

6-26-2015

USING ELECTROENCEPHALOGRAPHY TO ASSESS RISK TAKING BEHAVIOR IN VARYING LEVELS OF CONGRUENCY

John F. L. Pinner

Follow this and additional works at: https://digitalrepository.unm.edu/psy_etds

Recommended Citation

Pinner, John F. L.. "USING ELECTROENCEPHALOGRAPHY TO ASSESS RISK TAKING BEHAVIOR IN VARYING LEVELS OF CONGRUENCY." (2015). https://digitalrepository.unm.edu/psy_etds/113

This Thesis is brought to you for free and open access by the Electronic Theses and Dissertations at UNM Digital Repository. It has been accepted for inclusion in Psychology ETDs by an authorized administrator of UNM Digital Repository. For more information, please contact disc@unm.edu.

John F. L. Pinner

Candidate

Department of Psychology

Department

This thesis is approved, and it is acceptable in quality and form for publication:

Approved by the Thesis Committee:

Dr. James F. Cavanagh , Chairperson

Dr. Robert Annett

Dr. Vincent Clark

**USING ELECTROENCEPHALOGRAPHY TO ASSESS RISK
TAKING BEHAVIOR IN VARYING LEVELS OF
CONGRUENCY**

by

JOHN F. L. PINNER

B.A., Interdisciplinary Studies, Adams State College, 2012

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Master of Science

The University of New Mexico
Albuquerque, New Mexico

May 2015

ABSTRACT

Electroencephalography (EEG) is an often-used tool of assessment to measure the electrical activity of populations of neurons at the scalp. Here, we used EEG in conjunction with a computer-based amalgamation of two common behavioral assessments: The Eriksen Flanker Task and the Balloon Analogue Risk Task to assess how varying levels of congruency modulate risky behavior. We recruited 36 participants from the University of New Mexico Department of Psychology research pool (Female = 26; Mean Age = 21.28, SD = 4.54). In this task, participants indicated the direction of the ‘arrow in the center’ from a line of five characters ‘<<<<< or >>>>>’ (congruent) and ‘<<><< or >><>>’ (incongruent). We presented these stimuli in trials of 10, 30, 50, 70, and 90% incongruency. By selecting the correct direction of the stimuli, participants inflated a virtual balloon by one pump for each selection until the balloon popped or they cashed out on the points earned in each trial. In this study, we aim to show how likely participants are to exhibit risky behavior (pumps) in varying levels of congruency, and to assess brain activity characteristics during this decision-making process. We found no significant relationship between pumps and increasing levels of incongruency ($RHO = 0.09, p = 0.58$). However, we did find a significant difference ($p \leq 0.01$) in theta power between congruent and incongruent cues, and that this difference was significantly correlated with pumps ($RHO = 0.34, p = 0.04$). Together, these findings suggest while decreasing incongruency is not associated with increased risky behavior across all participants, individual differences in theta band power reflects differing tendencies towards risky behavior.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION	1
Cognitive Control.....	1
Electroencephalography.....	2
Conflict	2
Risk	4
CHAPTER 2 METHODS.....	6
Participants.....	6
Flanker_BART Task.....	6
EEG Recording and Preprocessing.....	7
CHAPTER 3 RESULTS.....	9
Statistical Analysis.....	9
Performance	9
EEG During Cues	9
CHAPTER 4 DISCUSSION.....	16
Alternate Explanation	18
REFERENCES.....	19

Chapter 1

Introduction

Cognitive Control

Humans have a marvelous ability to assess situations, make judgments on appropriate actions dependent on the characteristics of situations, and to hold active contextual information to help inform appropriate adjustments to actions. This ability, focus of many studies, is commonly referred to as cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001), and can more precisely be described as the ability to attend and react to pertinent information, while inhibiting responses elicited by non-significant stimuli (Cohen & Ridderinkhof, 2013). Multiple studies have implicated various brain areas/regions such as the anterior cingulate cortex (Botvinick et al., 2001; Botvinick, 2007; Cavanagh, Zambrano-Vazquez, & Allen, 2011), mid and lateral prefrontal cortex (Cavanagh, Cohen, & Allen, 2009; Nigbur, Ivanova, & Stürmer, 2011; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004), supplementary motor areas (Nigbur et al., 2011), and parietal areas (Cohen & Ridderinkhof, 2013), as being involved in cognitive control processes.

Cognitive control and action monitoring are of crucial significance in the Eriksen Flanker task (Eriksen & Eriksen, 1974). This task requires participants to attend to a stimulus in the center of multiple, congruent or incongruent stimuli that are to be ignored, and take appropriate actions dependent on the center stimuli (see Figure 1b). Studies have shown that this cognitive control is implemented through oscillations, synchronizations, power enhancement, and locking of theta band activity (Cavanagh, Cohen, & Allen, 2009; Cavanagh & Frank, 2014; Cavanagh, Zambrano-Vazquez, &

Allen, 2011; Cohen & Ridderinkhof, 2013; Nigbur, Ivanova, & Stürmer, 2011). Theta band is commonly defined as 4-8Hz and has been found to reflect increased demands in cognitive control and performance monitoring (Cavanagh et al., 2009), including during conflict, as in the Flanker task.

Electroencephalography

Electroencephalography is a measure used to assess changes in voltage over time of the electrical activity of populations of neurons at the scalp (Berger, 1929). This technique is widely employed in both clinical and research settings, and has proven effective in measuring motor, cognitive, and sensory responses (Luck, 2005). These responses are predominately analyzed using two methods: Evoked related potentials and time-frequency-based analysis, both of which have their advantages/disadvantages, strengths/weaknesses in different paradigms (Cohen, 2014). There is evidence that conflict-eliciting stimuli, such as in a Flanker task, results in both EEG theta band phase synchrony (Cavanagh, Cohen, & Allen, 2009) and non-phase-locked theta band activity (Cohen, 2014), lending to justification for both types of analyses. In the current study, we focus on time-frequency analyses to further elucidate the mechanisms of cognitive control, consequences of conflict, and the inspiration for risk-taking behaviors.

Conflict

Theta behavior, specifically in mid-frontal cortex, during the experiences of conflict shows specific patterns of activation. Based on signals from sensors over the medial prefrontal cortex (mPFC), it appears frontal midline theta expresses the need for cognitive control during experiences of novelty, conflict, negative feedback, and error recognition (Cavanagh & Frank, 2014). It is believed that the mPFC, the action

monitoring system, communicates this need for increased control to the lateral prefrontal cortex (LPFC), the control network, via theta phase synchronization (Botvinick et al., 2001; Cavanagh, Cohen, & Allen, 2009). Cohen et al., 2013 found significant theta band connectivity between the mPFC and LPFC during conflict trials compared to non-conflict trials when using a Simon task. However, this theta phase synchronization is not the only characteristic of theta during conflict, as Cavanagh et al., 2009 found that the degree of this synchronization predicts the mPFC theta power during error trials.

