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Signal or noise? Using a psychophysical approach to investigate the effects of attention and neurofeedback training on electrocortical predictive anticipatory activity (PAA) to true random stimuli

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Summary

The mathematics of fundamental physics imply both forwards-in-time and backwards-in-time (retrocausal) solutions. This suggests that scientists may find empirical evidence of retrocausal phenomena in nature. Indeed, there is experimental work suggesting that information about a future event, unknowable through inference alone, can be obtained before the event actually occurs. In addition to the behavioral evidence for precognition (e.g., Bem, 2011), a recent meta-analysis indicates that basic anticipatory physiology may be influenced retrocausally (Mossbridge et al., 2013); this effect has been termed presentiment (Bierman & Radin, 1997; Spottiswoode & May, 2003; Radin, 1997), or predictive anticipatory activity (PAA; Mossbridge et al., 2014). Despite this body work, many questions remain regarding whether PAA is 'anomalous' or an inherent part of human physiology that conforms to basic psychophysical principles. We outline a systematic research program using methods from psychophysics to investigate the effects of attention and neurofeedback training on electrocortical PAA. Uncovering how various physical and psychological parameters modulate PAA could lead to increased effect sizes and produce more replicable effects, inform theory (in physics, psychology, neuroscience/physiology), and ultimately lead to a technological realization of retrocausal signaling (e.g., see Franklin, Baumgart, & Schooler, 2014; Mossbridge et al., 2014).

Our basic design is based on an experiment by Radin et al. (2011). In this study, participants (either experienced meditators or non-meditators) had their EEG monitored while at unpredictable intervals they were randomly exposed to a light or a sound. Radin et al. (2011) report evidence for electrocortical PAA; the pre-stimulus EEG activity of experienced meditators differed significantly depending on whether the subsequent stimulus was going to be a light or a sound. Our goal is to expand on this paradigm by parametrically varying stimulus properties (stimulus intensity, duration of presentation, and duration between stimuli) and attentional variables (task, the effects of attention training, pre-task attentional state, pre-trial attentional state, and the effects of neurofeedback).

We see this work as a stepping stone towards the realization of technology that utilizes PAA. If PAA is a ubiquitous element of human experience, then it should be able to be used in real time to predict in advance true random binary events mapped onto meaningful real-world events (e.g., roulette spins, stock market fluctuations, etc; see Franklin, Baumgart, & Schooler,

2014). Importantly, we will build this into our experimental setup by mapping the light flash and auditory tone to a binary target and evaluating recorded pre-stimulus EEG potentials in real time to mark our prediction before the future random target is determined by the random number generator. This provides a very straightforward indication of PAA. A hit rate can be calculated and compared against chance (50%). Signal detection theory (SDT; Green & Swets, 1966) will be used examine measures of sensitivity (d'), specificity, and criterion level/shifts and how these measures interact with the attentional variables. In addition, we plan to utilize a number of control conditions expected to produce chance results to allow for more precise estimates of the variability in the signal. This will include conditions in which the computer program is running and EEG is measured but the subject does not see/hear the stimuli, and using pre-stimulus changes from baseline from earlier trials to predict the current stimulus.

Some examples of questions we can ask regarding these manipulations' influence on electrocortical PAA include:

-What if the lights are made dimmer/brighter and the sounds softer/louder?
-What if the sounds/lights are presented for a long vs. short duration?
-Is there an optimal duration between stimulus presentations?
-What if there is a difficult task in which the stimuli are task-relevant (e.g., +3 for lights, -2 for sound) vs. an easy distracter task (e.g., simply counting backwards from 100 by 1's; ignoring the lights/sounds)?
-What are the effects of meditation experience/training?
-To what extent is it best to be in a low vs. high state of arousal?
- Can measuring attentional state in real time (via EEG, pupil dilation, and heart rate (HR)), and using these DVs as covariates increase the signal?
- Can neurofeedback training increase the signal?

Operating from our newly established nonprofit laboratory (tanclab.org), we bring a unique skill set in neuroscience, psychology and physics to answer the questions outlined above. With this background and expertise, we are confident that with the right resources we can make significant progress towards the goals outlined in the proposed research agenda below.

