TRABAJO FINAL DE GRADO

Artículo científico de producción empírica

Cross modal value-driven attention modulates task performance and neural synchronization under reward uncertainty

Rodrigo Caramés Harcevnicow – 4.781.284-6

Tutor: Dr. Francisco Cervantes

Revisora: Prof. Titular. María Alejandra Carboni

Facultad de Psicología

Universidad de la República

Montevideo, Uruguay

Octubre, 2022

Cross modal value-driven attention modulates task performance and neural synchronization under reward uncertainty

Abstract

In addition to voluntary goals and stimulus salience, a stimulus' prior associated reward also influences selective attention. Previous studies have demonstrated that previously reward-associated auditory stimuli can affect a later visual task, even as such stimuli become task irrelevant. We show that the same can happen the other way around, as task irrelevant reward-associated visual stimuli interferes with the performance of an audiovisual task. This interference negatively correlates to synchronization in simultaneously acquired electroencephalography (EEG) data with the auditory signal, expressed by increased inter trial phase coherence measures. EEG analyses showed that both reward and uncertainty associations jointly modulated neural synchronization. Through behavioral and neural data, our findings suggest that value-driven cross modal attentional capture dynamically interferes with visual and auditory processes. Interference occurs under increasing neural synchronization to a contextually irrelevant reward-associated signal dynamics. The results thus specify an additional cross-modal modulation directionality, and provide further evidence of the relevance of reward uncertainty for such effects.

Keywords: Value-driven attention - auditory attention - cross-modal attention - Inter trial phase coherence

Introduction

Attention is the cognitive function that directs the processing capabilities of the brain towards the aspects of the daily information load that matter most at the given moment (Purves et al., 2008). This attentional selection has been traditionally understood to be guided by a voluntary, goal-driven mode, in which attention is directed in accordance with one's goals, expectations, or knowledge, and by an involuntary, stimulus-driven mode, in which attention is captured by particularly salient stimuli in the environment (Theeuwes, 2010).

However, recent research has shown that learned value plays an important role in the guidance of attention. This has been demonstrated in studies like Anderson et al. (2011) where participants were initially presented with a training task in which visual stimuli were associated with different reward outcomes. Later, participants completed a different unrelated testing task which used the same previously reward-associated stimuli in a contextually irrelevant manner. The results showed that reward-related stimuli cause significant and persistent distraction as a consequence of reward learning, continuing to capture attention even in the absence of task relevancy or physical salience. This reveals an involuntary mechanism of attentional selection that is value-driven, coining the term value-driven attentional capture (VDAC).

In order to elucidate how these attentional systems are organized, previous studies have shed light on the cross modal modulation of VDAC at the neural level. For instance, Anderson (2016) presented an auditory training task and a visual testing task where the previous auditory stimuli were also featured. This experiment demonstrated that VDAC can divert attention from one sensory modality to another, causing distraction from the task at hand. Furthermore, Pooresmaeili et al. (2014) also studied the cross modal nature of VDAC finding opposite results as the previously reward-associated auditory stimuli now facilitated visual attentional capture. This difference in results could be due to the differing designs of the experiments, Anderson's auditory stimuli could be heard diotically, while Pooresmaeili's could only be heard on one ear, and thus could be spatially congruent with the visual stimuli presented only on one side of the screen. This last study also explored the neural component of VDAC with fMRI technique, finding that responses within cross-modal areas of the brain (i.e., superior temporal gyrus) were significantly affected by the reward value of sounds. Moreover, this effect was highly correlated with both behavioral and neural correlates of visual orientation sensitivity that were relevant for that task.

Importantly, the studies presented so far involved probabilistic reward systems. Some studies show that seeking information under high reward uncertainty conditions is supported by increases on memory and attentional demands (Monosov, 2020). Given that, it is important to distinguish if the VDAC effects are mainly driven by reward, reward uncertainty, or a combination of both.

Lastly, it is also important to investigate if VDAC results are being modulated by task difficulty as well. According to Kahneman's (1973) capacity model of attention, attention is seen as a limited resource (“sum of energy” in his original formulation) to be distributed among different tasks. To explain the criteria by which the distribution policy of these resources is guided, the model proposes that attentional capacity increases proportionally to the increase in the level of arousal. However, this increase may also be limited by task difficulty. According to the model, in simple tasks, more activation leads to better performance in the task. But in complex tasks the benefit of activation is maintained only up to a certain limit, after which further increases start to be detrimental. In addition, the distribution policy of attentional capacity can be affected by, among other things, automatic attention (originally referred as “enduring dispositions”) allocating resources for novel signals, such as suddenly moving objects. In VDAC, these may include signals indicating past or present reward. Simultaneously to the action of these factors, there is an evaluation of the capacity demands that each task requires. Based on this evaluation, attentional needs are anticipated, increasing them according to the difficulty of the task. However, it is important to clarify that this model uses attention and effort interchangeably, and while effort is indeed involved in difficulty, studies show that it is not the same as attention (Bruya & Tang, 2018).