Conflict is considered to be a teaching signal motivating a method of avoidance learning, effectively reallocating cognitive control and decision-making toward cognitive efficiencies (Botvinick, 2007). However, this “teaching” initially comes at a cognitive cost (Cavanagh et al., 2014), as conflict can be considered an index of cognitive load (Botvinick, 2007). The law of less work (Hull, 1943) posits that humans are lazy organisms that strive for efficiency to reduce the load intrinsic in existence. This idea, while originally describing physical work, has been used to explain strategic behaviors regarding cognitive work as well in the “law of least mental effort” (Zipf, 1949), stating that the anticipation of cognitive demand (conflict) acts as a cost on behavioral decision making (Kool et al., 2010). This cognitive load has been reflected in multiple studies, some showing that conflict acts as an aversive signal (Dreisbach, et al., 2012; Fritz et al., 2013), resulting in increased reaction times during conflict stimuli compared to neutral stimuli. Cavanagh et al., 2014 showed that conflict acts as a cost in reinforcement learning similar to effort, punishment, and errors, as the brain interprets the averseness of these control-dependent events. This cost of conflict is computed in the Anterior Cingulate Cortex (ACC), and is readily measured using EEG theta (Botvinick, 2007;

Cavanagh et al., 2011). But the question remains, how conflict acts on risky behavior and decision-making.

Risk

At a very basic level, risk is present when there exists some probability between an action and the likelihood of harm (Leigh, 1999). In the Balloon Analogue Risk Task (BART), participants display risky behavior by inflating a virtual balloon resulting in increased points (score) to a certain threshold at which point further risk results in popping the balloon (Lejuez et al., 2002). However, these poorer outcomes, or harm, can be overshadowed by the potential for greater rewards (higher score). By simulating risky situations that occur in the natural environment, the BART reveals general tendencies towards risky decision-making and not toward a specific risky behavior (Lejuez et al., 2002). In their 2002 study, Lejuez et al., found that risky behavior in the BART significantly correlated with both self-report measures of risk related constructs and real-world risk behaviors. Therefore, the BART can be considered a useful indicator of risk taking proclivity.

Multiple neuroimaging studies have investigated the neural substrates of risk-taking behaviors. In a Meta analysis, Krain et al. (2006) found that risk-taking behavior was associated with activation in the orbito-frontal cortex, rostral portions of the ACC, and parietal areas. Similarly, using fMRI during a risk task, Cristopoulos et al. (2009) found that increases in BOLD in the Cingulate increased the probability of a risky choice. Further, Ernst et al. (2002) found during a risk-task that activation was generally focused in the OFC, DLPFC, right ACC, right inferior parietal cortex, thalamus, anterior insula, and lateral cerebellum, and these findings were supported in the TMS study by Knoch et

al. (2006) in which they found that suppression of the right PFC increases risk-taking behavior. One EEG study assessing risk-taking behavior (Gianotti et al., 2009) found that tonic activity level in the right PFC predicts risk-taking behavior. Specifically, individuals with lower levels of tonic activity in the right PFC display more risk-taking behavior than individuals with higher levels. These findings, paired with the studies above discussing cognitive control and conflict, show that cognitive control, conflict, and risk share multiple areas of activation. Interestingly, to our knowledge, no one has assessed how the experience of conflict acts on risky decision-making.

The goal of the current study is two fold, to examine: 1) the risk-behaviors of participants as they experience varying levels of congruency, and 2) the EEG patterns of activity during these conditions. We hypothesize that: 1) participants will exhibit decreased risk-taking behaviors via reduced amount of pumps with increasing levels of incongruency, and 2) theta power, as a marker of cost of conflict, will be associated with risk-taking behavior.

Chapter 2

Methods

Participants

The University of New Mexico Institutional Review Board approved this experiment, and all participants provided written informed consent. All participants were right handed, had normal or corrected-to-normal vision, no history of neurological psychiatric or any other relevant medical problem, and were free from current psychoactive medication use. Participants were recruited via the UNM Department of Psychology subject pool. For participating in this study, participants received course credit. Four participants were removed from analysis due to taking psychoactive medications, resulting in 36 participants (Female: $n = 26$, Age: mean = 21.28, SD = 4.54 (18 to 39 years)). The task took an average of 59 minutes 15 seconds to complete.

Flanker_BART Task

The task created to assess risk-taking behavior during the experience of conflict was an amalgamation of two well-established tasks: the Eriksen Flanker Task (Flanker) (Eriksen & Eriksen, 1974) used to assess response inhibition and the Balloon Analogue Risk Task (BART) (Lejuez et al., 2002) used to assess risk-taking behaviors (Fig.1). We administered detailed instructions followed by a training session to familiarize the participants with the task. This version of Flanker_BART was assigned a Balloon-Wise Probability meaning each balloon in the task was assigned pump/pop-value between 1-128, with the minimum pumps resulting in a popped balloon at one pump and a maximum possible pumps resulting in a popped balloon at 128 pumps. Additionally, the congruency conditions of the Flanker task was divided into 5 levels of congruency: 10%

incongruent, 30% incongruent, 50% incongruent, 70% incongruent, and 90% incongruent, where incongruent trials result in stimulus presentation of ‘<<><>’ or ‘>><>>’ and congruent trials result in stimulus presentation of ‘<<<<<<’ or ‘>>>>>>’. Each session consisted of 75 trials (balloons), with 15 balloons per congruency level.