LITERATURE REVIEW

Einstein (1905) revolutionized the concept of time with his theories of special and general relativity. Since the advent of relativity and the discovery of non-local effects within the field of quantum mechanics, some physicists no longer view the passing of time as necessarily being the same as it is experienced subjectively (Atkinson, 2000). J. Cramer, who developed the

Transactional Interpretation of quantum mechanics based on time-symmetry (Cramer, 1986), has also proposed that information can be transmitted backwards in time via standard quantum mechanics (not just apparent retrocausal influence without information transfer, as in Wheeler's delayed-choice experiment; Wheeler, 1984).

A survey of the parapsychological literature reveals empirical support for retrocausal influences with evidence continuing to accumulate that information about some future event may influence aspects of behavior and physiology in the past. For example, it has been shown that physiological measures (e.g., skin conductance, HR, pupil dilation) are higher preceding the onset of randomly presented arousing versus neutral stimuli; what we will refer to as predictive anticipatory activity (PAA; Mossbridge et al., 2014). A recent meta-analysis of 26 published reports between 1978 and 2010 found significant evidence for PAA across studies (Mossbridge et al., 2012).

We aim to build on this work by taking a 'psychophysical' approach (e.g., see Boff, Kaufman, & Thomas, 1986) to characterize the relationship between the physical stimuli and electrocortical PAA. The most frequently reported measures of PAA are skin conductance and heart rate (HR). Much less work has been done investigating the neural correlates of PAA, in particular EEG. For example, from the recent meta-analysis (Mossbridge et al., 2012), only 2/26 studies collected EEG. Given that the most commonly reported measures of PAA are from the peripheral nervous system - skin conductance, HR, and pupil diameter - one would suspect a similar PAA correlate in the central nervous system. EEG is also a good measure due to its high temporal resolution and current technology that allows for online signal processing and robust single trial analyses (Garipelli et al., 2013).

Our proposed setup is based on 2 EEG studies[1] in which participants were exposed at random intervals to either a light vs. no light (Radin & Lobach, 2007) or a light vs. a sound (Radin et al., 2011). Although the results should be interpreted cautiously given the relatively small samples, they indicate that pre-stimulus EEG activity of females (Radin & Lobach, 2007) and experienced meditators (Radin et al., 2011) differed significantly depending on the identity of the unpredictable future stimulus at occipital electrodes. We plan to explore this design by manipulating stimulus and task properties and adapting the analysis so that PAA is assessed at the trial level as a hit or miss (50% chance) and, importantly, in real time. Predictions will be made in advance of the random number generator (RNG) output. A time-stamped guess will be

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For brevity, we are neglecting to mention a handful of ERP studies that, although provide insight about neural correlates of PAA, utilize different tasks/analysis than the EEG study.

recorded before a target is automatically selected. Initial predictions will be informed by meta-analysis (Mossbridge et al., 2012) and theoretical work on time symmetry. For example, Bierman (2010) proposed a model of presentiment based on this symmetry, called "Consciousness-Induced Restoration of Time Symmetry (CIRTS)".

SDT will be used to analyze hit rates/false alarm rates at different stimulus thresholds and examine their interaction with various attentional variables. We will also examine the influence of criteria shifts (i.e., changing aspects of the prediction algorithm). With SDT we can establish how basic stimulus features like intensity and duration influence PAA and the impact of attentional variables (e.g., making stimuli task-relevant/irrelevant).

Given these findings with experienced meditators, and in general, the knowledge of the impact attention has on behavior and physiology (Franklin et al., 2013; Schooler et al., 2014), we plan to utilize neurofeedback which has been used to train attention. Interestingly, the electrocortical potentials reported by Radin et al. (2007; 2011), slow cortical potentials (SCPs), are thought to play a role in the regulation of attention (Rockstroh et al., 1990) and have recently been the target of neurofeedback training for ADHD (Mayer, Wyckoff, & Strehl, 2013). Through Brain-Computer Interfaces (BCI) with EEG users can learn to 'incidentally' alter the SCP through practice. This approach is now being considered a tool for the investigation of PAA (Baumgart, 2014). Baumgart (2014) investigated whether *a pre-EEG signal* can be trained over time by including a retrocausal 'neurofeedback' condition, where the stimuli are determined by the pre-EEG signal, rather than a RNG (elaborated below). By triggering the stimulus response to the appropriate pre-stimulus signal, it was hypothesized that the effect may be enhanced. Preliminary pilot data (Baumgart, 2014) suggests the presence of PAA for a non-meditator only in blocks with neurofeedback.