In the present study we address whether VDAC operates cross-modally in dynamic audiovisual settings, filling certain gaps in the literature such as the directionality of the cross modal modulation. Unlike previous studies where auditory stimuli affect a visual task, we tested if visual stimuli can similarly affect an audiovisual task, as well as if this results support either of the opposing findings. As discussed above, another gap is the question of whether uncertainty and task difficulty both have considerable effects on reward associations. For these ends, we created a VDAC training paradigm with a reward structure controlling for the uncertainty associated with the reward, as well as counterbalancing task difficulty across participants. Reaction times and hit rate scores were collected, as well as inter trial phase coherence, to determine how they are dynamically modulated in the auditory domain by reward-associated visual (color) signals.

Materials and methods

Subjects. Thirty-four subjects (15 female; mean age 26.4 ± 4.0 SD; 4 left-handed) with no history of neurological or psychiatric disorders voluntarily participated in the study. All participants provided formal written informed consent. They reported normal hearing and normal or corrected to normal visual acuity. The experiments were performed in accordance with WMA Declaration of Helsinki guidelines (World Medical Association, 2013). The Ethics in Research Committee of the Faculty of Psychology at Universidad de la República approved the experimental procedures.

Experimental setup. Visual presentations were delivered over a CRT monitor (E. Systems, Inc., CA) with 40 cm size, 83 dpi resolution, and 85 Hz refresh rate. EEG recordings were performed using a BioSemi ActiveTwo 64-channel system (BioSemi, Netherlands) with 10/20 CMS/DRL (ground) layout, at 2048 Hz digitization rate and parallel audio signal sampling via optic link. A 5th order cascaded integrator-comb low-pass filter with −3 dB point at 410 Hz was applied to sensor channels online, after which all signals were decimated to 1024 Hz. Online high-pass response was fully DC coupled. Full experimental sessions lasted ~2.5h.

Due to risks associated to Sars-Cov-2 at the time of recording, the following guidelines were implemented: experimenter and participants wore a face mask at all times, the experimenters wore a face shield and disposable hospital gown during contact times, and participants entered the lab room after EEG headcap and electrode gel cap preparation at an open air facility. The experimenter stayed at a separate room while the participant performed the task, with lab room doors left open.

The main experimental session consisted of an initial Training task (Tr1) followed by a Testing task (Tt1). Thereafter, participants performed a second round of Training (Tr2) and Testing (Tt2) tasks. Presentation and response logging were performed with PsychoPy (Peirce, 2007) software for the Training tasks; and with MATLAB R2010a (Natick, United States) for the Testing tasks.

Training tasks. In an arrow version of the Eriksen flanker task (Eriksen & Eriksen, 1974), participants were asked to respond quickly and accurately to the direction of a central target. Congruent, incongruent and neutral flanker conditions were balanced and presented over 216 trials in each of the Training tasks. At the start of a trial, a static colored ring display was shown (Figure 1A). The ring's internal [/external] diameter was approximately 21 [/27] degrees of visual angle (dva) and displayed in either solid red ('r', hexadecimal #FF0000), green ('g', #00FF00), blue ('b', #0000FF), cyan ('c', #00FFFF), magenta ('m', #FF00FF), or yellow ('y', #FFFF00), over a black background. After the initial 200 ms ring presentation, the white target and flanker symbols were presented subtending 6 dva horizontally. The symbols were shown along with the colored ring for 940 ms, after which the ring disappeared. The symbols remained for an additional 50 ms, after which there was a 1.5 s timeout period so that missed or late responses led to invalid trials. Both Training tasks had an identical reward structure, consisting of points awarded over valid and correct trials. The amount of points earned was determined by the color of the accompanying ring. Participants earned 80 points upon correct response when the ring color corresponded to the high reward and low uncertainty condition ('HrLu'). Similarly, they earned 20 points per correct response at trials where the ring had a low reward and low uncertainty condition ('LrLu'). For trials with high uncertainty, participants could earn points that were pseudo-randomly sampled from a normal distribution (standard deviation = 7 points), rounded to the nearest integer. The mean of the distribution depended on the color: high reward and high uncertainty conditions ('HrHu') had a mean of 80 points; low reward and high uncertainty ('LrHu') earned 20 points on average. Colors were paired to reward conditions for each subject in according to a cohort schedule (Table 1) to balance for color-specific effects. Two colors ('b' and 'y') were used as baseline and were never associated with rewards. Any incorrect trial earned no points, and invalid trials were deducted 50 points. Points accumulated separately over each task. Trial conditions and colors were presented in random order, and an ad lib pause was made every 72 trials, indicating the points accumulated. The order of trials was randomized in each task.