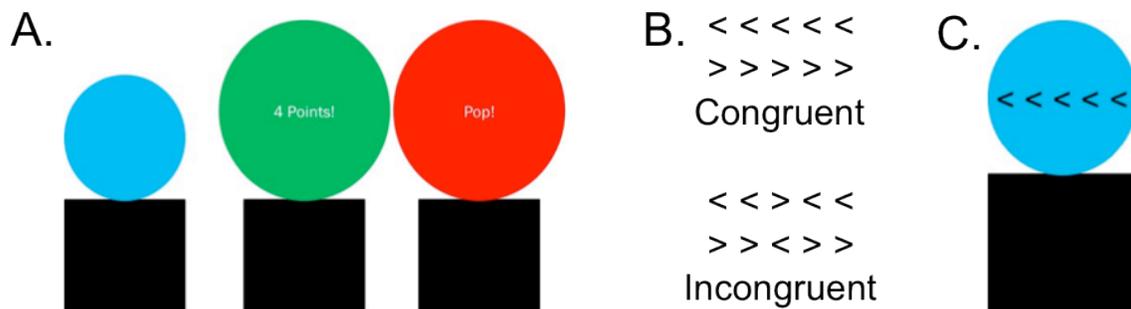


Figure 1. Flanker_BART task: **A.** Training: Initially, participants learned the BART task and were instructed to inflate a virtual balloon by pressing the spacebar on a computer keyboard, and to cash out on the points earned in each trial by pressing the return key (enter key). Participants either cashed out receiving notification of a point reward or received a “Pop” of their balloon and received zero points. They did this for 4 trials **B.** Next, participants learned the Flanker portion of the task by being instructed to attend to the direction that only the center arrow is pointing, ignoring the 2 arrows on both sides of the center arrow, and to select that direction with the left or right trigger buttons. When all five arrows point in the same direction, this is considered a congruent condition. When the center arrow points in the opposite direction than the other arrows, this is considered an incongruent condition. They did this for 10 trials. **C.** Finally, participants were trained on the Flanker_BART task, combining the instructions, procedures, and decision-making processes from the two independent tasks. Correct and incorrect responses on the Flanker portion of the task determined whether the balloon in the BART portion of the task would inflate or deflate, respectively. During this portion of the task participants received a warning of “Too Slow” if their RT was too slow, and if an incorrect choice is made, the balloon decreased in size by 1 pump. They did this for 4 trials (balloons). After training, participants completed 15 trials in each of the 5 levels of congruency (10%, 30%, 50%, 70%, 90% incongruent) for a total of 75 trials.

EEG Recording and Preprocessing

EEG was recorded continuously across 0.1-100Hz with a sampling rate of 500 Hz and an online CPz reference on a 64-channel Brain Vision system. Data were then epoched around the cues (-1,500 to 2,000 ms), from which the associated responses and

feedbacks were isolated. CPz was re-created, and data were then re-referenced to FCz and automatically processed by APPLE (Cavanagh) to identify bad channels to be interpolated, bad epochs to be rejected, and to identify bad independent components. Time-Frequency measures were computed by multiplying the fast Fourier transformed (FFT) power spectrum of single trial EEG data with the FFT power spectrum of a set of complex Morlet wavelets (defined as a Gaussian-windowed complex sine wave: $e^{i2\pi ft} e^{-t^2/(2\sigma^2)}$, where t is time, f is frequency (which increase from 1-50Hz in 50 logarithmically spaced steps), and defines the width (or ‘cycles’) of each frequency band, set according to $4/(2\pi f)$), and taking the inverse FFT. The end result of this process is identical to time-domain signal convolution, and it resulted in estimates of instantaneous power (the magnitude of the analytic signal), defined as $Z[t]$ (power time series: $p(t) = \text{real}[z(t)]^2 + \text{imag}[z(t)]^2$). Each epoch was then cut in length (-500 to 1,000ms). Power was normalized by conversion to a decibel scale ($10 \times \log_{10}[\text{power}(t)/\text{power}(\text{baseline})]$), allowing a direct comparison of effects across frequency bands. The baseline for each frequency consisted of the average power from -300 to -200 ms prior to the onset of the cues.

Chapter 3

Results

Statistical Analysis

A priori hypotheses between congruency conditions and behavioral outcomes within the Flanker_BART task will be tested via a series of correlations. All data were z-score transformed. Additionally, EEG power was used to assess differences between values of congruency and responses and behavior. Finally, power analyses were computed on the theta power for cues and response conditions.

Performance

As shown in Figure 2, contrary to our prediction that risk-taking behavior (here defined as number of pumps) would decrease with increasing levels of incongruency, we found a non-significant increase in pumps with increasing levels of incongruency ($RHO = 0.09, p = 0.58$). As expected, we found a non-significant relationship between Cash-Out ($RHO = 0.04, p = 0.83$) and Pops ($RHO = -0.04, p = 0.83$) by levels of congruency. There was a significant increase in errors committed with increasing levels of incongruency ($RHO = 0.57, p = 0.0003$). Finally, there was a significant increase in reaction time in congruent cues by increasing levels of incongruency ($RHO = 0.60, p = 0.0001$), and a near significant increase in reaction time in incongruent cues by increasing levels of incongruency ($RHO = 0.32, p = 0.0562$).

EEG During Cues

In order to assess theta band activity (~4Hz-8Hz), time-frequency analyses were run on all conditions (10%, 30%, 50%, 70%, 90% incongruent) and further divided by all

