

FROM PREPARATION TO ASSESSMENT: EXPLORING
THE NEURAL SUBSTRATES OF APPROACH-
MOTIVATED GOAL PURSUIT

by

AUSTIN HUNTER THREADGILL

PHILIP A. GABLE, COMMITTEE CHAIR
ALEXA M. TULLETT
IAN M. MCDONOUGH
LAUREN E. KOIS
ANTHONY P. BUHR

A DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Psychology
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2019

Copyright Austin Hunter Threadgill 2019
ALL RIGHTS RESERVED

ABSTRACT

Decades of research have suggested that emotive states drive much of human behavior. However, little work has examined the relationship between emotions and the neural correlates of action processes. The present research sought to begin to bridge this gap by examining the bi-directional relationship between emotion and neural correlates of motor activity during goal pursuit. Across two studies, I examined the relationship between approach-motivated affect and two psychophysiological variables: beta suppression over the motor cortex and the reward positivity (RewP). Using a monetary incentive delay paradigm, Experiment 1 sought to understand how previous goal pursuit performance impacts neural activity associated with motor-action preparation during future goal pursuit. Results indicated that past performance did not impact motor-action preparation in approach-motivated states, but behavioral results suggested that differences in reaction time due to past performance was manipulated within approach-motivated and neutral states. Experiment 2 used a modified monetary incentive delay paradigm to examine whether manipulating motor-action preparation independent of motivational state influenced neural correlates of emotional responding. Results indicated that motor action preparation, independent of motivational state, increased emotional responding to appetitive pictures. These results indicate that the relationship between motor-action preparation and approach motivation are bi-directional, integrating information from both psychological processes to engage goal pursuit.

DEDICATION

This dissertation is dedicated to my fiancé, Mary Helen Deck, and my ever-supportive family. Your never-ending love has guided and supported me throughout this entire journey.

LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of variance
EEG	Electroencephalography
ERP	Event-related brain potential
et al.	Et alii or “and others”
e.g.	“for example”
Hz	Hertz
i.e.	Id est or “that is”
ISI	Interstimulus interval
ITI	Intertrial interval
ms	Milliseconds
RewP	Reward positivity
RT	Reaction time
s	Seconds
vs.	Versus
F	Fisher’s F ratio: A ratio of two variances
n	Sample size of group
f	Cohen’s f effect size measure
p	Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
=	Equal to

η_p^2

Partial eta squared effect size measure

ACKNOWLEDGEMENTS

If I were to take the time to thank everyone who has helped me see this dissertation to its completion, it would be longer than the actual dissertation itself. I am most indebted to my advisor, Dr. Philip Gable, without whom would I be the researcher that I am today. I would also like to thank each of my committee members, Dr. Alexa Tullett, Dr. Ian McDonough, Dr. Lauren Kois, and Dr. Anthony Buhr, for their inputs and suggestions that helped make this a better project. Additionally, I would like to thank Lauren Neal, Ricardo Wilhelm, and Micayla Lacey for the countless hours spent in the lab teaching each other how to be better researchers. Finally, I owe endless thanks to my fiancé, my family, and God, all of whom have encouraged me, motivated me, and strengthened me from day one.

CONTENTS

ABSTRACT	ii
DEDICATION	iii
LIST OF ABBREVIATIONS AND SYMBOLS	iv
ACKNOWLEDGEMENTS	vi
LIST OF TABLES	viii
LIST OF FIGURES	ix
INTRODUCTION	1
EXPERIMENT 1	9
EXPERIMENT 2	35
GENERAL DISCUSSION	50
REFERENCES	55

LIST OF TABLES

1. Ratings to trial cues and flankers RT by trial type.....	17
2. Ratings to feedback cues.....	18
3. Effort ratings and flankers RT by previous outcome.....	19
4. Logged beta suppression by previous trial outcome.....	25
5. Beta suppression by previous trial outcome and block number	27
6. RewP amplitude	28
7. Picture ratings	45
8. N1 amplitudes	46

LIST OF FIGURES

1. Experiment 1 example trial. The intertrial interval (ITI) will be 1500 ms13
2. Logged flanker RTs for the 2 (block) x 3 (previous trial outcome) interaction. Error bars indicate standard error of the mean.....23
3. Logged beta activity for the 2 (block) x 3 (previous trial outcome) interaction. Error bars indicate standard error of the mean.....25
4. ERP waveforms for win and loss feedback during consequence and neutral trials at site Cz. The RewP is circled29
5. RewP amplitude for the 2 (block) x 2 (outcome) interaction. Error bars indicate standard error of the mean.....30
- 6A. Experiment 2 example movement trial. The ITI was 1500 ms39
- 6B. Experiment 2 example memory trial. Stimuli timing is similar to movement trials (with the exception of pictures, which were each displayed for 3 s). For memory trials with neutral pictures, a neutral picture replaced both of the appetitive pictures presented above. For the memory task at the end of the trial, the stimuli appeared on the screen until the participant responded. The ITI was 1500 ms40
7. ERP waveforms for appetitive and neutral pictures during movement and memory trials at an index of sites Fz, FCz, and Cz. The N1 is circled.....47

INTRODUCTION

Movement is essential for goal pursuit. Whether in pursuit of food, water, or sex, or running away from some predator, movement is necessary in order to survive. In order to do this, a complex nervous system has evolved that increases the likelihood of surviving and producing offspring (Chiel & Beer, 1997), incorporating a large array of perceptual, cognitive, and affective mechanisms to produce individual goal-directed behaviors. One mechanism that seems to have large influences on motor activity is emotion. Because emotion permeates every step of goal pursuit, it seems likely that there is a relationship between neural correlates of motor activity and emotion. Thus, the current research seeks to investigate how approach-motivated affect relates to a specific aspect of movement; more specifically, the aim of this dissertation is to disentangle the bi-directional relationship between neural correlates of motor-action preparation and approach-motivated affect.

The Motivational Dimensional Model of Affect

Much of human behavior is predicated on the motivation to act. The motivation to move towards or away from some stimulus is often driven by the affective state of the organism. Affective states vary on a variety of dimensions. One dimension of emotion is that of affective valence, or whether an emotion is pleasant or unpleasant. Another dimension of emotion is that of motivational direction, or the propensity to either move towards (approach motivation) or withdraw from (withdrawal motivation) an object or goal. Finally, approach- and withdrawal-motivated affects vary in their motivational intensity. Motivational intensity refers to the amount

of motivation within an affect. Within a given motivational direction, motivational intensity can range from low to high. For example, contentment and sadness are both lower in motivational intensity than desire and anger.

During goal pursuit, a complex sequence of behaviors occurs, all of which arise from internal motivations inherent within affect. High and low intensity approach-motivated affects facilitate specific goal pursuit behaviors, occurring at different stages of goal pursuit. High intensity approach-motivated affective states, such as desire or anger, are preparatory states that facilitate goal pursuit, in which organisms are actively preparing and attempting to obtain some object or goal (pregoal; Gable & Harmon-Jones, 2010a, 2010b, 2011a; Gable, Hart, Threadgill, & Adams, 2019a). For example, past research has shown that high intensity approach-motivated states narrow cognitive scope, likely so that organisms may focus cognitive resources and ultimately obtain the goal (Gable & Harmon-Jones, 2016). In contrast, low approach-motivated affective states, such as contentment or sadness, occur after the desired object or goal has been obtained (postgoal). These states likely reflect the assessment of whether goal attainment has or has not occurred, as well as looking forward to other goal pursuit opportunities (Kaplan, Van Damme, & Levine, 2012).

High and low intensity approach-motivated affects are associated with different patterns of neural activity in the brain. For example, high intensity approach-motivated affects increases relative left frontal activation, while low intensity approach-motivated affects do not (Harmon-Jones, Harmon-Jones, Fearn, Sigelman, & Johnson, 2008). Consequently, affects high and low in approach-motivational intensity influence brain activation associated with the preparation for, attempt at, and feedback assessment of goal pursuit. The current experiments aim to better understand how motivation impacts two neurophysiological correlates of approach-motivated

goal pursuit. More specifically, I will examine beta suppression over the motor cortex and the reward positivity (RewP).

Beta Activity over the Motor Cortex

Beta activity over the motor cortex, measured using electroencephalography (EEG), appears to be a neural correlate of motor-action preparation (Pfurtscheller, Stancák Jr., & Neuper, 1996; Sanes & Donoghue, 1993). During preparation for movement, suppression of beta oscillations occurs over the motor strip (McFarland, Miner, Vaughan, & Wolpaw, 2000; Pfurtscheller & Lopes Da Silva, 1999). Increases in beta suppression (i.e., less beta activation) relate to preparation for movement before a target stimulus (Doyle, Yarrow, & Brown, 2005). Additionally, research has found that increasing beta activity over the motor cortex (i.e., less beta suppression) using transcranial alternating-current stimulation slows the onset of future hand and finger movements (Pogosyan, Gaynor, Eusebio, & Brown, 2009; Wach et al., 2013). Finally, research has demonstrated that beta activation not only decreases when participants make motor movements, but also when participants *visualized* making motor movements (McFarland et al., 2000), implying that beta suppression occurs during the visualization of potential motor action. In sum, this past work suggests that lower levels of beta activation index greater motor-action preparation (Jenkinson & Brown, 2011).

Motivation appears to have disparate effects on beta suppression depending on what actions are necessary to ultimately attain the desired goal. For example, some work has linked reduced beta activity over the motor cortex with greater approach motivation at both the state and trait level. On the state level, research has found that increasing motivation through higher monetary incentives decreased beta activation (Meyniel & Pessiglione, 2014). As incentive levels increased, individuals became more motivated to act, leading to decreased beta activity.

Other work by Gable, Threadgill, and Adams (2016) used a monetary incentive delay paradigm to manipulate high (pregoal) versus low (postgoal) approach-motivated positive affective states. Presumably, pregoal positive states occur during the pursuit of a goal and likely prepare an individual to act, while postgoal approach-motivated positive states occur after a goal has been achieved, throttling back motivational intensity. Results revealed that beta activation was lowest in pregoal positive states, relative to postgoal positive and neutral states. This suggests that higher levels of motor-action preparation occur during high intensity approach-motivated states when actions toward a goal are needed. On the trait level, Threadgill and Gable (2018a) had participants complete measures of trait behavioral approach and avoidance motivation (BIS/BAS; Carver & White, 1994), as well as measures of regulatory control (UPPS-P Impulsive Behaviour Scale; Whiteside, Lynam, Miller, & Reynolds, 2005). Then, resting EEG activity was recorded. Results indicated that greater trait approach was negatively associated with resting beta activity (i.e., greater beta suppression), while greater trait impulsivity was associated with greater resting beta activity (i.e., less beta suppression). These results suggest that lower resting beta activity (i.e., greater beta suppression) over the motor cortex is related to traits associated with deliberate motivated motor behaviors. Together, this work provides evidence that motor-action preparation, as indexed by decreased beta activity over the motor cortex, is sensitive to approach motivation during goal pursuit.

