**Abstract**

Selective attention is thought to prioritize object features related to high rewards by increasing their saliency and decreasing the saliency of other features. This mechanism is proposed to be linked to the activity of the visual cortex. Electrophysiological studies have provided support for this account, but have focused on transient attention and neural activity when either high- or low-rewarded feature is present. In this study, we investigated the influence of reward presence and probability on the allocation of sustained feature-based attention using steady-state visual evoked potentials (SSVEPs). SSVEPs represent oscillatory responses of the visual cortex and allow for tracking of simultaneous allocation of attention toward multiple features. We recorded EEG in 40 participants while they completed the Random Dot Kinematogram task. Dots of two colors were tagged with different frequencies. On each trial, participants were instructed to attend one of the colors and detect coherent movements. After the first block (baseline), participants were informed that they could earn rewards (acquisition), and that the two colors were paired with high or low probability of earning a reward. In the third block (extinction) participants could not earn any rewards. Participants were faster and more accurate in the training and test blocks compared to baseline. No effect of reward probability on behavior was found. SSVEP amplitudes were increased for attended compared to unattended color. The amplitudes were decreased in training compared to baseline and test blocks. While the amplitude of the high-reward color remained the same across the blocks, the amplitude of the low-reward color was reduced in the training block. These results provide first evidence that SSVEPs can be used to detect the influence of rewards on feature-based sustained attention. Also, they provide an insight into the dynamics and trade-offs related to processing of features linked to different reward probabilities.

Keywords: attention; EEG; feature-based attention; reward; motivation; steady-state visually evoked potentials; frequency tagging

# Introduction

Given the limited processing capacity, selective attention is crucial in choosing which stimuli will be processed (Chun, Golomb, & Turk-Browne, 2011; Desimone & Duncan, 1995). Visual selective attention (VSA) prioritizes stimuli in accordance with current goals and knowledge based on previous learning (Chelazzi, Perlato, Santandrea, & Della Libera, 2013). Della Libera and Chelazzi were the first to show that objects related with high rewards are easier to select as targets and harder to ignore as distractors, while the opposite is true for objects related to low rewards (Della Libera & Chelazzi, 2009).

“Alternative formulation: humans are more efficient to select targets associated with high rewards, but relatively inefficient at ignoring them when they are shown as distractors. Interestingly, the ability to ignore a given distractor also improved when this was consistently followed by high (as opposed to low) rewards, whereas the ability to select the same items as targets became relatively impaired.” “In summary, the present results provide evidence that reward has a direct impact on human vision that is independent of its role in strategy and endogenous attentional set. Our results suggest that the anterior cingulate cortex—a cortical expression of the mesolimbic dopamine system—plays a crucial role in this source of attentional control.”

Similar results were also found for features and locations related to different reward contingencies (for recent reviews see: Anderson, 2016; Failing and Theeuwes, 2017). The mechanisms through which rewards influence selective attention are a matter of intensive empirical and theoretical work. However, most researchers in the field agree that rewarded locations, objects, and object features are prioritized by increasing their saliency, while the saliency of the other locations, objects, and object features is reduced. This mechanism is commonly linked to the activity of the neurons in the visual cortex (Roelfsema, van Ooyen, & Watanabe, 2010). This idea has received a significant amount of support in fMRI and ERP studies.

It is known that there is a bottom-up effect, but here we wanted to look at what happens when participants strategically change their attentional set.

**Hickey & van Peelen, 2017**

When reward is linked to a discrete category, for example, if detecting “people”’ in a scene always results in high-magnitude reward, then humans and other animals will look out for these objects and this involves the establishment of top-down attentional set. Attentional set changes how stimuli are encoded and, though interesting in its own right, this effect is theoretically distinct from the direct, low-level, and nonstrategic impact of reward feedback on already-encoded representations that is the focus of the current study (Hickey et al., 2010a; Maunsell, 2004).

Most of the human behavioral and neural data supporting the idea of facilitation of reward-related stimuli and suppression of other stimuli comes from cueing and visual search tasks. When it comes to feature-based attention, most of the work is based on visual search paradigms in which different features present in briefly presented search arrays are related to different reward contingencies. This approach has been useful for mapping brain responses to transient stimuli related to different reward schedules. However, these designs carry several problems. First, given that different features appear in different locations in the search array, it is hard to disentangle the contribution of feature-based from the contribution of spatial attention to the reward effects on attention. Second, these paradigms allow for investigating only transient effects of reward on attention, while there is no possibility of investigating more sustained allocation of attention towards certain features. Finally, these paradigms do not allow for simultaneous measurements of attention allocation towards stimuli related to different values.