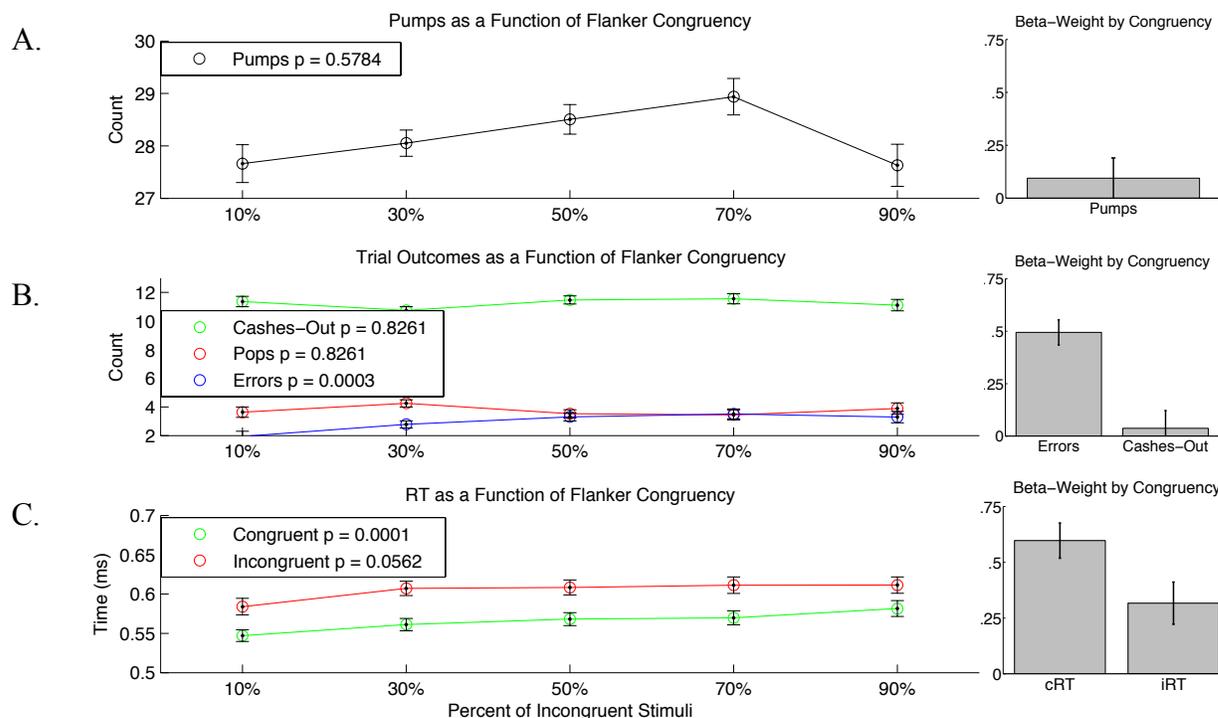


Figure 2. Behavioral summary: **A.** Average number of pumps as a function of flanker congruency ($RHO = 0.09$, $p = 0.58$). **B.** Average number of Cashes Out ($RHO = 0.04$, $p = 0.83$), Pops ($RHO = -0.04$, $p = 0.83$), and Errors ($RHO = 0.57$, $p = 0.0003$) as a function of flanker congruency. **C.** Congruent reaction time ($RHO = 0.60$, $p = 0.0001$) and incongruent reaction time ($RHO = 0.32$, $p = 0.0562$) as a function of flanker congruency. Bar graphs show Beta-weight of behavior \times congruency.

incongruent stimuli, all congruent stimuli, and the difference between all incongruent and all congruent stimuli for each condition, plus a total of theta activity regardless of congruency condition. In figure 3, TF plots represent averages of all conditions regardless of levels of congruence. There was increased EEG activity post-cue found in All Incongruent Cues (3A) and All Congruent Cues (3B), and a significant difference between the two (3C) concentrated in the theta band range and approximately 450 ms post-stimuli presentation. Significance threshold for the contour plot in figure 3C was set at $p \leq 0.01$.

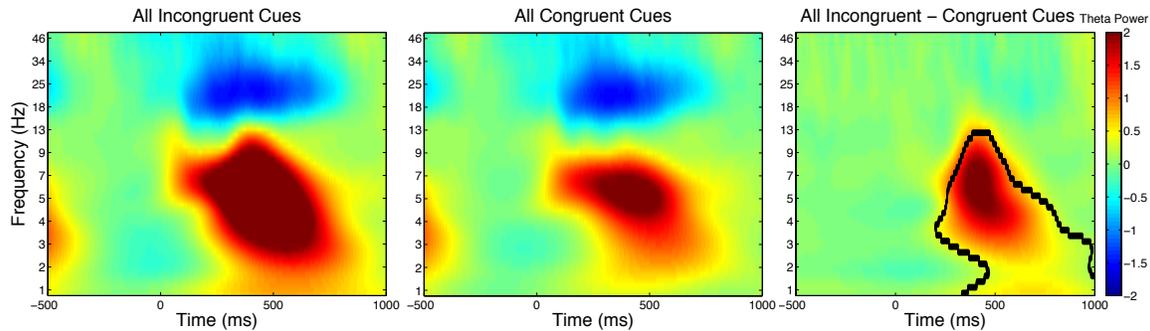


Figure 3: Time Frequency Plots of: **A.** All Cues of Incongruent Stimuli, **B.** All Cues of Congruent Stimuli, **C.** All Cues of Incongruent Stimuli – Congruent Stimuli. 0 ms marks the onset of the Flanker cue. Significance threshold for the contour plot in figure 3C was set at $p \leq 0.01$.

To assess the relationship between theta band activity during cues and pumps, data was first z-scored. We then performed Spearman correlations between pumps and theta power, not accounting for levels of congruency. We found significant correlations between total theta power, regardless of congruency, and pumps ($RHO = 0.45, p = 0.006$). Additionally, significant correlations were found between pumps and total theta power during incongruent cues ($RHO = 0.46, p = 0.005$), total theta power during congruent cues ($RHO = 0.46, p = 0.005$), and the difference (Figure 4) between incongruent minus congruent cues ($RHO = 0.34, p = 0.04$). This finding shows that individuals with more theta power pump more; suggesting that people who have stronger conflict monitoring tendencies exhibit increased risk-taking behavior.

To further disambiguate these findings, we assessed the relationship between theta power and pumps within each of the 5 different levels of congruency conditions (Figure 5). In the 10% incongruent condition, significant relationships were found between pumps and incongruent cues ($RHO = 0.49, p = 0.003$), congruent cues ($RHO = 0.38, p = 0.02$), and the difference between incongruent and congruent cues ($RHO = 0.45, p = 0.006$). In the 30% incongruent condition, we found significant associations between