This basic experimental setup (exposure to random lights/sounds) may seem exceedingly simple and one may wonder why, if such a signal were present, it has not been more well-documented. But as Mossbridge et al. (2012) note, without the proper design and balancing of stimuli, anticipation effects and other confounds can obscure the data. Our goal is to combine confirmatory methodology (Kennedy, 2013) with a 'psychophysics' approach. The type of thorough and systematic research program we propose has played a major role in the understanding of our basic perceptual and cognitive processes and, as such, could make significant contributions to our understanding of PAA.

RESEARCH PLAN AND METHODS

Below, we present our research plan and methodology. We propose 3 experimental series (detailed below): S1- light vs. no light, S2- light vs. sound, S3- altering task parameters to manipulate attention. In addition to real-time predictions of the RNG output as described below, as we build a large database (made publicly available), an ongoing aspect of this work will involve using state and trait measures of attention to improve prediction accuracy. We first describe the general methods (with default parameters) followed by details of individual experiments.

General Methods

Participants: Following traditional psychophysics methods, we will be collecting a large number of observations from a small number of individuals. For each experiment, we aim to run 5-10 participants (volunteers and staff). We outline safeguards below to ensure data integrity.

Stimuli: The visual stimulus (referred to as a 'light') will consist of a white screen that appears on what was previously a black background. The auditory stimulus will be a tone presented through headphones.

Procedure: Each experiment session will be divided into 8 runs of 20 trials each, with rest breaks in between. A trial will be divided into three time intervals, a pre-stimulus interval of 10 seconds, a stimulus/post-stimulus interval of 10 seconds, and a random interval of 0 to 10 seconds. There will also be a random interval preceding the start of each run, by default set to 10 to 20 seconds, for a break. The the random intervals make the exact stimulus time unpredictable and reduce anticipation effects.

During the pre-stimulus interval (-10 to 0 seconds relative to the stimulus triggering), the EEG potentials recorded from the posterior electrodes will be used to make the prediction regarding the identity of the upcoming stimulus (based on Radin & Lobach, 2007; Radin et al., 2011). Two sub-intervals will be defined, "baseline" and "signal" regions. The program will calculate the time-average of the potentials for these two intervals. At the end of the signal region, the program will compare the average potential for the baseline and signals regions. What is done with this information depends on which of the two operating modes is selected for the current run.

For "prediction" (P) mode, a prediction is made about upcoming random targets. The "neurofeedback" (NF) mode has the same overall structure as the P mode with one difference: the stimulus is not selected randomly but is instead selected based on the pre-stimulus potential. The process used is the same as in the prediction mode of calculating baseline and signal average potentials and making a comparison. Here, instead of using the result to guess an upcoming target, the result is used to select the target; the one which has a post-stimulus potential symmetric to the pre-stimulus potential. P and NF modes will either be alternated or blocked by experiment half (alternated: P NF P NF ..; NF P NF P NF…; Blocked: P P P P NF NF NF NF; NF NF NF NF P P P P) to investigate massed vs. distributed effects of NF. The four orderings will be randomized to create a blind experiment.

Data collection for each experimental session will last approximately 1 hour. The exact number will be determined by the specific design of the particular experiment (approximately 5-10). As the experiment gets underway we will include conditions expected to be at chance; e.g., during some of these sessions, the computer program will be running and EEG measured, but the subject will not see/hear the stimuli.

Data Collection: We plan to use a Mobita-w 32-channel Biopotential System headset to record the following high-fidelity wireless biopotential data: ECG, EEG, EMG and EOG, and Mirametrix S2 Eye Tracker to collect pupillometry data.

Data Analysis: We will be testing whether our prediction of light vs. no light or light vs sound - made in advance of the quantum RNG output used to determine the outcome – is better than chance (50%). The time-average of the potentials over baseline and signal regions will be compared to produce a guess of the upcoming target. If signal > baseline, a light flash is predicted, otherwise no stimulus or an auditory tone is predicted. Deciding the random stimulus before making a guess is not allowed by the program. It should also be emphasized that there is no known way for either experimenter or subject to affect the output of the random number generator. Also, importantly, we plan to adopt real-time signal processing techniques with SCPs that have allowed for robust single trial analysis of SCPs (Garipelli et al., 2013).