Cohort	**HrHu**	**LrHu**	**HrLu**	**LrLu**
1	r	g	c	m
2	g	r	m	c
3	c	m	r	g
4	m	c	g	r

Table 1. Color-reward associations. Participants received points on correct trials based on a high/low reward and a high/low uncertainty scheme that was defined by the color of a ring displayed during the trial. To balance color-reward conditions, associations were arranged into four subject cohorts. For instance, in cohort 1, participants always receive 80 points correct trials with a red ring ('HrLu' condition). In cohort 2, such reward is associated to green ring trials instead.

Tr1 and Tr2 tasks were identically constructed, except that characters conveying feedback information at the end of each trial were scrambled in Tr1, and were not in Tr2. Point deduction feedback in invalid trials was never scrambled in any task. Therefore, the reward structure of the task was not available to participants in Tr1, but was to be learned over Tr2. In both Tr1 and Tr2, participants were instructed to accumulate as many points as possible for conversion into tokens at the Testing tasks, in exchange for a prize at the end of the session.

Testing tasks. Participants performed a two-alternative forced choice audiovisual task, using concurrent visual flicker and auditory amplitude-modulated (AM) noise stimuli.

Listening task and stimuli. Participants were asked to listen, with their eyes closed, to a succession of two 54 s AM white noise stimuli of 9 and 11 Hz sinusoidal modulation rates respectively, and 75% modulation depth, sampled at 44.1 KHz. The order in which individual stimuli were presented was counterbalanced across subjects. Auditory stimuli in the experiment were constructed with MATLAB.

Visual stimuli. The flicker display consisted of a set of two symbol figures taken at random from a standard chess pool (king, queen, bishop, knight, rook, and pawn) per trial. Two replicates of each symbol flickered at either 9 or 11 Hz respectively, using a frequency approximation approach (Nakanishi et al., 2014) to match with the screen refresh rate. The symbols could be scattered over a circular surface extending 8 dva in diameter, and never overlapped with a central fixation cross shown (Figure 1B). This domain was surrounded by a ring-shaped aperture of similar dimensions as in the Training task, which was filled with a mixture of grey and colored dots. These colors were either r, g, b, c, m, or y, as before, and varied on a trial basis. The ratio of gray to colored dots was fixed at 7/3 and the diameter of each dot was 0.53 dva with a density within the aperture of 2.6 dots/dva. Dots flickered simultaneously at either 9 or 11 Hz, which was determined by their color. Dots and symbols of the same flicker rate were always in phase, were never overlaid on any other dot or symbol, and stayed in any given location for 1 s before change within delimited areas. The displays lasted 6 s in total per trial.

Auditory stimuli and audiovisual presentation. Two auditory stimuli were constructed as in the Listening task, but of 6 s duration each. The same stimuli were used across trials and participants. Audiovisual presentations consisted of either the 9 or 11 Hz AM noise stimulus paired to the visual flicker display for a given trial as described above. The auditory noise stimulus always matched the same flicker rate of the colored dots, with relative phase differences randomized. Participants were asked to accurately detect which of the two chess symbols did the noise sound correspond to in each trial, and instructed to ignore the colors, while keeping a central fixation. After a trial presentation, the two symbols presented were again shown at the left or right of the display, and participants selected which of them matched the sound via a button press. A high- or low-pitched feedback tone then indicated whether the response was correct or incorrect.

During data collection, it was decided to implement a less difficult version of the testing test were symbols stayed in a fixed spot during trials instead of moving around (although they still flickered), this was counterbalanced across subjects. Both Tt1 and Tt2 were identical for each participant, and the order of trials was randomized in each task.

Observers completed 120 trials in each Testing task with equally distributed symbol pairs, colors and auditory AM rates. Points earned at the immediately preceding Training task were converted into tokens by factoring percent correct performance at the Testing stage, e.g., 2000 points from Training were converted into 2 tokens for 100% correct responses at Testing, or into 1 token for 50% correct responses. Participants received a chocolate bar in exchange for tokens at the end of the session, and were offered the option to select a type of their preference when performance at the second half of the session exceeded the first.