Recording steady-state visually-evoked potentials (SSVEPs) offers possibilities to overcome these issues. SSVEPs represent oscillatory responses of the visual cortex that have the same frequency as the driving visual stimulus (Norcia, Appelbaum, Ales, Cottereau, & Rossion, 2015). They are generated by the primary visual cortex (V1-V3)[REF]. SSVEPs allow for the study of simultaneous allocation of selective attention towards multiple stimuli. Each of those stimuli can be flickering at different frequencies which will produce SSVEPs at those respective frequencies. SSVEPs have been particularly useful in the study of attention because the amplitude of SSVEPs is reliably increased by spatial and feature-based attention (Andersen, Müller, & Hillyard, 2012). The application of SSVEPs has allowed for a clear experimental dissociation between spatial and feature-based selective attention (Muller et al., 2006) and for tracking the time-course of feature-based attention (Andersen & Müller, 2010). To summarize, SSVEPs provide a signal of good signal-to-noise ratio which enables: tracking simultaneous allocation of attention across multiple stimuli of different features; provide a measure of sustained attention; and can dissociate between spatial and feature-based attention.

In the present study we aimed to better understand the influence of rewards on feature-based selective attention by simultaneously looking into the amount of attention allocated towards stimuli linked to high and low reward probabilities. We recorded the SSVEPs in conditions when participants attended colors linked to either high or low reward probabilities. This allowed for making a clear distinction between the effect of attention and the effect of reward magnitude. Finally, our experiment consisted out of three phases (baseline, acquisition, and extinction) that allowed us to investigate the influence of reward probability on attention when rewards are present, but also when they are no longer relevant.

**Andersen et al., 2012**

“In typical visual search paradigms, each element of the search display is presented at a unique location, and hence spatial locations and features are confounded”

SSVEPs scale with the amount of attention: Toffanin, P., de Jong, R., Johnson, A., & Martens, S. (2009). Using frequency tagging to quantify attentional deployment in a visual divided attention task. International Journal of Psychophysiology, 72(3), 289-298.

**Norcia et al., 2015**

*Advantages of SSVEPs*

“The SSVEP is particularly well suited to attention research questions, as it provides a high-SNR measure of neural activity that can be unambiguously associated with specific external stimuli, even when multiple stimuli are present at the same time. Importantly, it allows monitoring of responses made to stimuli that are outside of the focus of attention, something that is difficult to do with behavioral methods. Moreover, the SSVEP can be flexibly deployed over a number of configurations, including the tagging of both spatially distinct and spatially overlapping stimuli. In light of these attributes, the SSVEP approach has gained possibly its greatest utility in studies that have addressed the cognitive and neural mechanisms underlying volitional attention in human beings.”

*Dissociating spatial and feature attention*

“The multi-input SSVEP studies already discussed provide compelling evidence that volitional attention operates on spatially distinct regions of a scene to modulate neural processing in an adaptive, goal oriented manner. Ample evidence also exists that attention can operate in a nonspatial manner to enhance processing of particular visual features such as color, orientation, or direction of motion. Because the SSVEP can be obtained from multiple overlapping stimuli, this method has been particularly useful in elucidating the neural mechanisms underlying such feature-based attention.

“Beginning in 2006, Muller, Andersen, and Hillyard conducted a series of elegant studies aimed at dissociating the influence of attention to features and feature conjunctions from the influence of spatial attention. These studies utilized overlapping fields of randomly moving red and blue colored (or in some cases achromatic) dots that were modulated at distinct frequencies (Figure 15).”

*Attended vs. unattended advantage*

“Frequency tagging makes it possible to monitor the response to multiple stimuli that are simultaneously visible. This feature of the SSVEP makes it possible to measure the effects of allocating attention to spatial location even for stimuli that are outside of the focus of conscious attention. In the first application of the SSVEP to spatial attention (Morgan, Hansen, & Hillyard, 1996), two strings of alphanumeric characters were presented in the left and right visual hemifields

(Figure 13).”

**Soren chapter**

“SSVEPs allow us to register continuously the neuronal processes underlying the perception of each individual element in search displays (Soren chapter)”. “A number of studies have localized the major generators of the SSVEP to early visual cortical areas and the highest SSVEP amplitudes are commonly recorded at occipital and parietal electrodes. The specific cortical areas involved and their individual contributions to the total scalp-recorded signal appear to depend upon the driving frequency. For the SSVEP elicited by a pattern-reversing stimulus, which produces a percept of motion, combined SSVEP and fMRI recordings have identified early visual areas V1 (primary visual cortex) and the motion sensitive MT/V5 as the main generator sources with minor contributions from midoccipital (V3a) and ventral occipital (V4) areas.” In the PNAS paper: “the cortical currents giving rise to the SSVEP attention effect were localized to a region containing the early visual areas V1-V3.”