Other work has suggested that greater beta suppression might actually be associated with motivation to better inhibit making a motor movement, such as when action initiation should be stopped. For example, research has shown that, during a stop-signal task, beta activation was higher (i.e., less beta suppression) before successfully stopped trials than unsuccessfully stopped trials (Swann et al., 2009). Other research has found that macaque monkeys playing a rewarded

go/no-go task show increased beta activity to no-go signals, relative to go signals, suggesting that successful inhibition requires more beta activity (Zhang, Chen, Bressler, & Ding, 2008). This likely occurred because processes used to control impulses in order stop action initiation reflect the activation of the goal to stop impulsive reactions (Braver, 2012). Indeed, increasing beta activation by means of transcranial magnetic stimulation over the right inferior frontal gyrus, a region associated with increased regulatory control system functioning (Gable, Neal, & Threadgill, 2018), increases connectivity with the motor cortex, as seen by increased coherence in beta activation between the two regions during successful no-go trials in a go/no-go task (Picazio et al., 2014).

Because past research has found that both and decreasing beta activation of the motor cortex via activation of motivational states, this work possibly leaves unclear the relationship between motivation and neural correlates of motor-action preparation. However, it seems likely that differences in beta suppression during these motivated states are likely due to the actions necessary to achieve desired outcomes. When an organism is in an approach-motivated state, the goal is to move towards a desired outcome. In these situations, increasing motivation to move towards the goal leads to increases in motor-action preparation, as indicated by increased beta suppression. However, decreasing motivation, such as when one needs to disengage from goal pursuit decreases motor-action preparation (as indicted by decreased beta suppression), because continuing goal pursuit is futile. In contrast, when the goal is to stop an action from occurring, organisms need to increase regulatory behaviors that prevent motor movement. In these situations, it is likely the case that increasing motivation to stop decreases motor-action preparation, as indicated by decreased beta suppression. However, decreasing motivation to stop increases motor-action preparation, as indicated by increased beta suppression. Together, this

suggests that, regardless of the action-outcome, increasing motivation leads to changes in neural activity that bring about actions necessary for successful goal pursuit. For purposes of this dissertation, I will focus on how increasing approach motivation increases motor-action preparation to move towards a goal, as indexed by increased beta suppression over the motor cortex (i.e., less beta activity).

The Reward Positivity

Pregoa positive affects are likely associated with enhanced approach motivation because such states facilitate acquisition of desired goals (Kaplan et al., 2012; Larson & Steuer, 2009). This, in turn, should prime organisms to plan, prepare, and execute actions more efficiently. Consequently, these approach-motivated pregoal states should also enhance performance monitoring of rewarding feedback in order to maximize the probability of successfully attaining future rewards (Sutton & Barto, 1998). It seems likely that this feedback monitoring is critical in approach-motivated states in order to assess whether some goal or object was successfully or unsuccessfully attained.

One neurophysiological assessment of feedback processing is the RewP. The RewP is an event-related potential (ERP) component thought to reflect the immediate evaluation of performance feedback and action monitoring (Proudfit, 2015). Also known as the feedback negativity, feedback-related negativity, and medial frontal negativity, this ERP component is an underlying positive-going deflection occurring approximately 250 *ms* after performance feedback at frontocentral sites. Positive feedback evokes a larger positive-going wave than negative or neutral feedback (Holroyd, Hajcak, & Larsen, 2006; Levinson, Speed, Infantolino, & Hajcak, 2017). The RewP is sensitive to both outcome magnitude (Meadows, Gable, Lohse, & Miller, 2016a) and likelihood (Sambrook & Goslin, 2015), in that both high magnitude and

infrequent outcomes elicit a larger RewP than low magnitude and frequent outcomes, respectively. Changes in the RewP to infrequent outcomes may be indexing a reward prediction error signal associated with reinforcement learning (Holroyd & Krigolson, 2007; Nieuwenhuis, Holroyd, Mol, & Coles, 2004) The RewP likely arises from the anterior cingulate cortex (Gehring & Willoughby, 2002) and driven by the mesocorticolimbic dopamine system, a neural network associated with reward processing (Foti, Weinberg, Dien, & Hajcak, 2011; Santesso et al., 2008).

Past work has linked approach motivation with an enhanced RewP at both the state and trait level. On the state level, research has shown that high approach-motivated pregoal states evoke a larger RewP than neutral states (Angus et al., 2017; Threadgill & Gable, 2016), suggesting that the RewP may be sensitive to an outcome's motivational salience, rather than valence (Threadgill & Gable, 2019b). Furthermore, research has shown that as increases in potential monetary rewards enhance approach motivation, RewP amplitudes also increase (Meadows Gable, Lohse, & Miller, 2016b). RewP amplitudes are also larger in approach-motivated states than neutral states across incremental stages of goal pursuit (Threadgill & Gable, 2018b). This suggests that higher levels of feedback processing occur during high intensity approach-motivated states.

On the trait level, greater trait approach motivation measured using Carver & White's (1994) BIS/BAS scales correlates with larger RewPs in gambling tasks (Lange, Leue, & Beauducel, 2012). Larger RewPs have also been linked with measures of reward responsiveness (Bress & Hajcak, 2013), liking of desirable rewards (Angus, Kemkes, Schutter, & Harmon-Jones, 2015), and degree of perceived agency in obtaining awards (Yeung, Holroyd, & Cohen,

2005). Together, this work suggests that feedback monitoring, as measured by the RewP, is influenced by approach motivation.

The Current Experiments

A core component of emotion is that it has action tendencies to either move towards or move away (Carver & Scheier, 1998; Elliot, 1999). Presumably, appetitive states necessarily facilitate movement towards some goal or object, as well as how an organism interprets outcomes of that goal pursuit. The aim of my proposed research is to expand on the previously discussed findings by examining how different aspects of goal pursuit impacts beta suppression over the motor cortex and the RewP, both of which are neural correlates of goal pursuit and attainment. Specifically, across two experiments, I am seeking to answer two questions: does previous performance impact neural correlates of approach motivation in future goal pursuit, and is the relationship between motivation and motor-action preparation bi-directional?

EXPERIMENT 1

In Experiment 1, I examined whether successful or unsuccessful performance during previous goal pursuit impacts neural correlates of motor-action preparation during future goal pursuit. It seems likely that previous goal performance would impact how organisms engage in future goal pursuit. This idea stems from theoretical models of reinforcement learning, which propose that action selection occurs because individuals predict which actions will or will not be successful (Sutton & Barto, 1998; Rescorla & Wagner, 1972). As individuals learn from past experience what actions bring about desirable rewards, the likelihood of that specific operation being used in future goal pursuit increases. For example, research has shown that reinforcement learning has a distinct neural signature, as seen by a diminishing RewP as patterns of feedback are learned (Krigolson, Hassall, & Handy, 2014). However, at present, there has been no research examining how past performance impacts how individuals engage in future goal pursuit.

It seems likely that past performance could impact future goal pursuit by two divergent processes. The first mechanism that could impact future goal pursuit would be that, as organisms continuously attain goals, they reduce effort in order to conserve energy for future goal pursuit by beginning to “coast” (Carver, 2003; Frijda, 1994). Individuals have certain expectations about the likelihood of an action leading to some outcome. Any affect, regardless of valence, reflects an error signal within a feedback loop that uses the outcome expectation as a reference point. Positive affect arises because outcomes are going better than expected. Because this feedback loop detects an error in the feedback loop, the organism then takes appropriate responses to return to homeostasis. Thus, organisms would begin to “coast,” throttling back energy in order to

preserve it for future goal pursuit. This would be evolutionarily advantageous, in that, if organisms experienced positive affect, the organism could not give as much effort, so that they could divert attention and effort from other goals necessary for survival (Carver & Scheier, 1998). However, when negative affect occurs, organisms would show greater effort as they attempt to increase the likelihood of attaining the desired goal. Thus, winning leads to decreases in approach-motivated goal pursuit, while losing leads to increases in approach-motivated goal pursuit.

The second mechanism that could impact future goal pursuit would be that, as organisms continuously fail at attaining goals, they reduce effort in order to conserve energy, since current goal pursuit is futile (Klinger, 1977). Through an incentive-disengagement cycle, frustration builds as goal pursuit continuously is hampered or blocked. Organisms experience an increase in disappointment or depression (Klinger, 1975). They also may experience increases in hostility (Wessman & Ricks, 1966), decreases in self-esteem (Klug & Maier, 2014), and greater likelihood of exhibiting learned helplessness behaviors (Abramson, Seligman, & Teasdale, 1978). Consequently, disengaging from goal pursuit alleviates these negative outcomes, as well as decreases the likelihood of future approach-motivated goal pursuit. This can be seen on the neural level by research which found that individuals with chronic depression, a psychological disorder characterized by reduced reward reactivity and goal pursuit engagement, show decreases in neural signatures of approach motivation (i.e., frontal asymmetry) in a goal pursuit task, relative to healthy controls and those with late onset depression (Shankman, Klein, Tenke, & Bruder, 2007). Thus, by experiencing increases in negative affect, individuals would partake in the incentive-disengagement cycle, showing decreases in approach-motivated goal pursuit after losses, while experiencing increases in approach-motivated goal pursuit after wins. At

present, no research has examined how previous wins and losses will impact neural processes associated with motor-action preparation during future goal pursuit.

In the present research, participants completed a series of trials in a reaction time task. To manipulate approach motivation, in some blocks, if participants were faster than the average reaction time, they would receive a reward (points, while, if they were slower than the average reaction time, they lost points. In other blocks, feedback was unrelated to reaction times and did not indicate than an actual reward had been won.

Based on previous research, it seemed likely that two competing hypotheses may occur when examining the relationship between previous goal performance and motor-action preparation during future goal pursuit. If a tendency toward “coasting” is driving the relationship between past performance and future goal pursuit, winning previous trials would cause individuals to throttle back (since they are doing better than expected). Thus, beta suppression during trial cues for current trials should be highest when the previous two trials have been lost and lowest when the previous two trials have been won. However, if a tendency towards incentive disengagement is driving the relationship between past performance and future goal pursuit, losing previous trials would cause individuals to throttle back (since future goal pursuit is futile). Thus, beta suppression during trial cues for the current trial should be highest when the previous two trials have been won and lowest when the previous two trials have been lost. Regardless of how past performance impacts the pattern of means for motor-action preparation during future goal pursuit, it is likely that these effects would be especially pronounced in approach-motivated states, relative to neutral states, since changes in beta suppression are sensitive to approach-motivated goal pursuit. By understanding how previous performance

impacts future goal pursuit, the current study should elucidate how individuals use external feedback cues signaling how well goal pursuit is going while engage in future goal pursuit.