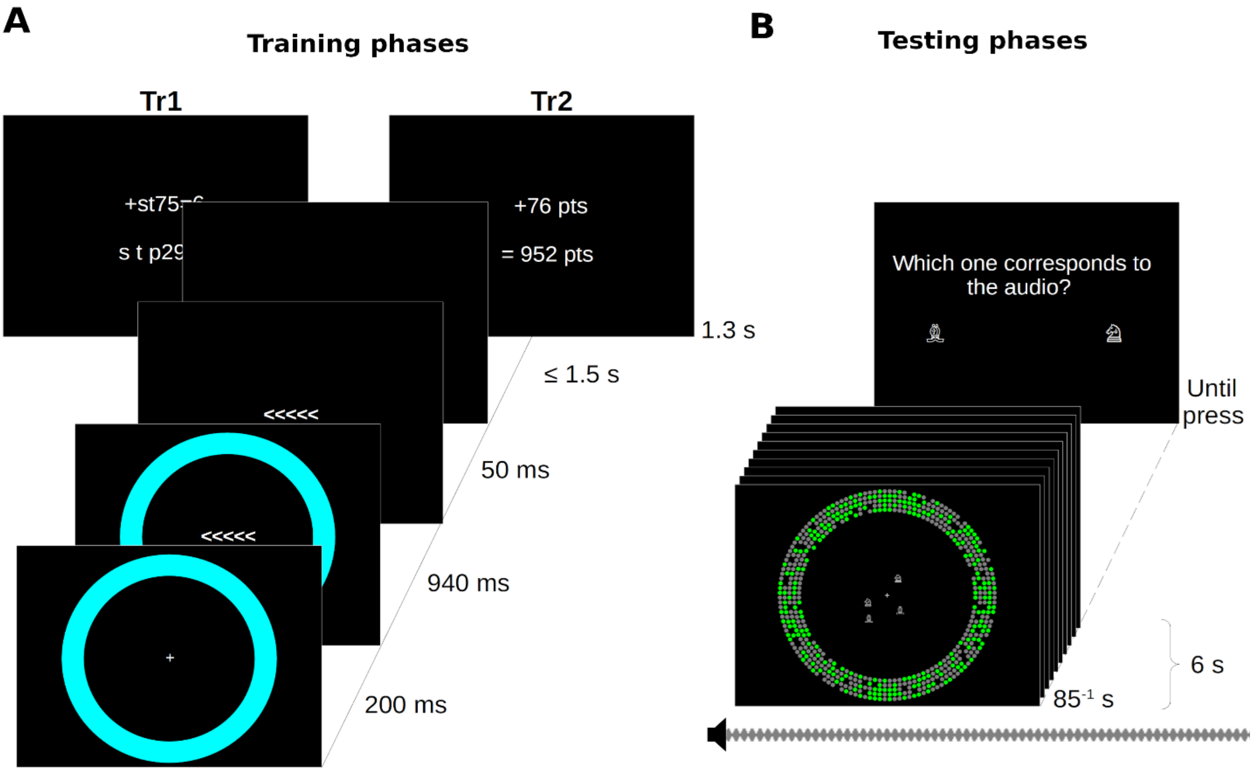

Figure 1. Training and testing tasks. (A) Participants begin with an Eriksen flanker task accompanied by a colored ring presentation. In this task they accumulate points over correct trials with a score that depends on the color shown. The feedback display is scrambled in Tr1, so that the underlying color-reward association cannot be learned effectively at first. Once a first round of Testing is finalized, participants perform a second

Training task (Tr2) with feedback now clearly shown. (B) Both Testing tasks consist of trials containing a dynamic 6 s audiovisual display. It consists of an AM noise (shown at bottom) simultaneous to a visual flicker video. The task is to determine to which of two flickering chess symbols does the sound correspond by rate (either 9 or 11 Hz). Also shown in the video is a ringed dot pattern of flickering grey and colored dots in phase with the chess symbols; only the colored dots flicker at an equal rate to the sound AM. Colors vary by trial and are the same as in the Training stage.

Data processing. For the training task, two independent variables were manipulated: reward, with two conditions (high or low) and uncertainty, with two conditions as well (high and low). The dependent variables recorded were reaction time (s) and hit rate (%).

The interference effect present in the flanker task was calculated by subtracting the mean data (reaction times or hit rate scores) in the incongruent condition minus the mean data in the neutral condition. While the facilitation effect was calculated by subtracting the mean data in the congruent condition minus the mean data in the neutral condition. A t test was performed on each to verify if the effects were significant.
A two-way ANOVA with a factorial design of 2x2 was also conducted on mean time and score differences for interference and facilitation.

