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Supplementation of gamma-aminobutyric acid (GABA) affects temporal, but not spatial visual attention

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ABSTRACT

In a randomized, double-blind, and placebo-controlled experiment, the acute effects of gamma-aminobutyric acid (GABA) supplementation on temporal and spatial attention in young healthy adults were investigated. A hybrid two-target rapid serial visual presentation task was used to measure temporal attention and integration. Additionally, a visual search task was used to measure the speed and accuracy of spatial attention. While temporal attention depends primarily on the distribution of limited attentional resources across time, spatial attention represents the engagement and disengagement by relevant and irrelevant stimuli across the visual field. Although spatial attention was unaffected by GABA supplementation altogether, we found evidence supporting improved performance in the temporal attention task. The attentional blink was numerically, albeit not significantly, attenuated at Lag 3, and significantly fewer order errors were committed at Lag 1, compared to the placebo condition. No effect was found on temporal integration rates. Although there is controversy about whether oral GABA can cross the blood-brain barrier, our results offer preliminary evidence that GABA intake might help to distribute limited attentional resources more efficiently, and can specifically improve the identification and ordering of visual events that occur in close temporal succession.

1. Introduction

One of the most prominent research questions in cognitive neuroscience today is how the human brain is able to process the fast flow of information from the quick, ever-changing visual environment around us. It must be able to select and extract meaningful information that is comparatively rare from oft-substantial levels of irrelevant background noise. The success of this filtering mechanism depends on complex perceptual and attentional operations, which collectively guide the efficient processing of objects and events. Indeed, any shortcomings or lapses can cost us dearly, as can be witnessed in traffic incidents. Optimizing perception and attention could therefore bring tangible benefits. One way of doing so is by altering the balance of neurotransmitters in the brain. A prime candidate is the inhibitory neurotransmitter gamma-aminobutyric acid (GABA), which is one of the most extensively studied brain chemicals.

Empirical evidence from a large variety of research fields points towards a link between GABA levels in the brain and visual attention (e.g., Petersen, Robinson, & Morris, 1987). For example, animal studies have shown that GABA producing neurons play a key role in the regulation of attentional resources (McGarrity, Mason, Fone, Pezze, & Bast, 2017; Paine, Slipp, & Carlezon, 2011). In line with this, blockade of cortical GABA receptors by antagonists is associated with impaired visuospatial attention as measured by a 5-choice serial reaction time task, which is analogous to tasks that assess sustained attention in humans (Paine et al., 2011). At the same time, if supra-normal GABA levels in the brain increase functional inhibition beyond an optimal level, impaired attentional processing has also been observed (Pezze, McGarrity, Mason, Fone, & Bast, 2014). Further evidence from animal studies suggests that the inhibitory neurotransmitter is directly involved in visual attention by mediating stimulus selectivity in the primary visual cortex of the cat brain (Katzner, Busse, & Carandini, 2011).

In humans, Sandberg et al. (2014) found a negative correlation between GABA levels in the occipital cortex and self-reported cognitive failures – the deficiency to attend to relevant stimuli and to suppress irrelevant information – in daily life. Possibly, GABA strengthens inhibitory processes in the visual cortex improving the ability to disengage from irrelevant stimuli and suppress elaborate object processing, thereby promoting a more balanced distribution of attentional resources (Sandberg et al., 2014).

Furthermore, GABAergic system alterations have been found to affect visual integration processes through lorazepam administration,

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which is a benzodiazepine that enhances the neurotransmitter's effects (Giersch, 2001). Experiments have also shown that identifying gaps between line segments is easier after lorazepam intake compared to a placebo intake, indicating that GABA modulates and improves the processing of discontinuities in line segments (Giersch, 2001; Giersch, Boucart, Danion, Vidailhet, & Legrand, 1995).

Finally, there is also indirect evidence from transcutaneous vagus nerve stimulation that GABA levels modulate the efficiency of response selection (Steenbergen et al., 2015a). Transcutaneous vagus nerve stimulation is a non-invasive experimental technique that triggers the release of the neurotransmitter in the brain (Van Leusden, Sellaro, & Colzato, 2015), and which has been mainly used to treat patients with epilepsy, who suffer from an abnormal reduction in GABA-ergic function (Treiman, 2001). Transcutaneous vagus nerve stimulation has been linked with increased GABA-ergic cortical activity (Capone et al., 2015), and increased free GABA levels in the cerebrospinal fluid (Ben-Menachem et al., 1995). Increased GABA-A receptor density has also been observed after long-term exposure (Marrosu et al., 2003). However, it is also known to affect a wide range of other physiological mechanisms. Steenbergen et al. (2015a) had their participants perform a stop-change action cascading task, in which the speed of changed responses was measured. Stimulation resulted in faster responses than a sham condition, suggesting that response selection was facilitated by increased GABA levels, although it must be noted these were not measured in the study so that the link between performance and GABA levels remains only circumstantially supported.