Methods

Forty-one introductory psychology students participated in exchange for partial course credit.¹

Participants first completed personality questionnaires.² Then, 64 EEG electrodes were applied. To become comfortable with the equipment, participants then completed eight minutes of baseline recording. Finally, participants participated in a reaction time game, where they had the ability to win points that could be exchanged for candy through a series of trials. Twelve practice trials were included at the beginning of the game.

Each trial ($n = 180$; see Figure 1 for example trial and stimuli timing) in the game began with a fixation cross. Trials were divided into 6 blocks of 30 trials each. In three blocks, participants had the chance to receive a reward based upon their trial performance (consequence trials). In the other three blocks, a reward could not be earned based on trial performance, and feedback was randomly given (neutral trials). Block order switched from consequence trials to neutral trials throughout the task. Additionally, to reduce EEG artifact, participants were instructed to watch each picture for the entire time it was displayed.

Next, participants performed the goal-related task, which was a flankers task (Eriksen & Eriksen, 1974). Participants were instructed to indicate the direction of the center arrow by pressing buttons on a response pad as quickly as possible. Directions indicated that if participants responded faster than the average participant from the previous semester, they would win the

¹ Differences in degrees of freedom for all analyses across both studies were due to loss of data for that specific analysis.

² There were no specific hypotheses including the questionnaires, but included them for secondary analyses at a later time.

trial. The flankers task remained on the screen until the participant responded. Across all trials, participants saw an equal number of left and right flankers.

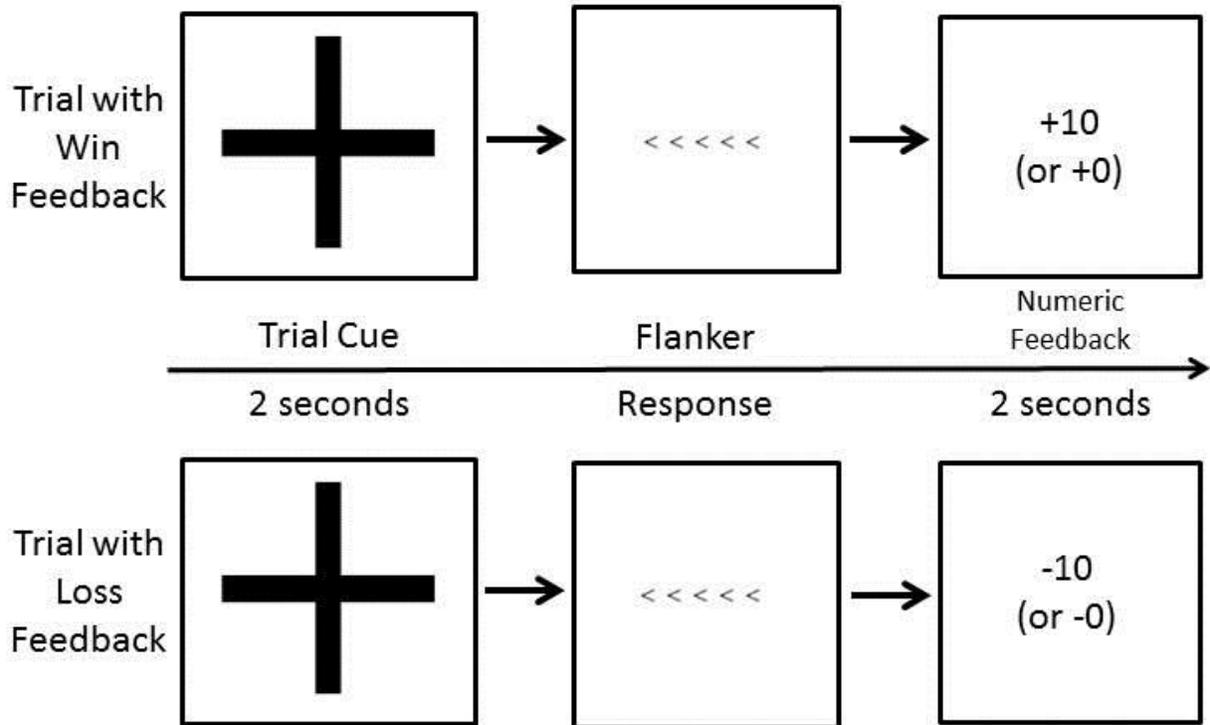


Figure 1. Experiment 1 example trial. The intertrial interval (ITI) will be 1500 ms.

Following the flankers task, participants received feedback indicating whether they did or did not receive points on the trial. In consequence trials, all trials resulted in either winning or losing 10 points. To indicate whether the participant won or lost on the trial, a circle appeared with either “+10” or “-10” presented in the center of the cue. In neutral trials, all trials resulted in neither winning nor losing points. However, all trials indicated whether they received positive or negative feedback. To indicate either positive or negative feedback on the trial, a square cue appeared with either a “+0” or “-0” presented in the center of the cue.

Half of the trials resulted in win feedback, and half of the trials resulted in loss feedback for both the reward and neutral trials. On neutral trials, feedback was not related to the

participant's reaction time and was randomly given. To make sure that participants believe that feedback is dependent upon their own reaction times in consequence trials, participants were told that this task is very hard, and that, on average, participants successfully completed the task on approximately half of the trials. However, in reality, half of consequence trials resulted in win feedback if the participant both was faster than 1500 *ms* and responded correctly. Otherwise, participants were given loss feedback. The remaining half of consequence trials resulted in loss feedback.³

After all trials, participants viewed trial and feedback cues for both the consequence and neutral blocks again and indicated how pleasing (1 = *positive*, 9 = *negative*) and arousing (1 = *exciting*, 9 = *calm*) each picture made them feel using Bradley & Lang's (1994) Self-Assessment Manikin by pressing numbers on a computer keyboard. Additionally, participants rated how much they felt the following emotions during each of the cues: sad, desire, enthusiastic, excited, angry, and anxious (1 = *no emotion*, 9 = *strongest feeling*; Ekman, Friesen, & Ancoli, 1980).

Additionally, participants were also asked questions about different scenarios they encountered in the game. More specifically, participants were asked how hard they tried (1 = *much less hard*, 9 = *much harder*) and how much effort they gave (1 = *much less hard*, 9 = *much harder*) when they had won the previous two trials, won once and lost once in the previous two trials, and lost the previous two trials during both the consequence blocks and neutral blocks.

³ Previous research using variations of this task have found that participants have average response rates of about 750 *ms*. This research has also found that participants had error-rates of approximately 5%. Assuming that participants miss approximately 5% of trials, this will result in participants seeing win feedback approximately 43 times and loss feedback approximately 47 times. However, previous research using variations of this task has used as little as 12 win trials in their variation of the task and found results consistent with research that utilized more trials. Additionally, pilot testing has found that participants believe that they answered quickly enough on about half of the trials. Therefore, given that participants typically respond much quicker than the liberal cut-off time and ascertain that they swiftly and correctly responded to about half of the trials, I did not expect the slight variation in the number of reward trial win feedback and reward trial loss feedback shown to be noticeable to participants. None of the participants reported that they noticed the slight variation in the number of reward trial win feedback and reward trial loss feedback that they received.

Participants also rated how they much they felt the following emotions during these different scenarios: sad, desire, enthusiastic, excited, angry, and anxious.

EEG Assessment and Processing

EEG was recorded from 64 tin electrodes mounted in a stretch lycra Quick-Cap (Electro-Cap, Eaton, OH) and referenced online to the left earlobe. A ground electrode was mounted midway between FPz and Pz. The electrode cap was based on the 10-20 system, and a sodium chloride-based conductance gel was used to assist in the decrease of impedances. Electrode impedances were kept under 5000 Ω . Signals were amplified with a Neuroscan SynAmps RT amplifier unit (El Paso, TX).

BrainVision Analyzer (Brain Products) were used for offline analysis. Data were rereferenced to the mastoid average. Data were then low-pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, and notch filtered at 60 Hz using Butterworth zero phase filters and digitized at 500 Hz. Then, a regression-based eye movement correction was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986). Individual channels were then rejected using an automated procedure, with artifacts defined as a 200 μ V change within a 160-ms interval and signals exceeding ± 180 μ V, after which data were visually inspected again to insure proper correction.

Beta Suppression

During the trial cues, epochs 1024 ms in duration were extracted through a Hamming window. Consecutive epochs were overlapped by 50% to avoid data loss. Next, power values corresponding to beta (13-30 Hz) were extracted using a Fast Fourier Transformation and log-transformed. Data were then averaged across regions of the head at sites corresponding with the motor cortex (McFarland et al., 2000; Pfurtscheller, Neuper, Brunner, & da Silva, 2005). Specifically, beta suppression was examined at sites C1-C6 and CP1-CP6.

Variables consisted of average beta activity during the trial cue based upon the outcome of the previous two trials. This created six conditions: beta suppression during consequence block trial cues following two wins, a win and a loss, and two losses, and beta suppression during neutral block trial cues following two wins, a win and a loss, and two losses. The first two trials in a block were excluded from analyses.

The Reward Positivity

To measure the RewP, data were epoched from 200 *ms* before feedback onset to 1000 *ms* after feedback onset, low-pass filtered at 35 Hz, and baseline corrected relative to the 200 *ms* prestimulus window. Aggregated waveforms were created and visually inspected for the RewP. The RewP was measured as the average amplitude within a window of 250-350 *ms* after feedback onset at site CZ (Threadgill & Gable, 2016, 2019b). This was done for wins and losses in both the reward and neutral conditions, resulting in four types of feedback: consequence win, consequence loss, neutral win, and neutral loss.

Hypotheses and Proposed Analyses

The primary dependent variables in Experiment 1 were beta suppression and the RewP. A 2 (block: consequence vs. neutral) X 3 (previous trial outcome: WW vs. WL vs. LL) repeated-measures ANOVA with beta suppression as the dependent variable was used. A significant interaction was hypothesized, with the greatest beta suppression occurring depending on whether participants have the propensity to coast when things are going better than expected or participants have the propensity to disengage when they encounter consecutive losses; this should be especially pronounced for consequence trials. For the RewP, a 2 (block: consequence vs. neutral) X 2 (outcome: win vs. loss) repeated-measures ANOVA was used. A significant interaction was hypothesized, with the largest RewPs during consequence trial win feedback.

Picture ratings to trial and feedback cues, effort ratings, and flankers response reaction times were used as manipulation checks. Using dependent-sample t-tests, it was predicted that trial and feedback cues during consequence blocks would elicit more positive valence, arousal, and desire than trial and feedback cues during neutral blocks. For the effort ratings, a 2 (block: consequence vs. neutral) X 3 (previous trial outcome: WW vs. WL vs. LL) repeated-measures ANOVA were expected to have significant interactions for both how hard participants indicated trying and how much effort participants indicated giving. Finally, a dependent-sample t-test was hypothesized to reveal that consequence blocks elicited faster responses to the flankers task than neutral blocks.