For the testing task, three independent variables were manipulated: reward, with two conditions (high or low) and uncertainty, with two conditions (high and low) as within subject variables, and lastly, difficulty, with two conditions (shifted and fixed) as between subject variable. The dependent variables recorded were hit rate (%) and inter trial phase coherence (%).

Hit rate scores were then analyzed by performing a three-way ANOVA with a factorial design of 2x2x2.
Inter trial phase coherence (ITPC) measures temporal and spectral phase-synchronization across trials within EEG (van Diepen & Mazaheri, 2018). It reaches its maximum value of 1 for perfectly phase-aligned signals and becomes 0 as the phase distribution becomes uniform. The relative change for ITPC at 9 Hz, 11 Hz and their two next harmonics, was calculated by subtracting the mean data in Tt2 minus mean data in Tt1, and then dividing that by mean data in Tt1.
By subtracting the relative change for ITPC in each reward and probability condition minus the relative change for ITPC in the neutral condition, we arrived to delta, a measure that avoids the confound of order effects. Delta scores were then analyzed by performing a three-way ANOVA with a factorial design of 2x2x2, as in the hit rate analysis.

Lastly, a Shepherd's robust correlation between hit rate score differences and inter trial phase coherence differences was run. Shepherd's correlation is equivalent to a Spearman's correlation after the outliers are removed.

Results

Training task. Results for Tr2 were analyzed. Reaction times were significantly increased when flankers were incongruent by a mean difference of 0.110ms, 95% CI [0.094 to 0.125], showing the presence of the interference effect, *t*(30) = 14.457, *p* < 0.001, while they were significantly lower when flankers were congruent by a mean difference of -0.010ms, 95% CI [-0.019 to -0.001], showing the presence of the facilitation effect, *t*(30) = -2.439, *p* = .021 (Figure 2A).

On the other hand, hit rate scores were significantly lower when flankers were incongruent by a mean difference of 0.085%, 95% CI [0.063 to 0.108], showing the presence of the interference effect, *t*(30) = 7.667, *p* < 0.001. However, hit rate scores were not significantly increased when flankers were congruent, so there was no facilitation effect, *t*(30) = -0.972, *p* = 0.339 (Figure 2B).

In other words, participants were slower and made more mistakes when flankers were incongruent, while they were only faster when flankers where congruent.

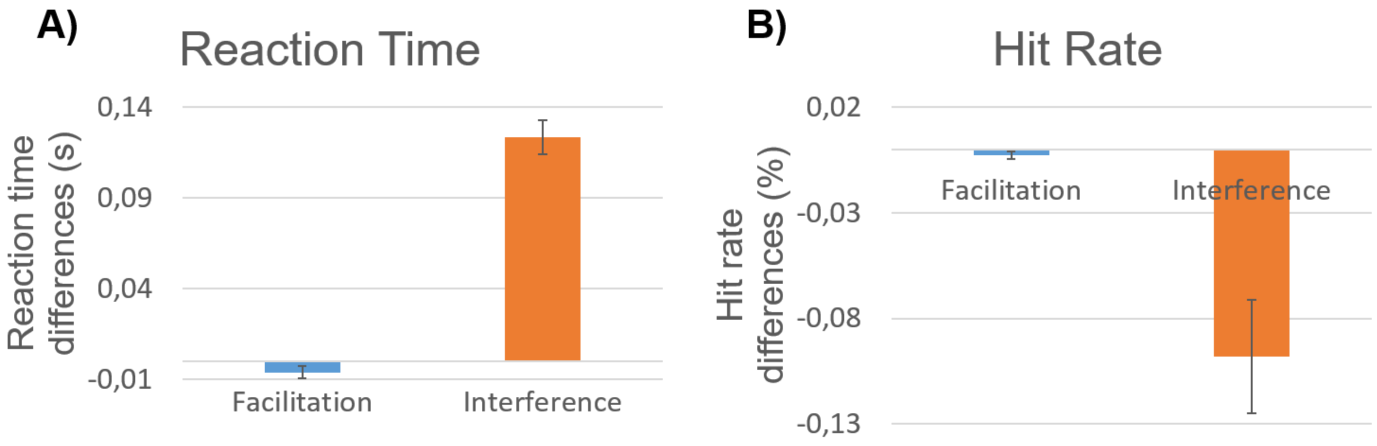

Figure 2. Training task results. (A) Reaction time differences were statistically significant for facilitation and interference effects. (B) Hit rate score differences were only statistically significant for interference effect.