SDT will be used to analyze hit rates/false alarm rates at different stimulus thresholds, plot receiver operating characteristic curves, and the influence of attentional variables on these measures of detection accuracy. We will also examine the influence of criteria shifts. As we gather data we will be able to adapt the thresholds used to predict a light vs. sound/no light. Exact binomial tests will be used to examine the significance of cumulative hit rates.

Experimental Series 1: Light vs. no light

In series 1 we propose 4 separate experiments using the above methodology to examine how PAA is influenced by (1a) the effects of the light at standard (med) brightness settings, (1b) the effects when the brightness is parametrically varied (low-med-high), (1c) the effects when the light flashes are of different durations (short-med-long), and (1d) when the light flashes are separated by different inter-trial intervals (short-med-long).

Experimental Series 2: Light vs. sound

Experimental series 2 consists of another 4 separate experiments to examine these same basic manipulations when the light is paired with a sound. Based on work by Radin et al. (2011) and our own pilot work (Baumgart, 2014) it may be the case that PAA becomes more detectable with multiple stimulus modalities. Also, the discrepancy between stimulus parameters (e.g., bright light paired with soft tone) may enhance the PAA (akin to 'distance effects'; Moyer & Landauer, 1967). In this second experimental series we will examine (2a) the effects of the basic light stimulus and tone at standard (med) settings, (2b) the effects when the brightness and sound are varied (low-med-high), (2c) the effects when the light flashes and sounds are of different durations (short-med-long), and (2d) when the light flashes and sounds are separated by different inter-trial intervals (short-med-long).

Experimental Series 3: Altering task parameters to manipulate attention

In all experiments in this final series the stimulus on a given trial will either be a light or a tone. Here we alter the task in 4 ways to systematically direct participants attention either towards or away from the light by having participants (3a) press a button just for the light (drawing focus towards light), (3b) press a button just for the sound (drawing away from light), (3c) count silently backwards by 1s (drawing focus away from light and sound), or (3d) count silently backwards alternating 1s and 2s (drawing focus most strongly away from light & sound).

Any systematic effect of these manipulations on PAA would provide support that PAA is perhaps not so anomalous, and that it follows basic psychophysical principles. Conversely, failing to find any systematic effects would suggest that we need to turn elsewhere; towards individual difference measures of state and trait attention.

Experimental Covariates

As prior work has indicated the influence of changes in attention on behavior and physiology (Franklin et al., 2013; Schooler et al., 2014) – with recent work demonstrating this in the context of a retrocausal practice task (Franklin et al., 2011ab, 2013) – to best characterize attentional state we will use scales to collect state and trait measures (MAAS, Brown & Ryan, 2003 & MWQ; Mrazek et al., 2013). We will also measure and use HR, EEG frequency analysis (e.g., see Macdonald et al., 2011), and pupil diameter (see Franklin et al., 2013) to provide physiological assessment of ongoing attentional state.

To account for decline effects, we will consider time on task effects (at the run, block, and session level) and seek participants with varying levels of involvement in disciplines that require extended periods of focus (meditators, musicians; Franklin et al., 2008). Analyses of these measures will be ongoing. As we collect data across studies, we will use this information to inform subsequent prediction algorithms.

Logistical Notes

All experiments will be logged ahead of time. If PAA proves difficult to detect in the early series, we may move more quickly to the next experimental series that manipulates attention. In addition we may attempt to specifically gear the studies towards expert meditators.

Final Thoughts

While our aim is to uncover positive indications of PAA that map onto other findings in perception and psychophysics, we pursue this work to answer a seemingly simple, yet often elusive, question – is there a signal or rather, just noise? This general question has guided researchers in perception and psychophysics for over a century, and the pursuit of an answer has lead to new discoveries, methodologies, and technologies even when particular hypotheses go against convention (e.g., the discovery of EEG; Millet, 2001). In this case, if the answer is yes, there is a signal, and we are able to increase its reliability and robustness the implications would be profound. For example, as indicated in our recent opinion piece (Franklin et al., 2014), it is our plan to adapt this paradigm to predict meaningful binary random events, like roulette spins/stock market fluctuations. We are confident that with the needed resources, the research agenda outlined above will allow for a solid and growing database with which to address this elusive question.

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