Results

All outliers (i.e., more than three standard deviations from the mean) were removed.

Additionally, means and standard deviations for all manipulation check data for Experiment 1 are presented in Tables 1-3.

Table 1

Ratings to Trial Cues and Flankers RT by Trial Type

	Consequence Trials		Neutral Trials	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Valence	4.50	1.81	5.55	1.66
Arousal	5.97	2.10	6.66	2.13
Desire	3.74	2.30	2.71	1.94
Flankers RT	6.47	0.21	6.54	0.25

Table 2

Ratings to Feedback Cues

	Consequence Trials				Neutral Trials			
	Win		Loss		Win		Loss	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Valence	3.51	2.33	6.15	2.23	4.74	1.96	5.77	1.77
Arousal	4.95	2.18	6.10	2.02	5.73	1.89	6.20	2.21
Desire	4.22	2.60	3.24	2.35	2.83	2.02	2.34	2.00

Table 3

Effort Ratings and Flankers RT by Previous Outcome

	Consequence Trials						Neutral Trials					
	Win-Win		Win/Loss		Loss-Loss		Win-Win		Win/Loss		Loss-Loss	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
How hard?	5.78	1.93	5.83	1.72	5.72	2.57	5.06	2.01	4.97	1.96	4.72	2.48
Effort?	6.19	1.98	6.19	1.58	5.89	2.53	5.06	1.87	4.94	1.88	5.06	2.29
Flankers RT	6.45	0.19	6.35	0.20	6.34	0.22	6.40	0.25	6.52	0.19	6.55	0.21

Manipulation checks.

Cue ratings.

For the trial cues, a dependent-sample *t*-test indicated that consequence trial cues were rated as more positive ($t(37) = -3.14, p = .003$) and desirable ($t(39) = 3.07, p = .004$) than neutral trial cues. Furthermore, consequence trial cues were marginally more arousing than neutral trial cues, $t(38) = -1.81, p = .078$.

For valence ratings to the feedback cues, a 2 (block: consequence vs. neutral) x 2 (outcome: win vs. loss) repeated-measures ANOVA revealed a marginally significant main effect of block, $F(1, 38) = 2.89, p = .097, \eta_p^2 = .07$. However, there was a significant main effect of outcome, $F(1, 38) = 26.68, p < .001, \eta_p^2 = .41$, such that win feedback was rated more positively than loss feedback. Finally, there was a significant interaction, $F(1, 38) = 7.20, p = .011, \eta_p^2 = .16$. Post-hoc analyses using Fisher's LSD indicated that consequence win feedback was rated more positive than both consequence loss ($p < .001$) and neutral win ($p = .006$) feedback. Additionally, neutral win feedback was rated more positive than neutral loss feedback, $p = .021$. There was no difference in valence ratings between consequence loss feedback and neutral loss feedback, $p = .372$.

For arousal ratings to the feedback cues, a 2 (block: consequence vs. neutral) x 2 (outcome: win vs. loss) repeated-measures ANOVA did not reveal a main effect of block, $F(1, 39) = 2.14, p = .152, \eta_p^2 = .05$. However, there was a main effect of outcome, $F(1, 39) = 9.92, p = .003, \eta_p^2 = .20$, such that win feedback was rated as more arousing than loss feedback. Finally, the interaction was not significant, $F(1, 39) = 2.29, p = .139, \eta_p^2 = .06$.

For desirability ratings to the feedback cues, a 2 (block: consequence vs. neutral) x 2 (outcome: win vs. loss) repeated-measures ANOVA revealed a main effect of block, $F(1, 40) =$

18.32, $p < .001$, $\eta_p^2 = .31$, such that consequence trials were rated as more desirable than neutral trials. Furthermore, there was a main effect of outcome, $F(1, 40) = 10.26$, $p = .003$, $\eta_p^2 = .20$. Finally, the interaction was not significant, $F(1, 40) = 1.13$, $p = .293$, $\eta_p^2 = .03$.

For ratings assessing how hard someone had tried on the current trial based upon outcome of the previous two trials, a 2 (block: consequence vs. neutral) x 3 (previous trial outcome: WW vs. WL vs. LL) repeated-measures ANOVA revealed a main effect of block, $F(1, 35) = 15.32$, $p < .001$, $\eta_p^2 = .31$, such that participants indicated trying harder on consequence trials than neutral trials. However, there was not a main effect of previous trial outcome, $F(2, 70) = 0.22$, $p = .800$, $\eta_p^2 = .006$. The interaction was not significant, $F(2, 70) = 0.18$, $p = .833$, $\eta_p^2 = .005$.

For effort ratings assessing how much effort someone had put forth on the current trial based upon outcome of the previous two trials, a 2 (block: consequence vs. neutral) x 3 (previous trial outcome: WW vs. WL vs. LL) repeated-measures ANOVA revealed a main effect of block, $F(1, 35) = 15.50$, $p < .001$, $\eta_p^2 = .31$, such that participants indicated putting forth more effort on consequence trials than neutral trials. However, there was not a main effect of previous trial outcome, $F(2, 70) = 0.16$, $p = .851$, $\eta_p^2 = .004$. The interaction was not significant, $F(2, 70) = 0.45$, $p = .642$, $\eta_p^2 = .01$.

Flanker reaction times

I then examined flankers reaction times to investigate whether participants were faster to respond in consequence trials than neutral trials. RTs were logarithmically transformed to normalize the data, and trials with incorrect responses or RTs more than three standard deviations away from the mean for each stimulus were removed. A dependent-sample t-test

found that participants were faster during consequence trials than neutral trials, $t(40) = -4.70$, $p < .001$, $d = .70$.

Finally, in an exploratory analysis, I examined how reaction times differed between consequence and neutral trials based upon the outcomes of the previous two trials. A 2 (block: consequence vs. neutral) x 3 (previous trial outcome: WW vs. WL vs. LL) repeated-measures ANOVA revealed a main effect of block, $F(1, 39) = 65.30$, $p < .001$, $\eta_p^2 = .63$, such that participants were generally faster on consequence trials than neutral trials. However, there was not a main effect of previous trial outcome, $F(2, 78) = 1.10$, $p = .339$, $\eta_p^2 = .03$. Finally, the interaction was significant, $F(2, 78) = 38.87$, $p < .001$, $\eta_p^2 = .499$ (see Figure 2). The interaction was unpacked by examining the one-way repeated-measures ANOVA for previous trial outcome for both reward trials and neutral trials.

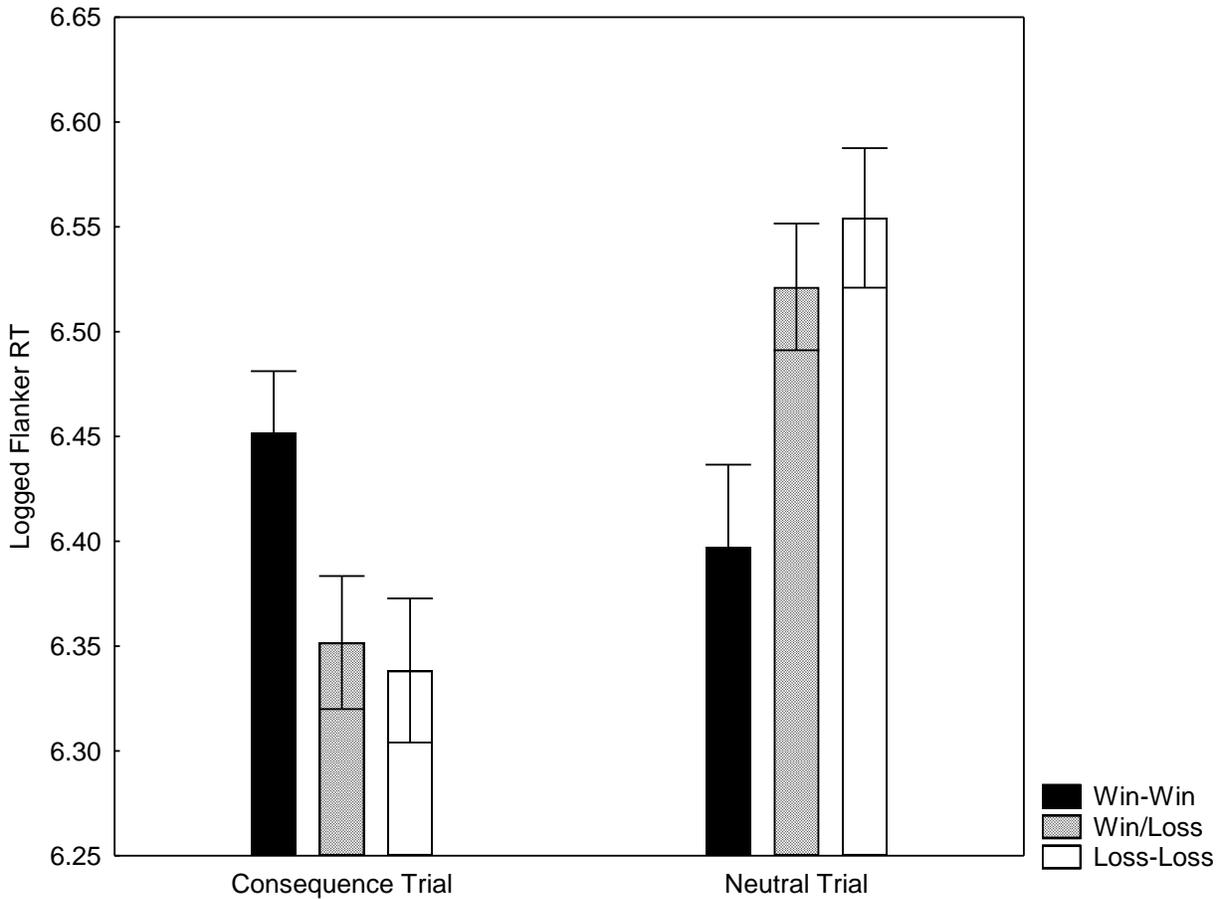


Figure 2. Logged flanker RTs for the 2 (block: consequence vs. neutral) x 3 (previous trial outcome: WW vs. WL vs. LL) interaction. Error bars indicate standard error of the mean.

A one-way repeated-measures ANOVA (previous trial outcome: WW vs. WL vs. LL) examining RTs to the flankers task during consequence trials was significant, $F(2, 78) = 19.48, p < .001, \eta_p^2 = .33$. Post-hoc analyses using Fisher's LSD indicated that participants responded slower to flankers tasks during consequence trials following two wins than both flankers tasks following a win and a loss ($p < .001$) and two losses ($p < .001$). There was no difference in reaction time during consequence trials between flankers tasks following a win and a loss and following two losses ($p = .503$).