The effect of reward and uncertainty on the observed behavioral indicators of interference and facilitation was addressed for Tr2 as well, since the reward structure was learned over the second round of training. First, a two-way ANOVA was conducted that examined the effect of reward and uncertainty on mean reaction time differences for interference. There was no significant reward by uncertainty interaction, *F* (1,30) = 2.275, p = .142, as well as no main effects on reward, *F* (1,30) = 0.189, p = .667, or uncertainty, *F* (1,30) = 1.050, p = .314. Second, a similar two-way ANOVA was conducted to examine the effect of reward and uncertainty on mean hit rate score differences for interference. There was no significant reward by uncertainty interaction, F (1,30) = 0.219, p = .643, as well as no main effects on reward, *F* (1,30) = 0.848, p = .364, or uncertainty, *F* (1,30) = 1.158, p = .291. Third, a two-way ANOVA was conducted that examined the effect of reward and uncertainty on mean reaction time differences for facilitation. There was no significant reward by uncertainty interaction, *F* (1,30) = 1.394, p = .247, as well as no main effects on reward, *F* (1,30) = 0.161, p = .691, or uncertainty, *F* (1,30) = 1.496, p = .231.

Overall, there were no significant effects of reward and uncertainty on the observed behavioral indicators of interference and facilitation, during the second training task.

Testing task. For behavioral data, a three-way ANOVA was conducted that examined the effect of reward, uncertainty and task difficulty on hit rate scores. There was no significant 3-way interaction, *F* (1,29) = 0.866, p = .431, and no significant reward by difficulty interaction, *F* (1,29) = 2.186, p = .131, or uncertainty by difficulty interaction, *F* (1,29) = 0.976, p = .389, or reward by uncertainty interaction, *F* (1,29) = 0.563, p = .459. There were no main effects on uncertainty, *F* (1,29) =0.770, p = .388, or difficulty, *F* (1,29) =1.592, p = .221. There was however, a main effect on reward that showed that hit rate was significantly lower when reward was higher, *F* (1,29) =5.294, p = .029 (Figure 3).

Figure 3. Behavioral testing task results. Hit rate scores in the high reward condition were significantly lower than the low reward condition.

For neural data, a three-way ANOVA was conducted that examined the effect of reward, uncertainty and difficulty on delta scores. There was no significant 3-way interaction, *F* (1, 30) = 0.200, *p* = .658, and no significant reward by difficulty interaction, *F* (1, 30) = 0.099, *p* = .755, or uncertainty by difficulty interaction, *F* (1, 30) = 2.563, *p* = .120. There were no main effects on uncertainty, *F* (1,30) = 0.295, *p* = .591, or reward, *F* (1,30) = 3.128, *p* = .087, or difficulty, *F* (1,30) = 0.129, *p* = .722. There was, however, a significant reward by uncertainty interaction, *F* (1, 30) = 5.912, *p* = .021.

Post hoc analysis showed that there was a statistically significant difference in delta between the HrHu and LrHu conditions *t*(31) = 3.371, *p* < 0.002 (Figure 4B).

In other words, synchronization increased most when reward and uncertainty were high. By contrast it did not change when uncertainty was low, despite the levels of reward involved at the association stage.

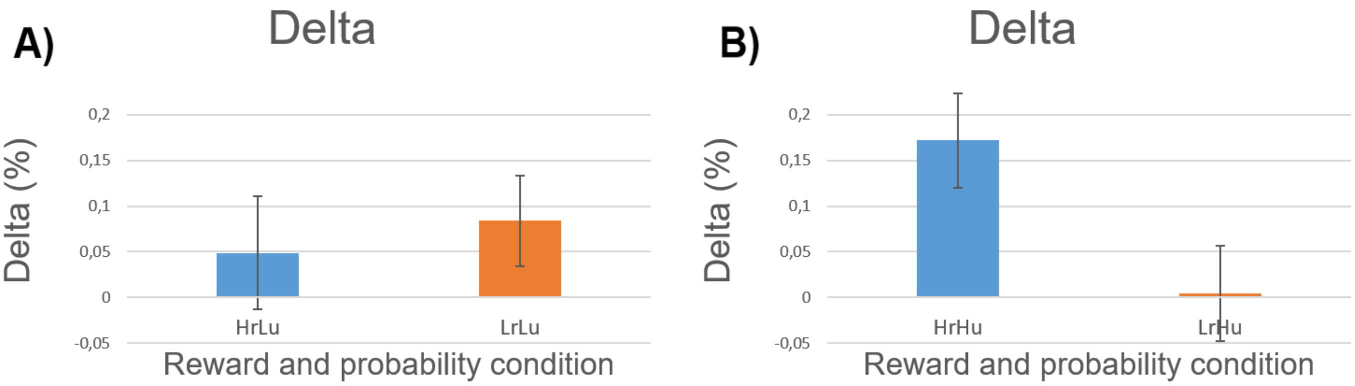

Figure 4. Neural testing task results. (A) Mean delta scores between high reward/low uncertainty and low reward/low uncertainty conditions show no statistically significant difference. (B) Mean delta scores between high reward/high uncertainty and low reward/ high uncertainty conditions show a statistically significant difference.