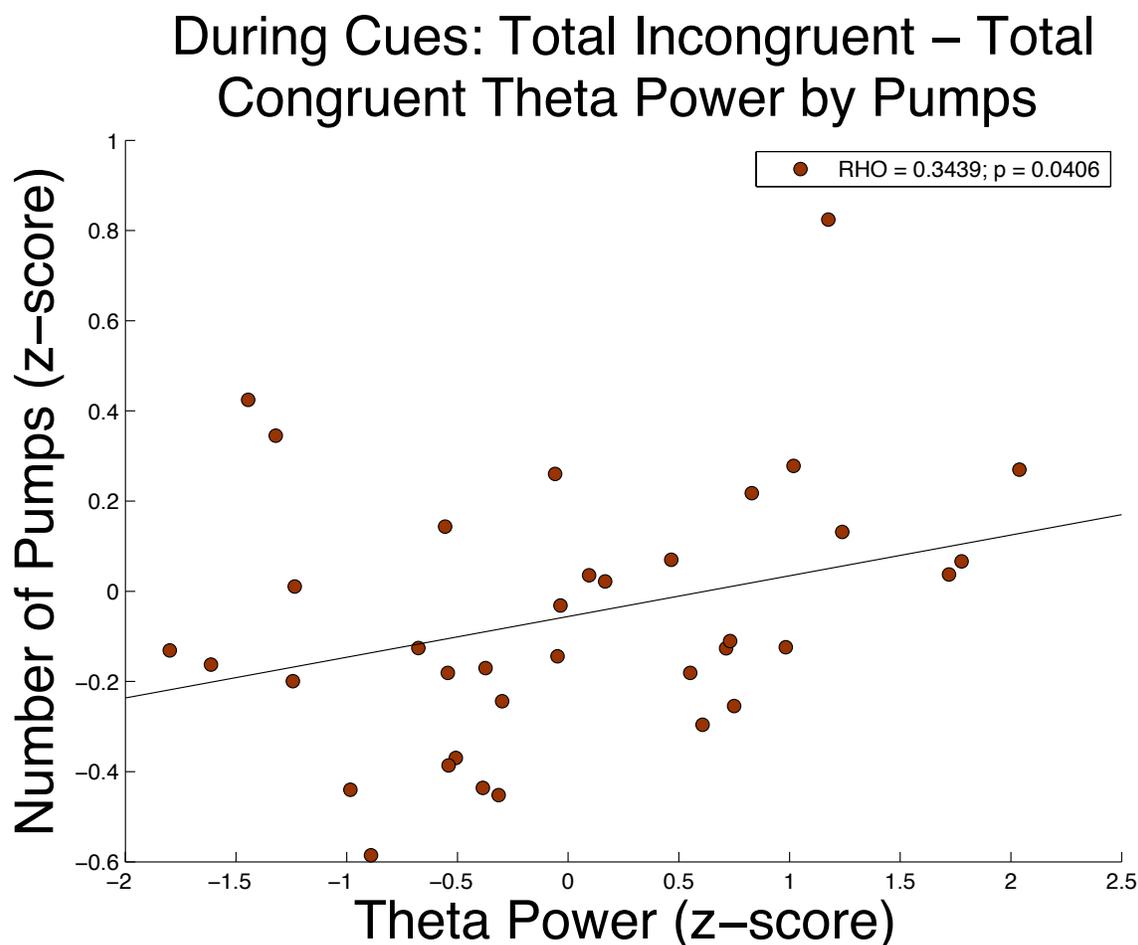


Figure 4: Between subjects correlation of the cue-locked theta power difference (all incongruent trials – all congruent trials) with the pumps (z-scored). $RHO = 0.34$, $p = 0.04$

pumps and incongruent cues ($RHO = 0.45$, $p = 0.006$), congruent cues ($RHO = 0.51$, $p = 0.002$), but not in the difference between incongruent and congruent cues ($RHO = 0.20$, $p = 0.25$). In the 50% incongruent condition, we found significant associations between pumps and incongruent cues ($RHO = 0.45$, $p = 0.007$), congruent cues ($RHO = 0.45$, $p = 0.005$), but not in the difference between incongruent and congruent cues ($RHO = 0.18$, $p = 0.28$). In the 70% incongruent condition, we found significant correlations between pumps and incongruent cues ($RHO = 0.44$, $p = 0.008$), not in congruent cues ($RHO = 0.28$, $p = 0.10$), and in the difference between incongruent and congruent cues ($RHO =$

0.45, $p = 0.006$). In the 90% incongruent condition, we found significant relationships between incongruent cues ($RHO = 0.46$, $p = 0.005$), congruent cues ($RHO = 0.43$, $p = .009$), but not in the difference between incongruent and congruent cues ($RHO = 0.17$, $p = 0.32$). The reliability of these findings suggest that individuals that exhibit increased theta power to cues are inclined to heightened risky behavior across levels of congruency regardless if the cue is an incongruent or congruent cue. Specifically, significant correlations between theta power and pumps were found in all 5 levels of congruency during incongruent cues, in 4 of 5 (all except 70% incongruent) levels of congruency during congruent cues, and in 2 of 5 (10% incongruent and 70% incongruent) levels of congruency when congruent theta was subtracted from incongruent theta. This suggests that individuals with stronger conflict monitoring characteristics are consistent across levels of congruency.

To investigate the relationship between theta band activity during cues and pumps, accounting for levels of congruency, we performed Spearman correlations between the linear change in pumps across congruency conditions (Fig 2A) and the similar slope in theta power across congruency conditions. We correlated the slopes of pumps x levels of congruency ($RHO = 0.09$, $p = 0.58$) and the slope of theta power difference (incongruent minus congruent) x levels of congruency ($RHO = -0.34$, $p < 0.01$), and found a significant correlation between the two ($RHO = 0.35$, $p = 0.04$) (Figure 6).

The slope of pumps across congruency conditions reflects how conflict affects risky decision-making; we found no clear group-wise effects (Fig 2A). The slope of theta