A one-way repeated-measures ANOVA (previous trial outcome: WW vs. WL vs. LL) examining RTs to the flankers task during neutral trials was significant, $F(2, 78) = 23.30, p <$

.001, $\eta_p^2 = .37$. Post-hoc analyses using Fisher's LSD indicated that participants responded faster to flankers tasks during neutral trials following two wins than both flankers tasks following a win and a loss ($p < .001$) and two losses ($p < .001$). There was no difference in reaction time during neutral trials between flankers tasks following a win and a loss and following two losses ($p = .179$).

Beta suppression.

To examine how performance on the past two trials influenced beta suppression on the next trial, a 2 (block: consequence vs. neutral) X 3 (previous trial outcome: WW vs. WL vs. LL) repeated-measures ANOVA revealed a main effect of block, $F(1, 40) = 8.91, p = .004, \eta_p^2 = .18$, such that consequence trials elicited greater beta suppression than neutral trials. However, there was not a main effect of previous trial outcome, $F(2, 80) = 0.05, p = .954, \eta_p^2 = .001$. Finally, the interaction was not significant, $F(2, 80) = 0.24, p = .785, \eta_p^2 = .006$ (see Figure 3 and Table 4).

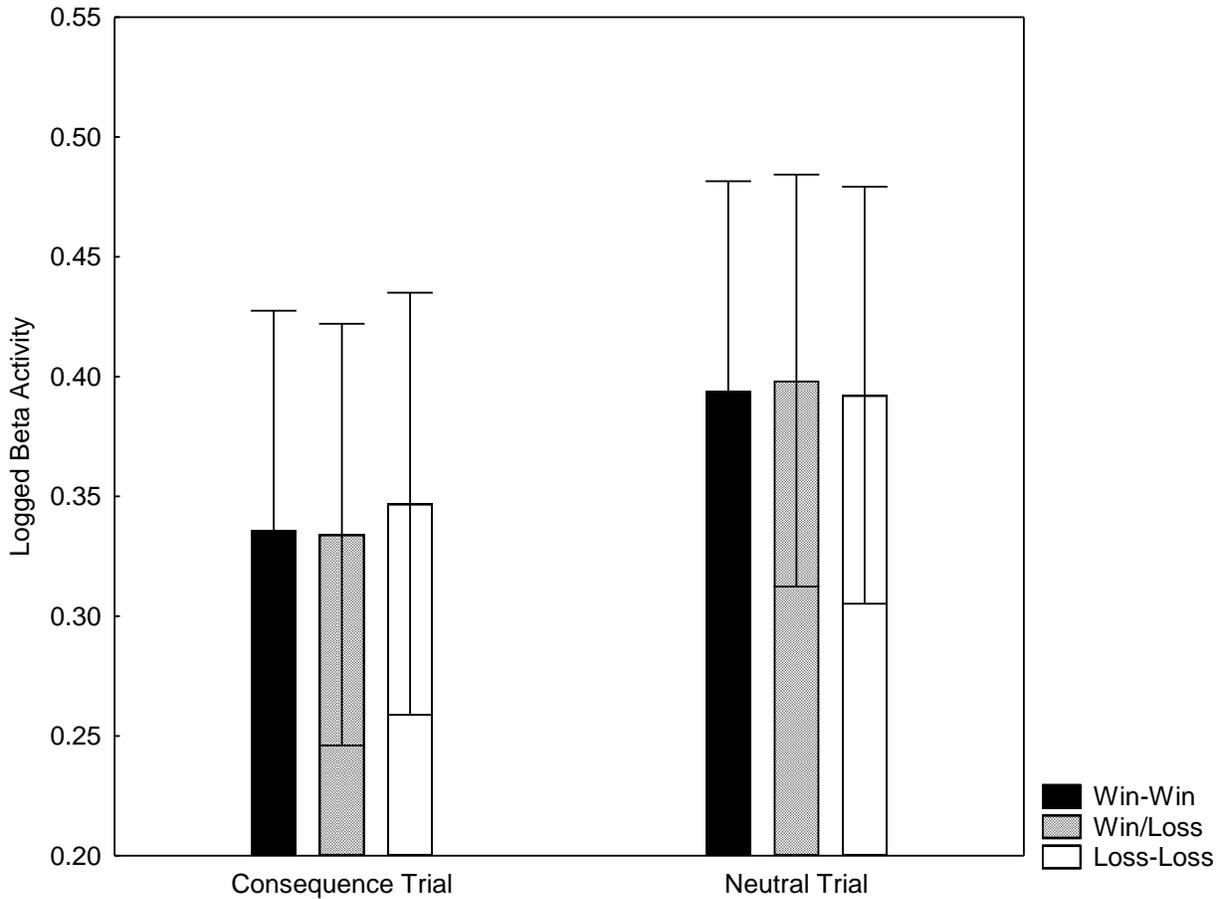


Figure 3. Logged beta activity for the 2 (block: consequence vs. neutral) x 3 (previous trial outcome: WW vs. WL vs. LL) interaction. Error bars indicate standard error of the mean.

Table 4

Logged Beta Suppression by Previous Trial Outcome

	Consequence Trials		Neutral Trials	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Win-Win	0.34	0.59	0.39	0.56
Win/Loss	0.33	0.56	0.40	0.55
Loss-Loss	0.35	0.56	0.39	0.56

Because beta suppression may vary across the different blocks across the length of the experiment, I conducted a 3 (block order: first block vs. second block vs. third block) X 2 (block: consequence vs. neutral) X 3 (previous trial outcome: WW vs. WL vs. LL) repeated-measures

ANOVA. Results indicated that there was a main effect of block, $F(1, 37) = 7.52, p = .009, \eta_p^2 = .17$, such that consequence trials elicited greater beta suppression than neutral trials. However, there was not a main effect of either block order ($F(2, 74) = 0.94, p = .395, \eta_p^2 = .02$) or previous trial outcome ($F(2, 74) = 0.001, p = .998, \eta_p^2 = .00005$). Finally, neither any of the two-way interactions (F 's $< 1.82, p$'s $> .128$) nor the three-way interaction was significant ($F(4, 148) = 0.76, p = .473$; see Table 5).

Table 5

Beta Suppression by Previous Trial Outcome and Block Number

	Consequence Trials						Neutral Trials					
	Win-Win		Win/Loss		Loss-Loss		Win-Win		Win/Loss		Loss-Loss	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Block 1	0.25	0.61	0.26	0.57	0.30	0.56	0.34	0.59	0.31	0.59	0.31	0.59
Block 2	0.35	0.58	0.30	0.58	0.29	0.58	0.36	0.60	0.35	0.60	0.32	0.60
Block 3	0.27	0.61	0.31	0.58	0.31	0.62	0.33	0.56	0.37	0.54	0.35	0.55

The reward positivity.

Finally, a 2 (block: consequence vs. neutral) X 2 (outcome: win vs. loss) repeated-measures ANOVA for the RewP to feedback cues found a main effect of block, $F(1, 39) = 4.78$, $p = .035$, $\eta_p^2 = .11$, such that consequence trials elicited larger RewPs than neutral trials.

However, neither the main effect of outcome ($F(1, 39) = 0.68$, $p = .413$, $\eta_p^2 = .017$) nor the interaction ($F(1, 39) = 0.01$, $p = .906$, $\eta_p^2 = .0003$) was significant (see Figure 4, Figure 5, and Table 6).

Table 6

RewP Amplitude

	Consequence Trials		Neutral Trials	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Win Feedback	5.30	7.28	3.83	5.58
Loss Feedback	4.96	5.97	3.35	5.12

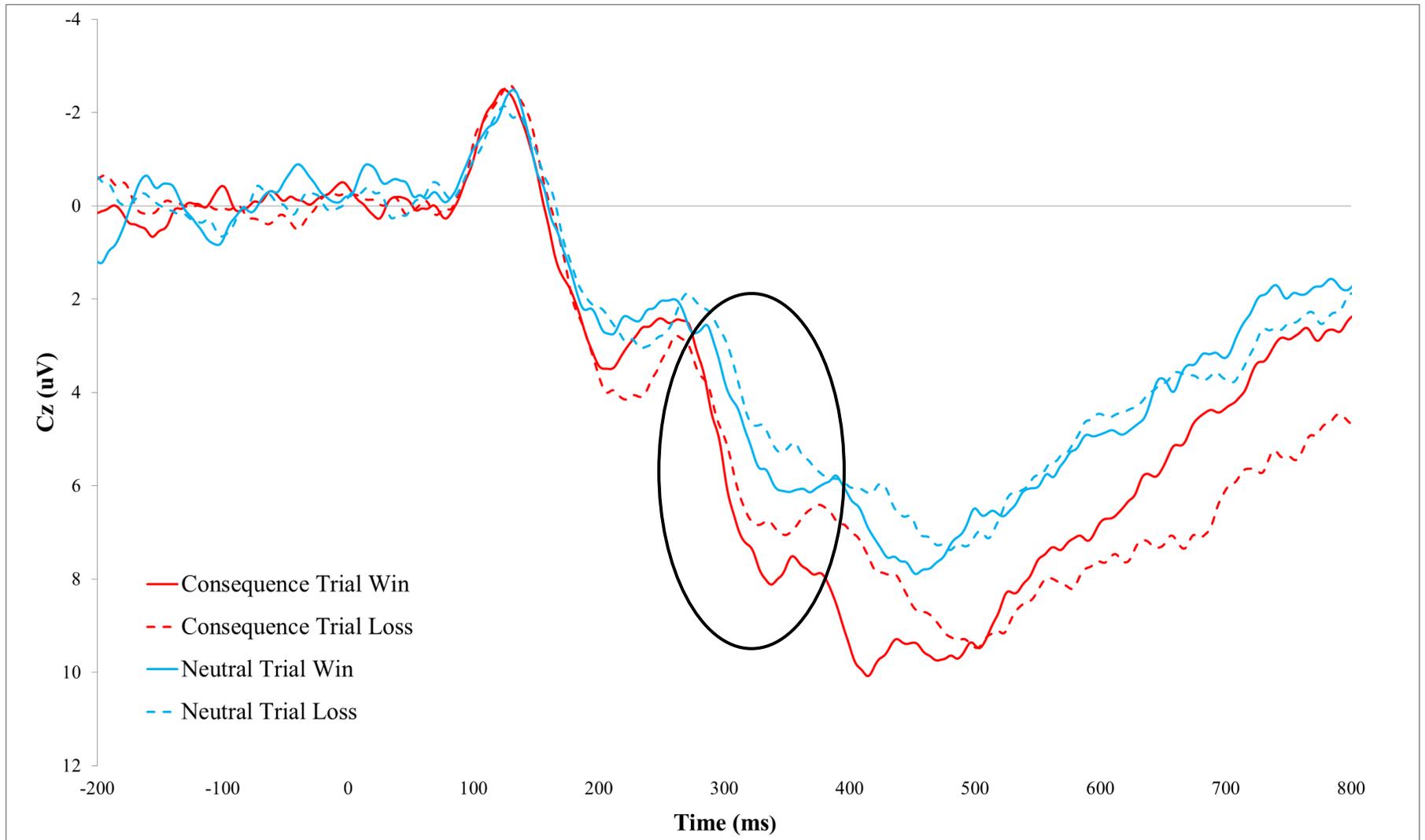


Figure 4. ERP waveforms for win and loss feedback during consequence and neutral trials at site Cz. The RewP is circled.