A Shepherd's robust correlation was run to determine the relationship between subject hit rate score differences and ITPC differences between HrHu and LrHu conditions. There was a negative correlation between hit rate score differences and ITPC differences, which was statistically significant, Pi (30) = -0.37, *p* = 0.039 (Figure 5).

In other words, participants' performance deteriorated due to their hit rate scores as synchronization increased.

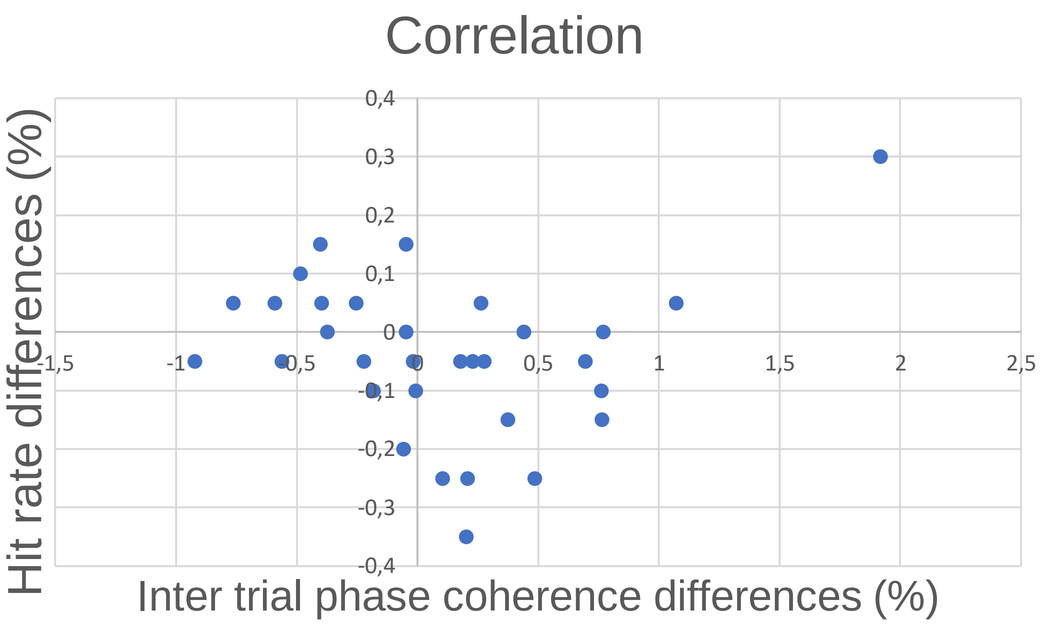

Figure 5. A statistically significant negative correlation between hit rate score differences and inter trial phase coherence differences for testing task.

Discussion

The objective of this study was to examine whether VDAC can operate cross-modally causing reward-associated visual stimuli to interfere or facilitate an audiovisual task, as well as providing accompanying neural evidence. We additionally incorporated uncertainty and difficulty in our experimental design, in order to distinguish the possible effects of reward, reward uncertainty and task difficulty.

In the training task, the interference effect was found in reaction time and hit rate scores, which showed a significant increase and drop respectively when flankers were incongruent. Facilitation effects were only found in reaction times, with a significant drop when flankers were congruent. Although we did not find facilitation effects in our hit rate scores, the rest of the results were in line with what was expected from the classic flanker task (Eriksen & Eriksen, 1974), where congruent flankers consistently elicit facilitated responses (lower reaction times) while incongruent flankers elicit interfered responses (higher reaction times and lower hit rate scores).

Behavioral results in the testing task showed that hit rate was significantly lower when reward was higher, showing that visual stimuli can interfere with an audiovisual task in an analog way as reward-associated auditory stimuli affect a visual task (Anderson, 2016). Our results also follow Anderson's interference results rather than Pooresmaeili et al (2014) facilitations. One reason could be due to our experimental design being closer to Anderson's, as our auditory stimuli were heard diotically, while our visual stimuli associated with a reward could never overlap with the flickering symbols. This limited any chance for stimuli to be spatially congruent like in Pooresmaeili's design.