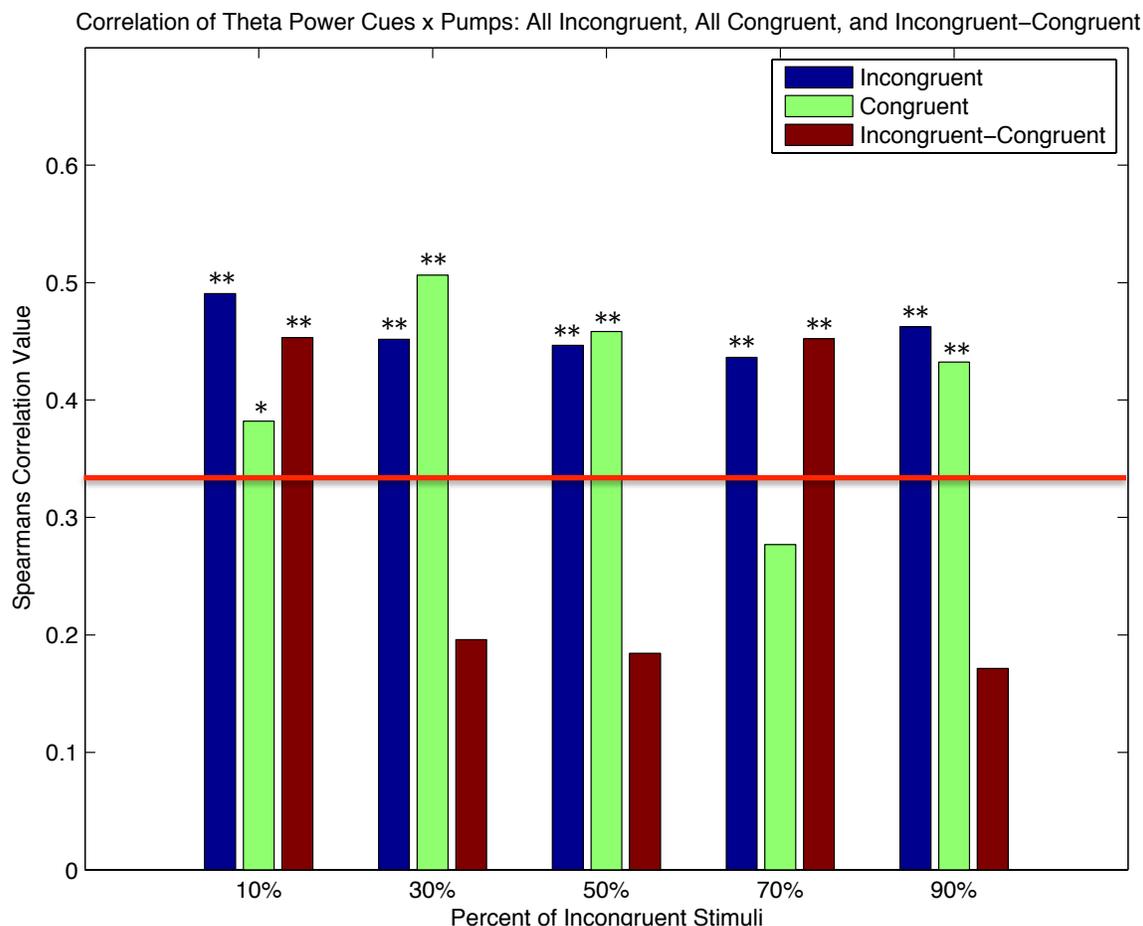
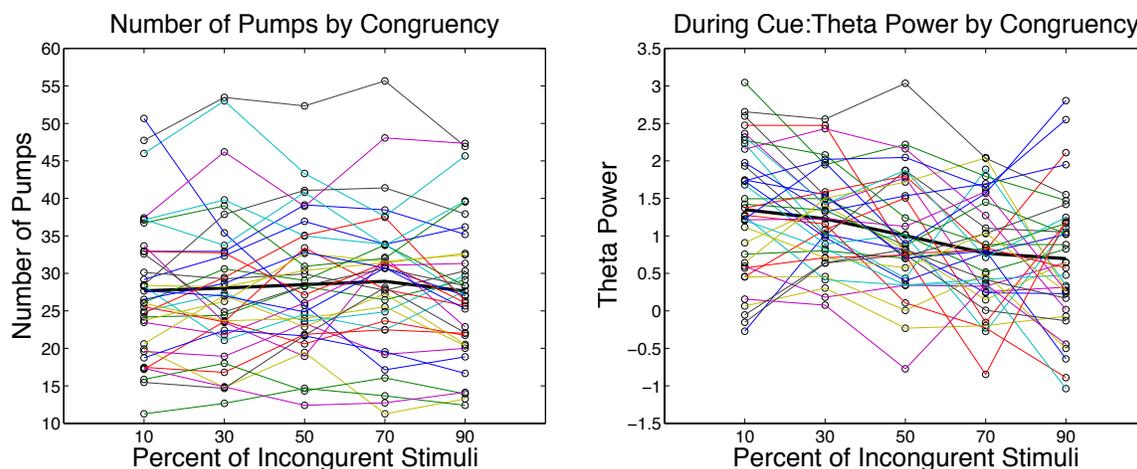


Figure 5: Correlation values of theta power during cues with pumps. These are separated by conditions of 10% incongruent stimuli, 30% incongruent stimuli, 50% incongruent stimuli, 70% incongruent stimuli, 90% incongruent stimuli. These are further divided into 3 groups each of theta power of cue to incongruent stimuli, congruent stimuli, and the difference between incongruent and congruent responses. * = $p \leq 0.05$, ** = $p \leq 0.01$.

power across congruency conditions reflects the amount that an individual experiences a change in conflict as incongruency becomes more commonplace. Critically, this could go in either direction: participants could find a large proportion of incongruent trials to be harder (positive slope of theta X congruency), or they could find a smaller proportion of incongruent trials to be more demanding due to their rarity (negative slope of theta X congruency). By correlating these slopes, we can observe how individual differences in the experience of conflict (measured by theta) relate to risky decision-making (measured by pumps).



Spearman's RHO During Cue: Slope of Theta Power by Congruency X Slope of Pumps by Congruency

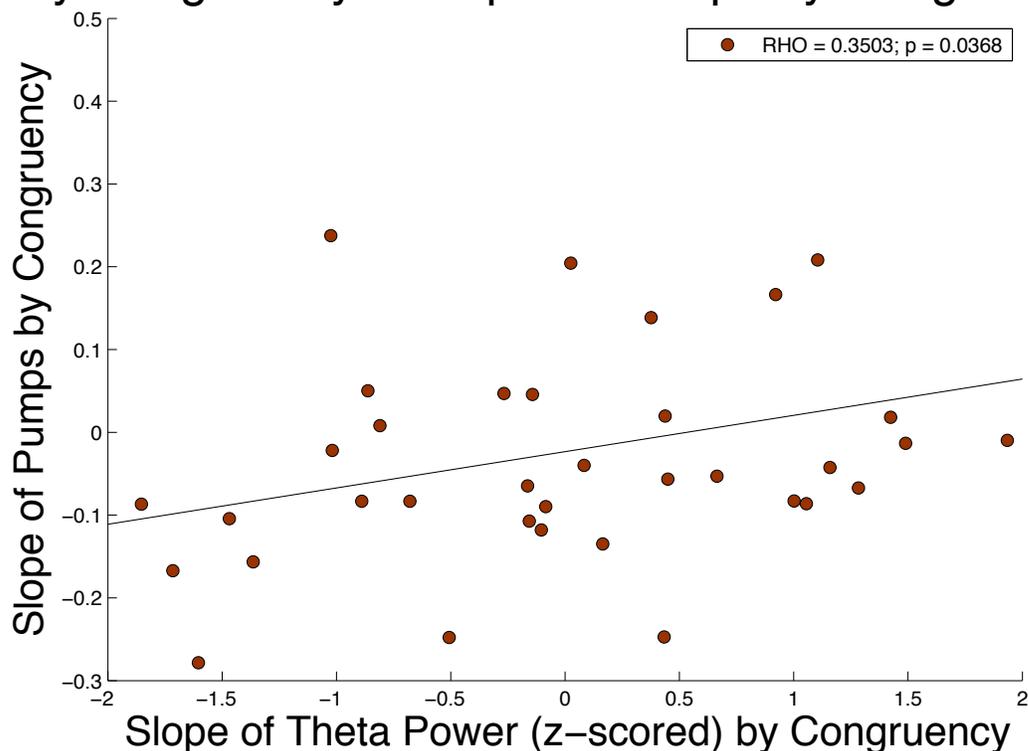


Figure 6: The top left panel shows each participant's pumps across the different levels of congruency. The top right panel shows the each participant's theta power across the different levels of congruency. The bold black line highlights the mean during each level of congruency. In the scatterplot, the X-axis is the slope of theta power difference (incongruent minus congruent) across levels of congruency. The Y-axis is the slope between pumps and levels of congruency.