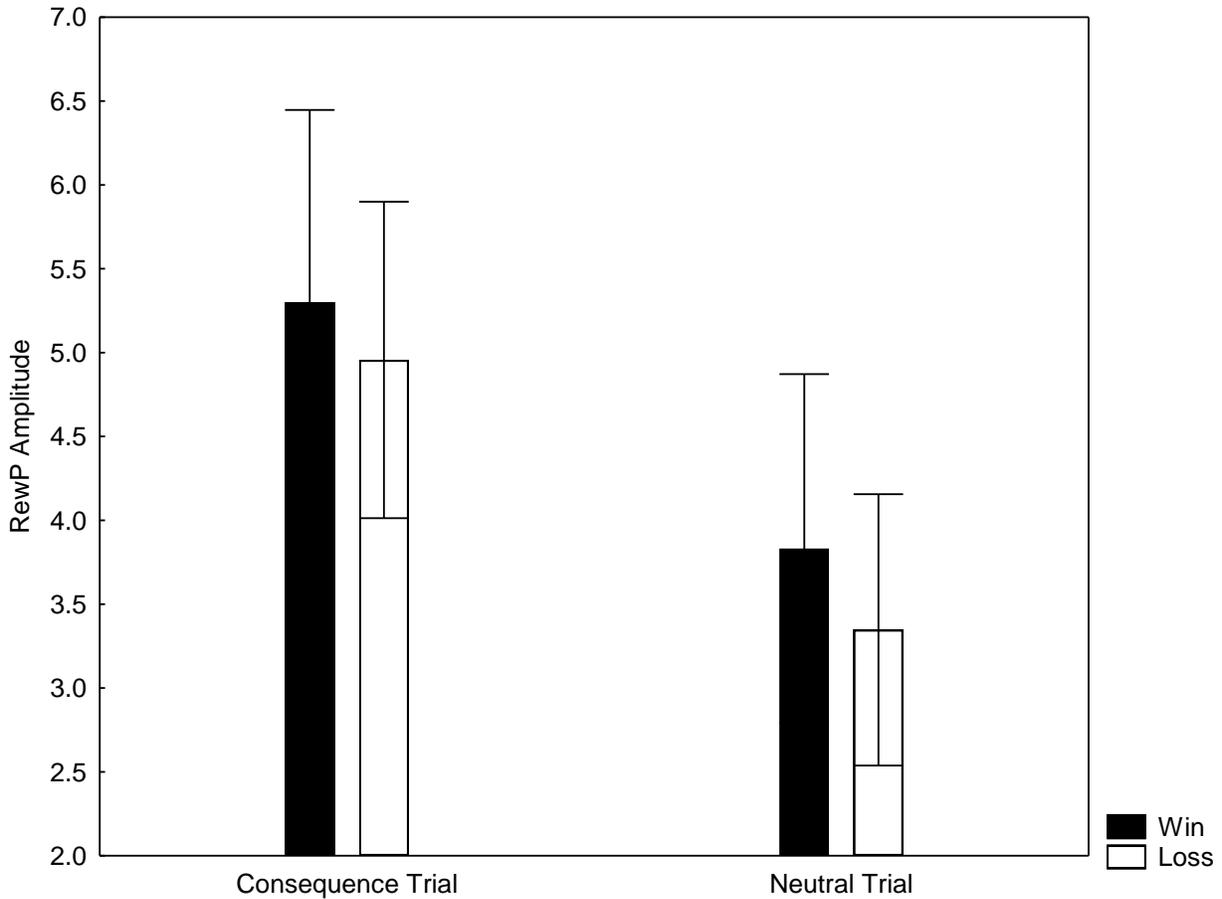


Figure 5. RewP amplitude for the 2 (block: consequence vs. neutral) x 2 (outcome: win vs. loss) interaction. Error bars indicate standard error of the mean.

Experiment 1 Discussion

Experiment 1 revealed that participants experienced more arousal, positive valence, and desire to trial cues during consequence blocks than neutral blocks, suggesting that participants experienced more approach motivation during the pursuit of rewards. This is supplemented by the fact that participants were faster to respond to the flankers task during consequence blocks than neutral blocks. Together with self-reported emotion ratings, these manipulation checks indicate that participants experienced increased approach motivation in consequence blocks than neutral blocks.

Results of Experiment 1 also replicated previous work examining the relationship between approach motivation and beta suppression (Gable et al., 2016; Threadgill & Gable, 2018a). Past work has found that approach-motivated states elicit greater beta suppression than neutral states. The present study found that there was a main effect of block on beta suppression. More specifically, consequence (i.e., approach-motivated) trials elicited significantly more beta suppression than neutral trials. Furthermore, replicating past work (Threadgill & Gable, 2016, 2019b), results indicated that participants were faster to respond to the flankers task during consequence trials than during neutral trials. Together, these results suggest that approach-motivated states enhance both motor-action preparation and goal-directed performance.

Beta suppression during consequence blocks were originally hypothesized to either exhibit less beta suppression during trial cues following two wins or less beta suppression during trial cues following two losses depending on whether individuals were coasting during the goal task when outcomes were going better than expected or individuals were disengaging during the goal task when outcomes were worse than expected. This was not found, but, rather, replicating past research, consequence trials elicited significantly more beta suppression than neutral trials. This may have occurred for two reasons. First, it may be the case that the experimental paradigm was not sensitive enough to detect how beta suppression changes based upon previous outcomes because there was not enough trials with the same outcome in consecutive order to elicit coasting or disengagement effects. In the present study, participants would see no more than three outcomes in a row of the same kind within a block. It may be the case that there was too much variation in previous trial outcomes (constantly changing between winning and losing), and, thus, coasting or disengagement effects were not able to be elicited. Changes in beta suppression possibly only occur when there are a longer string of consecutive win or loss outcomes. For

example, it is possible that individuals may not have remembered the specific outcomes of the two preceding trials, but, instead, only considered whether they believed they were winning more often than not or losing more often than not. However, the current experiment may not have presented enough consecutive wins and losses to examine how beta suppression changes based upon past performance.

A more likely explanation is that it may be the case that beta suppression simply tracks the current task at hand and ignores the outcomes of previous trials when preparing to make a movement. Beta suppression occurs during motor-action preparation (Doyle et al., 2005; McFarland et al., 2000). While beta suppression was clearly sensitive to the motivation of the block (as seen by the difference in beta suppression between consequence and neutral blocks), beta suppression did not appear to exhibit an interaction between motivational state and previous trial outcome. It may be the case that participants were updating what behaviors they should make during the next trial *before* the next trial began. When the trial cue for the current trial appeared, participants focused on the trial at hand without regard for how they had performed on the previous trial. Thus, beta suppression would simply track whether or not participants could win a reward (i.e., motivational state), as indicated by consequence blocks increasing beta suppression during trial cues relative to neutral blocks. This proposition is reinforced by the fact that exploratory analyses examining flankers reaction times based upon the outcomes of the previous two trials does show a coasting effect during consequence blocks. When participants had won the previous two trials in a consequence block, participants were slower to respond to the flankers task on the current trial, as compared to when participants had either won once and lost once in the previous two trials or lost the previous two trials. If beta suppression during current trials tracked previous trial outcomes, it would be expected that fluctuations in beta

activity would mimic that of the goal-directed task. Rather, it appears that beta activity only differentiates between consequence and neutral blocks, suggesting that it does not discriminate between momentary differences between trials. In other words, beta activity was sensitive to the motivational state elicited by the block, but not to the outcome of previous trials within the block. Future research should clarify the relationship between approach motivation, previous performance outcomes, and neurophysiological correlates of motor-action preparation by designing a task that can test these competing hypotheses (such as by incorporating longer sequences of wins and losses within each block).

Although the predicted interaction for the RewP did not occur, results indicated that there was still a main effect of consequence trials eliciting larger RewPs than neutral trials. Past research has found that the RewP appears to be more sensitive during motivated trials than during neutral trials for both wins and losses (Threadgill & Gable, 2016, 2019b), and that wins and losses may not elicit distinct RewPs during motivated trials (Threadgill & Gable, 2019b). Thus, together with previous research, it appears that the RewP is sensitive motivation independent of feedback outcome.

Functionally, increasing motor-action preparation to approach-motivating stimuli may prove adaptive. When organisms decide to pursue approach-motivating stimuli, increasing motor-action preparation assists in obtaining the desired object or goal. The individual is ready to make whatever movements necessary to obtain the goal, increasing the likelihood of actually obtaining the goal. If an individual sees an approach-motivating stimuli and does not increase motor-action preparation while preparing to pursue the desired goal, the likelihood of obtaining that goal drops, because the organism is not able to do the necessary movements quickly and accurately enough to successfully obtain that goal. Furthermore, this is particularly important

when there is competition for the desired goal or object. If other competitors prepare to pursue the goal while the organism themselves does not take the necessary steps to pursue the goal, it is more likely that the rival is able to complete the required steps to obtain the goal more quickly than the organism, which, in turn, prevents the organism from achieving the desired goal.

The current results found that approach motivation increases beta suppression, relative to neutral states. This suggests that differences in approach motivation lead to differences in neural correlates of motor-action preparation. However, at present, it is unclear whether this relationship between approach-motivated affective states and beta suppression during motor-action preparation is bi-directional. In Experiment 2, I sought to extend previous work by addressing a different kind of question: does motor-action preparation (independent of approach motivation) influence emotive responses? That is, do differences in beta suppression, manipulated independently of motivational state, influence neural correlates of emotional responding? Experiment 2 was designed to investigate whether manipulating beta suppression would alter neural responses to appetitive stimuli by examining the relationship between motor-action preparation and emotional responding.

