driven attentional capture. *Perception & Psychophysics* 55, 485-496.
- Bahrami, B., Lavie, N., Rees, G., 2007. Attentional Load Modulates Responses of Human Primary Visual Cortex to Invisible Stimuli. *Current Biology* 17, 509-513.
- Barnhardt, J., Ritter, W., Gomes, H., 2008. Perceptual load affects spatial and nonspatial visual selection processes: an event-related brain potential study. *Neuropsychologia* 46, 2071-2078.
- Fu, S., Fedota, J., Greenwood, P.M., Parasuraman, R., 2010a. Early interaction between perceptual load and involuntary attention: An event-related potential study. *Neuroscience Letters* 468, 68-71.
- Fu, S., Fedota, J.R., Greenwood, P.M., Parasuraman, R., 2010b. Dissociation of visual C1 and P1 components as a function of attentional load: An event-related potential study. *Biological Psychology* 85, 171-178.
- Fu, S., Huang, Y., Luo, Y., Wang, Y., Fedota, J., Greenwood, P.M., Parasuraman, R., 2009. Perceptual load interacts with involuntary attention at early processing stages: Event-related potential studies. *NeuroImage* 48, 191-199.
- Handy, T.C., Soltani, M., Mangun, G.R., 2001. Perceptual load and visuocortical processing: event-related potentials reveal sensory-level selection. *Psychological Science* 12, 213-218.
- Hillyard, S.A., Teder-Salejarvi, W.A., Munte, T.F., 1998. Temporal dynamics of early perceptual processing. *Current Opinion in Neurobiology* 8, 202-210.
- Hopfinger, J.B., West, V.M., 2006. Interactions between endogenous and exogenous attention on cortical visual processing. *NeuroImage* 31, 774-789.
- Jeffreys, D.A., Axford, J.G., 1972. Source locations of pattern-specific components of human visual evoked potentials. I. Component of striate cortical origin. *Experimental Brain Research* 16, 1-21.

- Karns, C.M., Knight, R.T., 2009. Intermodal auditory, visual, and tactile attention modulates early stages of neural processing. *Journal of Cognitive Neuroscience* 21, 669-683.
- Kelly, S.P., Gomez-Ramirez, M., Foxe, J.J., 2008. Spatial Attention Modulates Initial Afferent Activity in Human Primary Visual Cortex. *Cerebral Cortex* 18, 2629-2636.
- Khoe, W., Mitchell, J.F., Reynolds, J.H., Hillyard, S.A., 2005. Exogenous attentional selection of transparent superimposed surfaces modulates early event-related potentials. *Vision Research* 45, 3004-3014.
- Lamy, D., Tsal, Y., Egeth, H.E., 2003. Does a salient distractor capture attention early in processing? *Psychonomic Bulletin & Review* 10, 621-629.
- Lavie, N., 1995. Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception Performance* 21, 451-468.
- Lavie, N., 2005. Distracted and confused?: selective attention under load. *Trends in Cognitive Science* 9, 75-82.
- Lavie, N., Tsal, Y., 1994. Perceptual load as a major determinant of the locus of selection in visual attention. *Percept Psychophys* 56, 183-197.
- Martinez, A., Anllo-Vento, L., Sereno, M.I., Frank, L.R., Buxton, R.B., Dubowitz, D.J., Wong, E.C., Hinrichs, H., Heinze, H.J., Hillyard, S.A., 1999. Involvement of striate and extrastriate visual cortical areas in spatial attention. *Nature Neuroscience* 2, 364-369.
- Nobre, A.C., Correa, A., Coull, J.T., 2007. The hazards of time. *Current Opinion in Neurobiology* 17, 465-470.
- Poghosyan, V., Ioannides, A.A., 2008. Attention Modulates Earliest Responses in the Primary Auditory and Visual Cortices. *Neuron* 58, 802-813.
- Rauss, K., Pourtois, G., Vuilleumier, P., Schwartz, S., in press. Effects of attentional load on early visual processing depend on stimulus timing. *Human Brain Mapping*.
- Rauss, K.S., Pourtois, G., Vuilleumier, P., Schwartz, S., 2009. Attentional load modifies early activity in human primary visual cortex. *Human Brain Mapping* 30, 1723-1733.
- Schwartz, S., Vuilleumier, P., Hutton, C., Maravita, A., Dolan, R.J., Driver, J., 2005. Attentional load and sensory competition in human vision: modulation of fMRI responses by load at fixation during task-irrelevant stimulation in the peripheral visual field. *Cerebral Cortex* 15, 770-786.
- Talsma, D., Mulckhuyse, M., Slagter, H.A., Theeuwes, J., 2007. Faster, more intense! The relation between electrophysiological reflections of attentional orienting, sensory gain control, and speed of responding. *Brain Res* 1178, 92-105.
- Vogel, E.K., Luck, S.J., 2000. The visual N1 component as an index of a discrimination process. *Psychophysiology* 37, 190-203.