Chapter 4

Discussion

Contrary to our hypothesis, we did not find a decrease in risky behavior with increasing levels of incongruency (Figure 2). In fact, we found a non-significant increase in risky behaviors with increasing levels of incongruency. This can perhaps be explained by the idea that the incongruent stimuli in the 10% incongruent condition was experienced as having a higher impact as it was more rare in this condition than when experienced in the 90% incongruent condition, and therefore could be a stronger inhibitor of risk-taking behavior. Perhaps the individual is adapting to the higher levels of conflict in the 90% incongruent condition where prediction allows increased number of pumps compared to the 10% incongruent condition where conflict becomes more novel and salient.

We feel confident that our participants were experiencing increased conflict with increasing levels of incongruency, as evidenced by significant correlations between errors and levels of congruency, reaction time during congruent stimuli and levels of congruency, and a near significant relation between reaction time during incongruent stimuli and levels of congruency. Multiple studies have implicated increasing errors and reaction times with the experience of conflict (Botvinick et al., 2001; Botvinick 2007; Cavanagh et al., 2009; Dreisbach et al., 2012).

It is plausible that looking at the EEG activity, keeping in mind studies of theta band activity during cognitive control, action monitoring, and conflict, can bolster the above interpretation of the behavioral results. We found significant theta band power in congruent cues, incongruent cues, and in the difference between congruent and incongruent cues (Figure 3), highlighting a significant difference between incongruent

and congruent cues ($p \leq 0.01$). This difference between incongruent and congruent cues indicates that our participants EEG were sensitive to the increased demands produced by incongruent stimuli. Further, this significant difference between incongruent and congruent cues significantly correlated with pumps (Figure 4), suggesting that individuals with increased sensitivity to the differences between incongruent and congruent cues, exhibited by heightened theta power, are more likely to show increased risky decision-making (pumps), and that this tendency is consistent across levels of congruency with all incongruent cues, most congruent cues, and in 40% of the analyses distinguishing between incongruent and congruent cues (Figure 5) showing significant correlations with increased risk-taking behavior. Perhaps, this global sensitivity to congruent and incongruent stimuli in a conflict task such as in the Flanker, points to a general human tendency to increase conflict monitoring when conditions call for increased cognitive control.

It is known that cognitive control, vital in the Eriksen Flanker Task (Eriksen & Eriksen, 1974), is reflected by theta band activity during conflict (Cavanagh, 2009). As discussed in the introduction section, it is known that conflict acts as a cost due to its heightened cognitive requirements (Botvinick, 2007; Cavanagh et al., 2014; Dreisbach, et al., 2012; Fritz et al., 2013). Our results showed a decrease in theta band activity with increasing levels of incongruency (Figure 6), and that theta band activity was significantly correlated with the slope of pumps by levels of congruency. This indicates that perhaps individuals interpret the conflict experienced during the low incongruence probability trials more aversive or costly than in the high incongruence probability trials. It is also possible that this increase of theta band activity for lower levels of incongruency

is indicative of increased action monitoring processes and increased cognitive control (Cavanagh & Frank, 2014). This increased monitoring and control at lower levels of conflict could facilitate greater inhibition of risky behavior (pumps), resulting in increased pumps at higher levels of conflict.

Alternate explanation

Theta, as a lingua franca, is not specific to conflict (Cavanagh et al., 2011). Theta also increases with cognitive effort (Smit et al., 2004; Smit, et al., 2005; Wascher, et al., 2013). This might suggest, given that theta power was negatively correlated with increasing amounts of incongruency, that our participants viewed the 10% incongruent condition as more cognitively effortful compared to the 90% incongruent condition. This could be due to the novelty of incongruency in the 10% incongruent condition being more cognitively taxing to determine the appropriate response. It is possible that both of the latent variables contribute to the manifest variable with varying strengths. Ultimately, effort might be a common variable between conflict, theta, and risk (number of pumps), and might be what is really driving these effects, and conflict may represent a tangential role in risky decision-making.

These findings, while not exactly what we predicted, offer insight to the interplaying dynamics of the brain's interpretation of the environment and its resulting behavioral changes.

References

- Bastos, A.M., Usrey, W.M., Adams, R.A., Mangun, G.R., Fries, P., & Friston, K.J. (2012). Canonical Microcircuits for predictive coding. *Neuron*, 76, 695-711. doi: 10.1016/j.neuron.2012.10.038
- Berger, H. (1929). Ueber das elektrenkephalogramm des menschen. *Archives fur Psychiatrie Nervenkrankheiten*, 87, 527-570.
- Botvinick, M.M. (2007). Conflict monitoring and decision making: Reconciling two perspectives on anterior cingulate function. *Cognitive, Affective, & Behavioral Neuroscience*, 7(4), 356-366.
- Botvinick, M.M., Braver, T.S., Barch, D.M., Carter, C.S., & Cohen, J.D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, 108(3), 624-652. doi: 10.1037/0033-295X.108.3.624
- Cavanagh, J.F., Cohen, M.X., & Allen, J.J.B. (2009). Prelude to and resolution of an error: EEG phase synchrony reveals cognitive control dynamics during action monitoring. *The Journal of Neuroscience*, 29(1), 98-105. doi: 10.1523/JNEUROSCI.4137-08.2009
- Cavanagh, J.F., & Frank, M.J. (2014). Frontal theta as a mechanism for cognitive control. *Trends in Cognitive Sciences*, 18(8), 414-421. doi: 10.1016/j.tics.2014.04.012
- Cavanagh, J.F., Masters, S.E., Bath, K., & Frank, M.J. (2014). Conflict acts as an implicit cost in reinforcement learning. *Nature Communications*, in press. doi: 10.1038/ncomms6394