*Chelazzi 2013*

“When performance is considered determinant for the achievement of rewards, then plasticity is observed at the level of the specific processes that enabled it (i.e., target selection and distracter inhibition), and learning takes the form of an instrumental type of adaptation (Della Libera & Chelazzi, 2009). Differently, when rewards are viewed as random, fortuitous events, then a direct and passive association takes place between the perceived stimuli and the rewards that follow them (Della Libera, Perlato, & Chelazzi, 2011).”

“Recent research suggests that both types of reward-based attentional learning involve brain structures usually associated with attentional control, including posterior parietal cortex (Krebs et al., 2011; Peck et al., 2009), and the processing of rewarding information, including the striatum and the anterior cingulate cortex (Hickey, Chelazzi, & Theeuwes, 2010a; O’Doherty, 2004; Schultz, 2006; Weil et al., 2010). Moreover, and perhaps most interestingly, they can affect the neural representation of visual stimuli at the level of extrastriate visual cortex, including area V4 and the inferotemporal cortex (Frankó, Seitz, & Vogels, 2010; Hickey, Chelazzi, & Theeuwes, 2010a; Jagadeesh et al., 2001; Mogami & Tanaka, 2006; Pessiglione et al., 2008; Weil et al., 2010), and this can occur even outside the context of a task as the result of the shear association of a stimulus with reward (Frankó, Seitz, & Vogels, 2010)”

“To sum up, the studies on attentional processing of stimuli associated with biased rewards reveal that when highly rewarded stimuli are task relevant they may lead to faster and more accurate performance in visual search tasks (Della Libera & Chelazzi, 2009; Kristjánsson, Sigurjónsdóttir, & Driver, 2010), and in the Stroop task (Krebs, Boehler, & Woldorff, 2010; Krebs et al., 2011); they also engender stronger inter-trial priming effects (Hickey, Chelazzi, & Theeuwes, 2010a; Kristjánsson, Sigurjónsdóttir, & Driver, 2010) and a higher resistance to the attentional blink phenomenon (Raymond & O’Brien, 2009). When the same stimuli act as distracters that need to be ignored they often lead to stronger effects of involuntary attentional capture (Anderson, Laurent, & Yantis, 2011a, 2011b; Rutherford, O’Brien, & Raymond, 2010) and greater interference effects (Della Libera & Chelazzi, 2009; Krebs, Boehler, & Woldorff, 2010; Krebs et al., 2011). However, it should be recalled that while some of the above results could all be reconciled with the notion of value learning, and the ensuing influence on attentional priority, some other results require a different explanation, namely one where rewards cannot only increase the salience of certain visual stimuli, thus facilitating their selection, but also increase the efficiency with which other stimuli can be suppressed. We have proposed that the latter effects can only be accounted for by making reference to notions of instrumental conditioning, whereby the delivery of rewards in relation to the suppression of a certain stimulus will reinforce the tendency for attention mechanisms to suppress the same stimulus on future occasions, not unlike the influence of instrumental conditioning on motor performance.”

We show that:

1) Introduction of rewards affects feature-based attention both behaviorally and in SSVEPs

2) Leads to lower levels of attention for the low rewarded stimuli, while high rewarded stimuli stay at the same level

3) The lingering effect of reward is present in the absence of rewards, even though our measure of feature-based attention goes back to baseline

**Maunsell, 2004**

However, the few neurophysiological studies that have varied the difficulty of a spatial attention task have shown that neuronal modulations by attention vary depending on task demands [29,30,34].

**SSVEPs**

**The present study**

Our goal is to use SSVEPs in order to, for the first time, assess the influence of reward probability on sustained feature-based attention. How this fits with the theoretical models presented in the first part of the intro? Present the main idea and design of the study. We manipulate reward probability, not magnitude (Maunsell, 2004).

In order to better understand the underlying neural substrates of reward-guided deployment of attention in relation to depressive symptoms, we have decided to add an EEG study to our project. This study is focusing on the steady state visually evoked potentials (SSVEPs) which represent the oscillatory responses of the visual cortex to flickering stimuli (Norcia, Appelbaum, Ales, Cottereau, & Rossion, 2015). This method has already been successfully used to explore the “attention grabbing” by irrelevant emotional stimuli (Attar, Andersen, & Müller, 2010) and is particularly interesting because it provides not just a measure of which stimuli capture attention, but also a continuous measure of how much attention is simultaneously being paid towards different stimuli. The first aim of this study is to investigate the possibility of using the SSVEPs to detect differences in the amount of attention deployed towards stimuli based on their associated reward value (Study 2a). The second aim of this study is to explore if the amount of attention being paid towards reward-related stimuli is linked to depression levels and anhedonic symptoms in particular (Study 2b).