Our neural results showed significant delta changes whenever reward was both high and variable (high uncertainty). Delta factors represent the neural synchronization with the auditory signal under the presence of the colored dots. Throughout the trials, the phases in the audio stream were consistently the same (i.e. always starting in the same valley), while phases in the video stream were not consistent (starting in random frames for every trial). As the ITPC measures these consistencies across trials (phase synchronization), it will reflect more the contribution of the audio stream than its video counterpart. The results show how this neural synchronization increases before versus after reward association. Color hue was explicitly not relevant to the testing task, and was controlled by changing the color associated to reward for each participant. Visual color signals' contribution to the neural data was further limited by their being out of phase across trials. So we can conclude that these results reflect primarily auditory modulations by reward uncertainty associated to visual signals. On the other hand, task difficulty did not have any significant effect on our results, which could suggest that VDAC operates independently from task difficulty. More research is needed to see whether it operates also in very easy tasks (e.g. Anderson 2011) in cases where dynamic stimuli are involved such as here. It is also important to point out that changes in ITPC that can be caused by oscillatory power, Event-Related Potencial (ERP) latency and ERP amplitude, rather than by changes in the phase of the task itself (van Diepen & Mazaheri, 2018). Future studies should take this factors into account when incorporating ITPC into their experimental design.

Furthermore, correlation results provide a link between the neural and behavioral results, showing that as neural synchronization with the colored dots increases, performance decreases. This further demonstrates participants' attentional capture rather than facilitation.

The present study has addressed the question of whether VDAC operates cross- modally in dynamic audiovisual scenarios. We have shown that task-irrelevant reward associations from dynamic visual stimuli can interfere with the performance of an audiovisual task. We additionally provided evidence that neural synchronization with the auditory stream was significantly modulated by such visual signals, provided they had a history of high reward value and uncertainty. Moreover, increases in this neural synchronization negatively correlated to decreases in task performance.

References

Anderson, B. A. (2016). Value-driven attentional capture in the auditory domain. *Attention, Perception, & Psychophysics*, *78*(1), Article 1. https://doi.org/10.3758/s13414-015-1001-7

Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences*, *108*(25), Article 25. https://doi.org/10.1073/pnas.1104047108

Bruya, B., & Tang, Y.-Y. (2018). Is Attention Really Effort? Revisiting Daniel Kahneman’s Influential 1973 Book Attention and Effort. *Frontiers in Psychology*, *9*. https://www.frontiersin.org/articles/10.3389/fpsyg.2018.01133

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*(1), 143–149. https://doi.org/10.3758/BF03203267

Kahneman, D. (1973). *Attention and Effort*. https://philpapers.org/rec/kahaae

Monosov, I. E. (2020). How Outcome Uncertainty Mediates Attention, Learning, and Decision-Making. *Trends in Neurosciences*, *43*(10), 795–809. https://doi.org/10.1016/j.tins.2020.06.009

Nakanishi, M., Wang, Y., Wang, Y.-T., Mitsukura, Y., & Jung, T.-P. (2014). Generating Visual Flickers for Eliciting Robust Steady-State Visual Evoked Potentials at Flexible Frequencies Using Monitor Refresh Rate. *PLoS ONE*, *9*(6), e99235. https://doi.org/10.1371/journal.pone.0099235

Peirce, J. W. (2007). PsychoPy—Psychophysics software in Python. *Journal of Neuroscience Methods*, *162*(1–2), 8–13. https://doi.org/10.1016/j.jneumeth.2006.11.017

Pooresmaeili, A., FitzGerald, T. H. B., Bach, D. R., Toelch, U., Ostendorf, F., & Dolan, R. J. (2014). Cross-modal effects of value on perceptual acuity and stimulus encoding. *Proceedings of the National Academy of Sciences*, *111*(42), Article 42. https://doi.org/10.1073/pnas.1408873111

Purves, D., Brannon, E. M., Cabeza, R., Huettel, S. A., LaBar, K. S., Platt, M. L., & Woldorff, M. G. (2008). *Principles of cognitive neuroscience* (pp. xv, 757). Sinauer Associates.

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychologica*, *135*(2), 77–99. https://doi.org/10.1016/j.actpsy.2010.02.006

van Diepen, R. M., & Mazaheri, A. (2018). The Caveats of observing Inter-Trial Phase-Coherence in Cognitive Neuroscience. *Scientific Reports*, *8*(1), Article 1. https://doi.org/10.1038/s41598-018-20423-z

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, *310*(20), 2191–2194. https://doi.org/10.1001/jama.2013.281053