EXPERIMENT 2

It seems likely that increasing motor-action preparation independent of motivational state may also increase neural indices of approach-motivated affect. Research has found that before one decides to make a movement towards a goal, readiness potentials in the motor cortex (which are highly correlated with beta suppression) begin to increase in activity *before* a conscious decision to make a movement towards a goal has occurred (Lau, Rogers, Haggard, & Passingham, 2004; Libet, Gleason, Wright, & Pearl, 1983; Trevena & Miller, 2002). Additionally, Soon, Brass, Heinze, and Haynes (2008) found that activity over the motor cortex could predict spontaneously-decided motor movement approximately 7 to 10 seconds before participants reported which movement they were going to make. These results suggest that unconscious motor-action preparation may actually aid in eliciting decisions to make movement towards a target stimuli or goal. Presumably, the increase in motor-action preparation increases emotional responding that drives behavior to pursue desirable objects or goals. Increasing neural activity related to motor-action preparation independent of motivation may actually increase motivated responding to appetitive stimuli.

Emotional responding will be measured by examining the N1, an ERP component occurring approximately 100 *ms* after the onset of a stimulus (Weinberg & Hajcak, 2010). While not a direct index of emotion, the N1 has been found to increase to motivationally relevant stimuli, such as affective pictures, relative to neutral stimuli (Cuthbert, Schupp, Bradley, McManis, & Lang, 1998; Foti, Hajcak, & Dien, 2009). The N1 is proposed to be associated with motivated attentional capture (Keil et al., 2001) and detailed processing of visual stimuli (Vogel

& Luck, 2000). Accordingly, the N1 is larger to visual probes when they appear in goal-relevant locations, suggesting that the N1 is an indicator of enhanced processing for goal-related actions (Baldauf & Deubel, 2009). Together, this work suggests that the N1 is sensitive to appetitive attentional processing.

Of particular interest is past research that has found that the N1 to appetitive stimuli is modulated by changes in cognition that occur independent of motivational state. More specifically, appetitive pictures following narrowed attentional scope, which has been linked with greater approach motivational intensity (Gable & Harmon-Jones, 2008a; Threadgill & Gable, 2019a), elicit larger N1s than both neutral pictures following narrowed attentional scope and appetitive pictures following broadened attentional scope (Gable & Harmon-Jones, 2011b). This suggests that the N1 is an optimal candidate for examining whether there is a bi-directional relationship between motor-action preparation and emotional responses. Because of this bi-directional relationship between approach motivation and N1 amplitudes, my predictions focus on the N1.

In the present task, beta suppression, a neural index of motor-action preparation, was manipulated by having participants either prepare to make a movement towards a goal-directed performance task (i.e., respond to a flankers task), which should increase beta suppression, or prepare to remember features of the goal-directed performance task (i.e., no response to a flankers task, but still engaged in the task), which should inhibit beta suppression (Androulidakis et al., 2007).

In my paradigm, participants were instructed to either prepare to make a movement towards a goal-directed task or to remember features of the goal-directed task for a memory task at the end of the trial. As they prepared to make a movement towards a goal-directed task or to

remember features of the goal-directed task, an approach-motivated positive or neutral picture appeared. Participants then made their response to the goal-directed task (or remembered features of the goal-directed task). I predicted that greater motor-action preparation, manipulated independently of motivational state, would enhance emotional responding to appetitive pictures. More precisely, it was predicted that a motor-action preparation manipulation, in which participants would prepare to make a movement would cause greater N1 responses to appetitive pictures than a steady-state manipulation, in which participants would hold a tonic position.

Methods

Fifty-one introductory psychology students will participate in exchange for partial course credit.

Similar to Experiment 1, participants first completed personality questionnaires.⁴ Then, EEG electrodes were applied. To become comfortable with the equipment, participants then completed eight minutes of baseline recording. Finally, participants participated in a reaction time paradigm, where they had the ability to win points that can be exchanged for candy through a series of trials by either responding quickly and accurately or by remembering a stimuli. Twelve practice trials were included at the beginning of the game. ITI was 1500 *ms*.

Each trial ($n = 96$; see Figures 6A and 6B for example trials and stimuli timing) began with a trial cue, indicating how participants would respond to the goal-related flanker task. Trials beginning with a white circle indicated that participants should respond quickly and accurately to a performance task as soon as it appeared on the screen (movement trials). In contrast, trials beginning with a white square indicated that participants should not respond to the performance task when it appears on the screen, but, rather, should remember what the performance task was

⁴ Similar to Experiment 1, there were no specific hypotheses including the questionnaires, but included them for secondary analyses at a later time.

(memory trials). On these trials, participants were instructed to keep both hands on the response pad, but they were not to make a movement when the performance task appeared on the screen. To emphasize the importance of staying still on memory trials, EMG electrodes were placed on the arm, so that participants would believe that any muscle movement during memory trials could be detected.

Half of the trials were movement trials, and half of the trials were memory trials. Trials were presented in 4 blocks of 24 trials. Block presentation was structured so that each block would contain the same number of trial type, and the same trial type was not presented more than three times in a row. To reduce EEG artifact, participants were instructed to watch each picture for the entire time it was displayed.

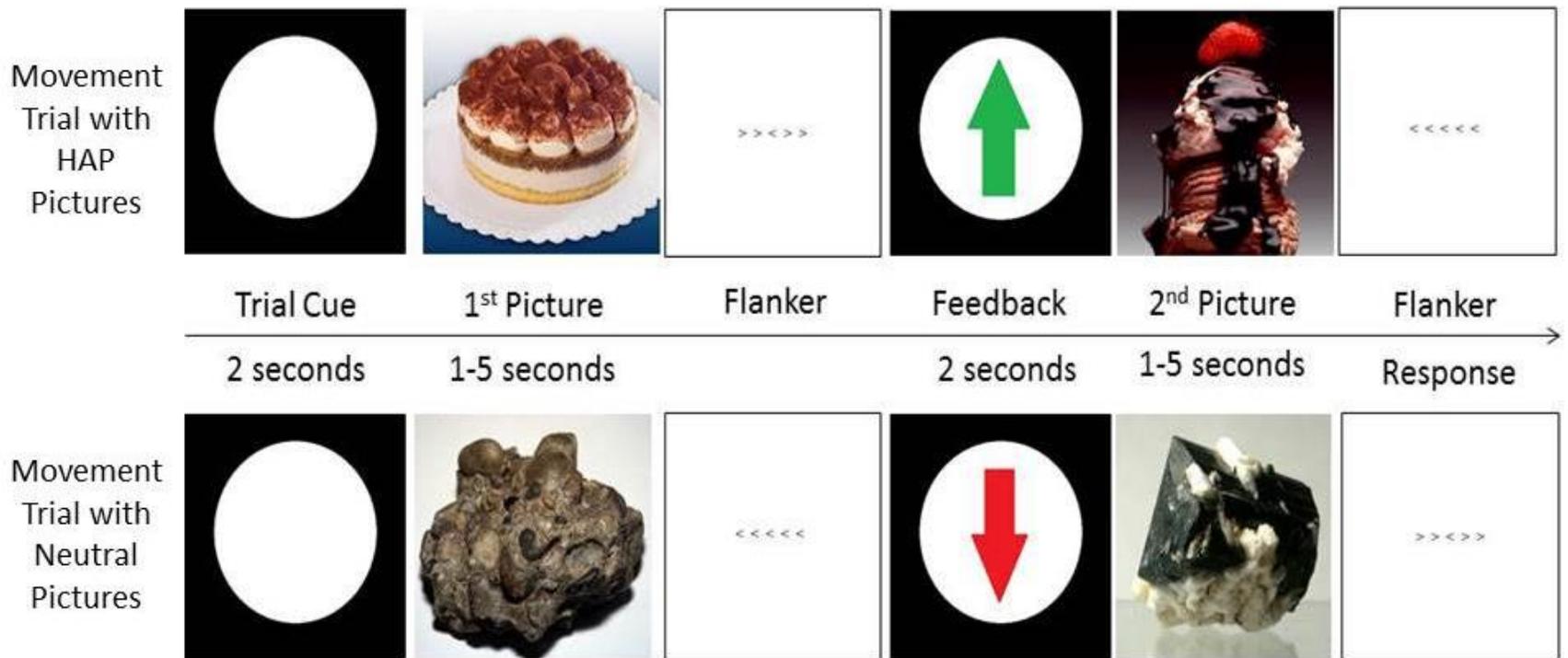


Figure 6A. Experiment 2 example movement trial. The ITI was 1500 ms.

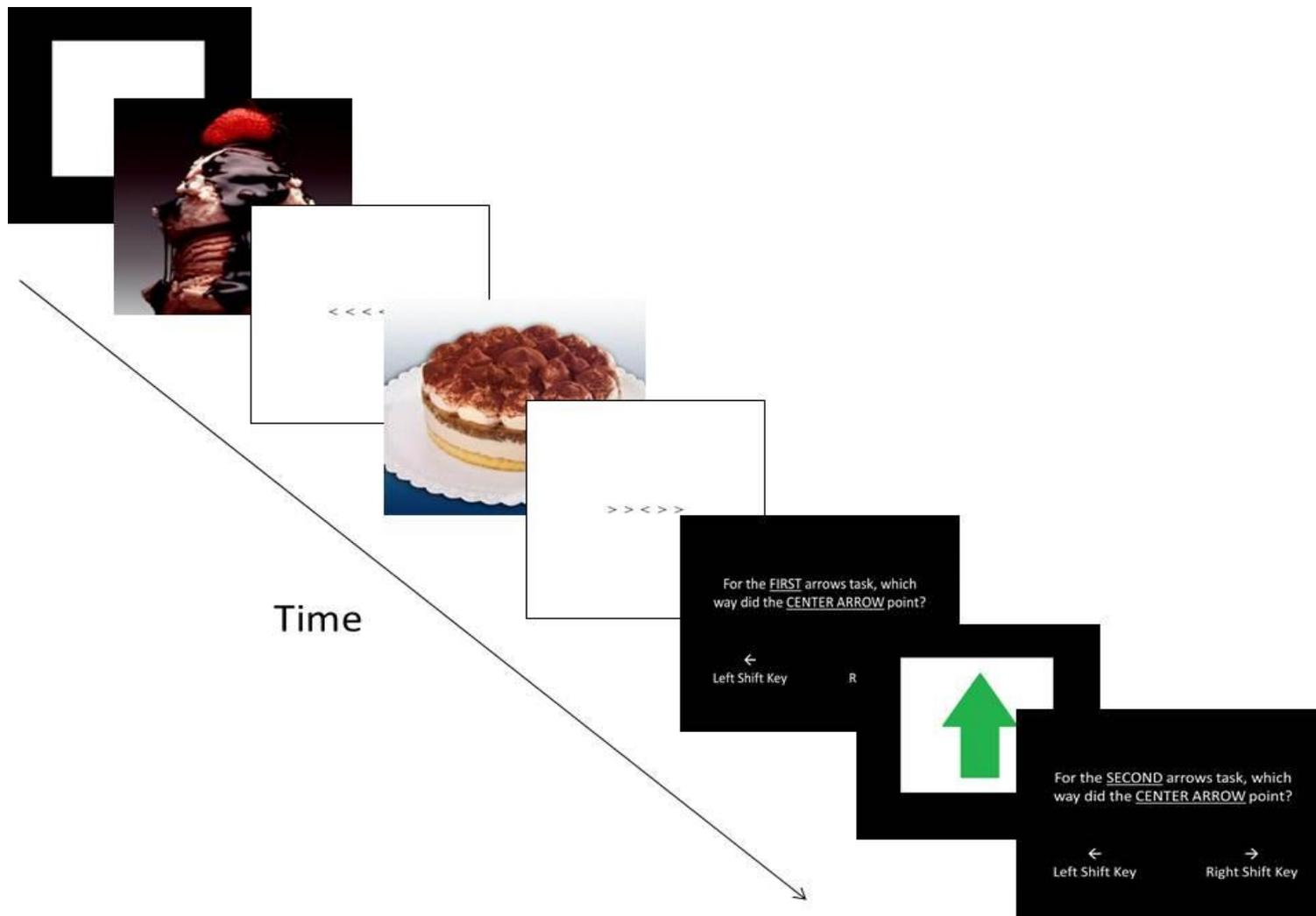


Figure 6B. Experiment 2 example memory trial. Stimuli timing is similar to movement trials (with the exception of pictures, which were each displayed for 3 s). For memory trials with neutral pictures, a neutral picture replaced both of the appetitive pictures presented above. For the memory task at the end of the trial, the stimuli appeared on the screen until the participant responded. The ITI was 1500 ms.