In view of these various effects of GABA, it would be desirable to be able to modulate GABA levels in the brain more easily, for instance to attain cognitively beneficial levels. As it happens, in the past few years, GABA has become more widely available as a food supplement to the general population (Boonstra et al., 2015), holding the promise that simply ingesting GABA could result in attaining cognitive benefits. However, the evidence to date for cognitive effects of GABA ingestion are limited. Indeed, it has long been thought that the blood-brain barrier would prevent the uptake of GABA, rendering its consumption ineffective (Van Gelder & Elliott, 1958). Nevertheless, Steenbergen, Sellaro, Stock, Beste, and Colzato (2015b) administered an oral dose of 800 mg GABA to participants, who performed a stop-change paradigm, as in the previously cited study by Steenbergen et al. (2015a), and observed enhanced action selection, replicating and extending their previous study.

In view of these results, it is conceivable that oral ingestion of a comparable dose of GABA could also enhance attentional processing, but there is no evidence for that to date. Therefore, the specific effect of GABA supplementation on attentional deployment was investigated in the present study. To measure both temporal and spatial aspects of attention, two different tasks were implemented: A rapid serial visual presentation (RSVP) task, and a visual search (VS) task. The overarching hypothesis was that GABA consumption should help to select relevant information and thus improve performance in both tasks. The RSVP and VS task have diverse backgrounds, which are briefly summarized below.

1.1. Rapid serial visual presentation

By means of RSVP, one of the most widely studied aspects of temporal attention is the attentional blink (AB), a phenomenon in which the second of two visual targets is often missed by observers when both targets occur at a stimulus onset asynchrony (SOA) between 150 and 500 ms (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). The challenge of the RSVP task lies in the identification and segregation of relevant targets that are close in temporal succession within a fast stream of consecutive distractors. The failure to process two target stimuli that are close in temporal succession is hypothesized to arise from a limited amount of attentional resources (e.g., Chun & Potter, 1995). In general, processing the first target (T1) is thought to undermine the proper processing of the second target (T2). The idea of limited cognitive resources has been supported by many previous studies (for a review, see Martens & Wyble, 2010).

Taking this idea one step further, it has been proposed that the blink arises due to an overinvestment in T1 identification, which leaves insufficient attentional resources for the processing of T2 (Olivers & Nieuwenhuis, 2006; Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006). Studies show that the AB effect is attenuated when this overinvestment is prevented. For example, extraneous cognitive load during an RSVP task leads to distracting mental activity thereby preventing elaborate processing of T1 and leaving more resources for the identification of the second target (Nieuwenstein, Chun, van der Lubbe, & Hooge, 2015; Zhang, Shao, Zhou, & Martens, 2010). The additional cognitive load presumably leads to a more balanced distribution of attentional resources, thereby preventing the allocation of too many resources towards T1 processing. Further support was obtained by Slagter et al. (2007), who found a positive correlation between P3 size – an event-related potential (ERP) component that is sensitive to (prior) attentional resource allocation – and AB magnitude, providing further support for the hypothesis that T2 identification success is dependent on attentional deployment during T1 processing.

A secondary aspect that has been studied with RSVP is temporal integration, which can be observed when targets succeed each other directly, without intervening distractors, at Lag 1 (Akyürek et al., 2012). Lag 1 is a special case in RSVP, because many studies report Lag 1 "sparing", a paradoxical improvement of target identification in the shortest Lag condition, where processing time is most limited (Visser, Bischof, & Di Lollo, 1999). This phenomenon may in turn be related to a loss of order information that is most prevalent in the Lag 1 condition, suggesting that the typical increase in identification performance may come at a cost (Hommel & Akyürek, 2005). Akyürek et al. (2012) provided proof that these performance characteristics at Lag 1 are related to the occurrence of temporal integration, a perceptual process by which the successive targets are combined into a single, integrated percept. Thus, next to providing an index of temporal attention and the AB, the RSVP task can also be used to assess temporal integration.

1.2. Visual search

Selection of task-relevant targets within an array of distractors is mediated by spatial attention – the allocation of attentional resources across a visual scene. Particularly in feature-based search tasks, in which the observer is asked to find the targets by virtue of a specific feature (e.g., a diamond shape), or feature combination (e.g., a red diamond), search depends on the similarity of targets and other elements in the display, typically referred to as distractors (Treisman & Gelade, 1980; Wolfe, 1994). When targets are more similar to distractors, they are harder to find. Similarity is defined on the feature level, but also by whether they are defined in the same feature dimension (e.g., color or shape) or not. If the search cannot be resolved simply by looking for anything deviant within a search array (i.e., by singleton search; Bacon & Egeth, 1994), dimensionality strongly determines search efficiency, such that search for targets that are defined by features that belong to the same dimension as those of the distractors is difficult (Müller, Heller, & Ziegler, 1995).

An exemplary task in which such effects have been observed is the dual-singleton task, in which a target is not the only deviant item in a search array of otherwise uniform distractors, but is always presented with another salient item; a "nontarget" (e.g., Akyürek & Schubö, 2011). Here search is defined by a specific feature, such as the color blue, and the nontargets then either share this feature dimension by also having a color, but not the target color (e.g., red), or another salient feature, such as having a different line orientation. Although the different-dimensional feature of line orientation also makes the nontarget salient within the array, target search is much easier than for the same-dimensional trials, leading to shorter reaction times. ERP