- Cavanagh, J.F., Neville, D., Cohen, M.X., Van de Vijver, I., Harsay, H., Watson, P., ...
 Ridderinkhof, R. (2012). Individual differences in risky decision-making among
 seniors reflect increased reward sensitivity. *Frontiers in Neuroscience*, 6, 1-7.
 doi: 10.3389/fnins.2012.00111
- Cavanagh, J.F., Zambrana-Vasquez, L., & Allen, J.J.B. (2011). Theta lingua franca: A
 common mid-frontal substrate for action monitoring processes.
Psychophysiology. doi: 10.1111/j.1469-8986.2011.01293.x
- Cohen, M.X. (2014). A neural microcircuit for cognitive conflict detection and signaling.
Trends in Neurosciences, 37(9), 480-490. doi: 10.1016/j.tins.2014.06.004
- Cohen, M.X. (2014). *Analyzing neural time series data: Theory and practice*.
 Cambridge, MA. MIT Press.
- Cohen, M.X., & Donner, T.H. (2013). Midfrontal conflict-related theta-band power
 reflects neural oscillations that predict behavior. *Journal of Neurophysiology*,
 110, 2752-2763. doi: 10.1152/jn.00479.2013
- Cohen, M.X., & Ridderinkhof, K.R. (2013). EEG source reconstruction reveals frontal-
 parietal dynamics of spatial conflict processing. *PLOS ONE*, 8(2), 1-14.
 doi: 10.1371/journal.pone.0057293
- Christopoulos, G. I., Tobler, P. N., Bossaerts, P., Dolan, R. J., & Schultz, W. (2009).
 Neural correlates of value, risk, and risk aversion contributing to decision making
 under risk. *The Journal of Neuroscience* 29(40), 12574-12583.
 doi: 10.1523/JNEUROSCI.2614-09.2009
- Doya, K. (2008). Modulators of decision making. *Nature Neuroscience*, 11(4), 410-416.
 doi: 10.1038/nn2077

- Dreisbach, G., & Fischer, R. (2012). Conflicts as aversive signals. *Brain and Cognition*, 78, 94-98. doi: 10.1016/j.bandc.2011.12.003
- Eriksen, B.A., & Erikson, C.W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics*, 16(1), 143-149.
- Ernst, M., Bolla, K., Mouratidis, M., Contoreggi, C., Matochik, J. A., Kurian, V., ... London, E. D., (2002). Decision-making in a risk-taking task: A PET study. *Neuropsychopharmacology*, 26(5), 682-691.
- Fritz, J., & Dreisbach, G. (2013). Conflicts as aversive signals: Conflict priming increases negative judgements for neutral stimuli. *Cognitive Affective Behavioral Neuroscience* 13, 311-317. doi: 10.3758/s13415-012-0147-1
- Gianotti, L. R., Knoch, D., Faber, P. L., Lehmann, D., Pascual-Marqui, R. D., Diezi, C., ... Fehr, E., (2009). Tonic activity level in the right prefrontal cortex predicts individuals' risk taking. *Psychological Science*, 20(1), 33-38.
- Holroyd, C.B., & Coles, M.G.H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, 109(4), 679-709.
- Hull, C.L. (1943). Principles of behavior. New York: Appleton-Century.
- Jocham, G., & Ullsperger, M. (2008). Neuropharmacology of performance monitoring. *Neuroscience and Biobehavioral Reviews*, 33, 48-60.
doi: 10.1016/j.neurobiorev.2008.08.011

- Knoch, D., Gianotti, L.R., Pascual-Leone, A., Treyer, V., Regard, M., Hohmann, M., & Brugger, P., (2006). Disruption of the right prefrontal cortex by low-frequency repetitive Transcranial magnetic stimulation induces risk-taking behavior. *The Journal of Neuroscience*, 26(4), 6469-6472. doi: 10.1523/JNEUROSCI.0804-06.2006
- Kool, W., McGuire, J.T., Rosen, Z.B., & Botvinick, M.M. (2010). Decision making and the avoidance of cognitive demand. *Journal of Experimental Psychology: General*, 139(4), 665-682. doi: 10.1037/a0020198
- Krain, A. L., Wilson, A. M., Arbuckle, R., Castellanos, F. X., & Milham, M. P. (2006). Distinct neural mechanisms of risk and ambiguity: A meta-analysis of decision-making. *Neuroimage* 32, 477-484. doi: 10.1016/j.neuroimage.2006.02.047
- Leigh, B.C. (1999). Peril, chance, adventure: Concepts of risk, alcohol use and risky behavior in young adults. *Addiction*, 94(3), 371-383.
- Lejuez, C.W., Read, J.P., Kahler, C.W., Richards, J.B. Ramsey, S.E., Stuart, G.L., ... & Brown, R.A. (2002). Evaluation of a behavioral measure of risk taking: The balloon analogue risk task (BART). *Journal of Experimental Psychology: Applied*, 8(2), 75-84. doi: 10.1037//1076-898X.8.2.75
- Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA. MIT Press.
- Nigbur, R., Ivanova, G., & Stürmer, B. (2011). Theta power as a marker for cognitive interference. *Clinical Neurophysiology*, 122(2011), 2185-2194. doi: 10.1016/j.clinph.2011.03.030

- O'Reilly, J. X. (2013). Making predictions in a changing world – inference, uncertainty, and learning. *Frontiers in Neuroscience*, 7, 1-10. doi: 10.3389/fnins.2013/00105
- Pastötter, B., Hanslmayr, S., & Bäuml, K.H.T. (2010). Conflict processing in the anterior cingulate cortex constrains response priming. *Neuroimage*, 50(2010), 1599-1605. doi: 10.1016/j.neuroimage.2010.01.095
- Ridderinkhof, K.R., Ullsperger, M., Crone, E.A., & Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science*, 306, 443-447.
- Rossignol, E. (2011). Genetics and function of neocortical GABAergic interneurons in neurodevelopmental disorders. *Neural Plasticity*, 2011, 1-25. doi: 10.1155/2011/649325
- Smit, A. S., Eling, P.A, Hopman, M. T., & Coenen, A. M. (2005). Mental and physical effort affect vigilance differently. *International Journal of Psychophysiology*, 57(211-217). doi: 10.1016/j.ijpsycho.2005.02.001
- Steenbergen, H., Band, G.P.H., & Hommel, B. (2012). Reward valence modulates conflict-driven attentional adaptation: Electrophysiological evidence. *Biological Psychology*, 90, 234-241. doi: 10.1015/j.biopsycho.2012.03.018
- Wascher, E., Bjorn, R., Sanger, J, Scen Hoffmann, Schneider, D., Rinkenauer, G., Heuer, H., & Gutberlet, I., (2013). Frontal theta activity reflects distinct aspects of mental fatigue. *Biological Psychology*, 96, 57-65. doi: 10.1016/j.biopsycho.2013.11.010
- Zipf, G.K. (1949). Human behavior and the principle of least effort. Cambridge, MA: Addison-Wesley.