Following the trial cue, participants then viewed the first affective picture of the trial. The picture was either an appetitive or a neutral picture ($n = 48$ for each picture type). Twenty-four pictures of each picture type appeared in both movement trials and memory trials. Appetitive pictures consisted of images of delicious desserts, which have been used in previous research to evoke approach-motivated positive affect (Gable & Harmon-Jones, 2008a, 2008b; Poole & Gable, 2014; Threadgill & Gable, 2019c). Neutral pictures consisted of rock images used in the same research and have been matched on size, shape, and color to the dessert pictures. Importantly, during movement trials, participants were told that each picture would be displayed for between one and five seconds, after which the first performance task appeared. This was done so that participants would be prepared to move through the entirety of the picture presentation. However, during memory trials, participants were told that each picture would be displayed for three seconds, after which the first memory task would appear. This was done so that participants would be able to hold a tonic steady state throughout the entirety of the picture viewing portion of the task.

After picture viewing, participants saw the first performance task, which was a flankers task (Eriksen & Eriksen, 1974). In movement trials, participants were instructed to respond as quickly and accurately as possible as soon as the flankers task appeared on the screen. In memory trials, participants were instructed to remember which direction the center arrow was pointing for a memory test that would occur at the end of the trial.

Participants were told that, across all conditions, successfully responding would reward the participant points. For movement trials, participants were told that rewards were ostensibly based on whether the participant beat the average reaction time from the previous semester on the trial. For memory trials, participants were told that rewards were based on whether the

participant was able to correctly indicate which direction the center arrow pointed during the memory test at the end of the trial. Within each condition, there were an equal number of left and right flankers ($n = 24$ for each combination of trial type and picture type).

Then, for movement trials, a feedback cue appeared indicating whether the participant did or did not gain points on the trial. The amount of points won were presented in a circle (10 points for successful performance, 0 points for unsuccessful performance). Half of the trials resulted in successful performance feedback, and half of the trials resulted in unsuccessful performance feedback. Memory trials did not have feedback at this time, but, rather, would simply proceed to the second picture in the trial.

After viewing the feedback (movement trials) or the first flankers task (memory trials), participants then saw a second picture. Similar to the first picture, the picture was either an appetitive or a neutral picture ($n = 48$ for each picture type). Twenty-four pictures of each picture type appeared in both movement trials and memory trials. Again, participants were told that each picture would be displayed for between one and five seconds, after which the second performance task appeared.

Next, participants then saw the second performance task, which, again, was another flanker task. In movement trials, participants were instructed to respond quickly and accurately as possible as soon as the flankers task appeared on the screen. In memory trials, participants were instructed to remember which direction the center arrow was pointing for a memory test that would occur at the end of the trial. Again, within each condition, there were an equal number of left and right flankers ($n = 24$ for each combination of trial type and picture type).

In movement trials, after the second performance task, participants proceeded to the next trial. However, in memory trials, participants then partook in a memory test. First, participants

indicated which direction the center arrow was pointing for the *first* flankers response. Then, a feedback cue appeared, indicating whether the participant did or did not gain points on the trial. The amount of points won were presented in a square (10 points for successful performance, 0 points for unsuccessful performance). Half of the trials resulted in successful performance feedback, and half of the trials resulted in unsuccessful performance feedback. Finally, participants then indicated which direction the center arrow was pointing for the *second* flankers response. Participants then proceed to the next trial.

After all trials, participants viewed each appetitive and neutral picture for three seconds each, indicating how much approach motivation (1 = *none*, 9 = *strongest feeling*), pleasure (1 = *none*, 9 = *strongest feeling*) and arousal (1 = *none*, 9 = *exciting*) each picture made them feel using Bradley & Lang's (1994) Self-Assessment Manikin by pressing numbers on a computer keyboard. Additionally, participants rated how much they felt the following emotions during picture viewing: sad, desire, nervous, enthusiastic, happy, excited, angry, down, mad, and anxious (1 = *no emotion*, 9 = *strongest feeling*; Ekman et al., 1980).

EEG Assessment and Processing

EEG was recorded from 64 tin electrodes mounted in a stretch lycra Quick-Cap (Electro-Cap, Eaton, OH) and referenced online to the left earlobe. A ground electrode was mounted midway between FPz and Pz. The electrode cap was based on the 10-20 system, and a sodium chloride-based conductance gel was used to assist in the decrease of impedances. Electrode impedances were kept under 5000 Ω . Signals were amplified with a Neuroscan SynAmps RT amplifier unit (El Paso, TX).

BrainVision Analyzer (Brain Products) were used for offline analysis. Data were rereferenced to the mastoid average. Data were then low-pass filtered at 100 Hz, high-pass

filtered at 0.05 Hz, and notch filtered at 60 Hz using Butterworth zero phase filters and digitized at 500 Hz. Then, a regression-based eye movement correction was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986). Individual channels were then rejected using an automated procedure, with artifacts defined as a 200 μ V change within a 160-ms interval and signals exceeding ± 180 μ V, after which data were visually inspected again to insure proper correction.

The N1

To measure the N1 for the first picture presented in each trial, data were epoched from 200 *ms* before picture presentation to 1000 *ms* after picture onset. Aggregated waveforms were created during picture viewing for both appetitive and neutral pictures following movement and memory trial cues. Based upon visual inspection, the N1 was measured as the average amplitude within a window of 60-180 *ms* after picture onset (Gable & Harmon-Jones, 2012; Ryerson, Neal, & Gable, 2017).⁵ Finally, an index of midline sites FZ, FCZ, and CZ was created, as the N1 was maximal at those sites (Foti et al., 2009; Ryerson et al., 2017).

Beta Suppression

During the trial cues, epochs 1024 ms in duration were extracted through a Hamming window. Consecutive epochs were overlapped by 50% to avoid data loss. Next, power values corresponding to beta (13-30 Hz) were extracted using a Fast Fourier Transformation and log-transformed. Data were then averaged across regions of the head at sites corresponding with the motor cortex (McFarland et al., 2000; Pfurtscheller et al., 2005). Specifically, beta suppression was examined at sites C1-C6 and CP1-CP6.

Hypotheses and Proposed Analyses

The primary dependent variables in Experiment 2 were the N1 to pictures and beta suppression to trial cues. A 2 (trial type: movement vs. memory) X 2 (picture type: appetitive vs.

⁵ Note that stating that N1s are “larger” means that they are more *negative*.

neutral) repeated-measures ANOVA was used. A significant interaction was hypothesized, with the largest N1s during appetitive pictures during movement trials. Additionally, to make sure that participants were exhibiting greater motor-action preparation during movement trials than memory trials, using a dependent-sample t-test, it was predicted that movement cues would elicit greater beta suppression than memory cues.

Emotion ratings to pictures were used as manipulation checks. Using dependent-sample t-tests, it was predicted that appetitive pictures would elicit more positive valence, arousal, and desire than neutral pictures.

Results

All outliers (i.e., more than three standard deviations from the mean) were removed.

Picture ratings.

First, a dependent-sample *t*-test indicated that appetitive pictures were rated as more positive ($t(50) = 8.06, p < .001, d = 1.11$), arousing ($t(50) = 7.93, p < .001, d = 1.10$), and desirable ($t(50) = 8.66, p < .001, d = 1.18$) than neutral pictures (see Table 7 for means and standard deviations).

Table 7

Picture Ratings

	Appetitive Pictures		Neutral Pictures	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Valence	3.92	1.59	2.49	1.02
Arousal	3.68	1.64	2.17	0.98
Desire	3.82	1.64	2.08	0.96

Beta suppression.

As a second manipulation check, a dependent-samples t-test revealed that movement trials ($M = 1.02, SD = 0.59$) elicited greater beta suppression than memory trials ($M = 1.15, SD =$

0.70), $t(47) = -2.13$, $p = .038$, $d = 0.32$, suggesting that movement trials successfully manipulated beta suppression independent of motivational state.

N1 amplitudes.

A 2 (trial type: movement vs. memory) X 2 (picture type: appetitive vs. neutral) repeated-measures ANOVA measuring fronto-central N1 amplitudes revealed a main effect for both trial type ($F(1, 44) = 4.14$, $p = .048$, $\eta_p^2 = .09$) and picture type ($F(1, 44) = 8.56$, $p = .005$, $\eta_p^2 = .16$). Importantly, the interaction was significant, $F(1, 44) = 4.33$, $p = .043$, $\eta_p^2 = .09$ (see Figure 7 and Table 8).

Table 8

N1 Amplitudes

	Movement Trials		Memory Trials	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Appetitive Pictures	-7.03	9.50	-3.05	7.60
Neutral Pictures	-3.73	7.71	-2.89	5.99

Post-hoc analyses using Fisher’s LSD indicated that N1 amplitudes to appetitive pictures during movement trials were larger than both N1 amplitudes to neutral pictures during movement trials ($p < .001$) and N1 amplitudes to appetitive pictures during memory trials ($p = .003$). However, there was no difference between either N1 amplitudes to neutral pictures during movement trials and N1 pictures to neutral pictures during memory trials ($p = .885$) or N1 amplitudes to appetitive pictures during memory trials and N1 pictures to neutral pictures during memory trials ($p = .441$). These results suggest the influence of movement preparation on beta suppression enhanced motivated attentional responding appetitive pictures alone.

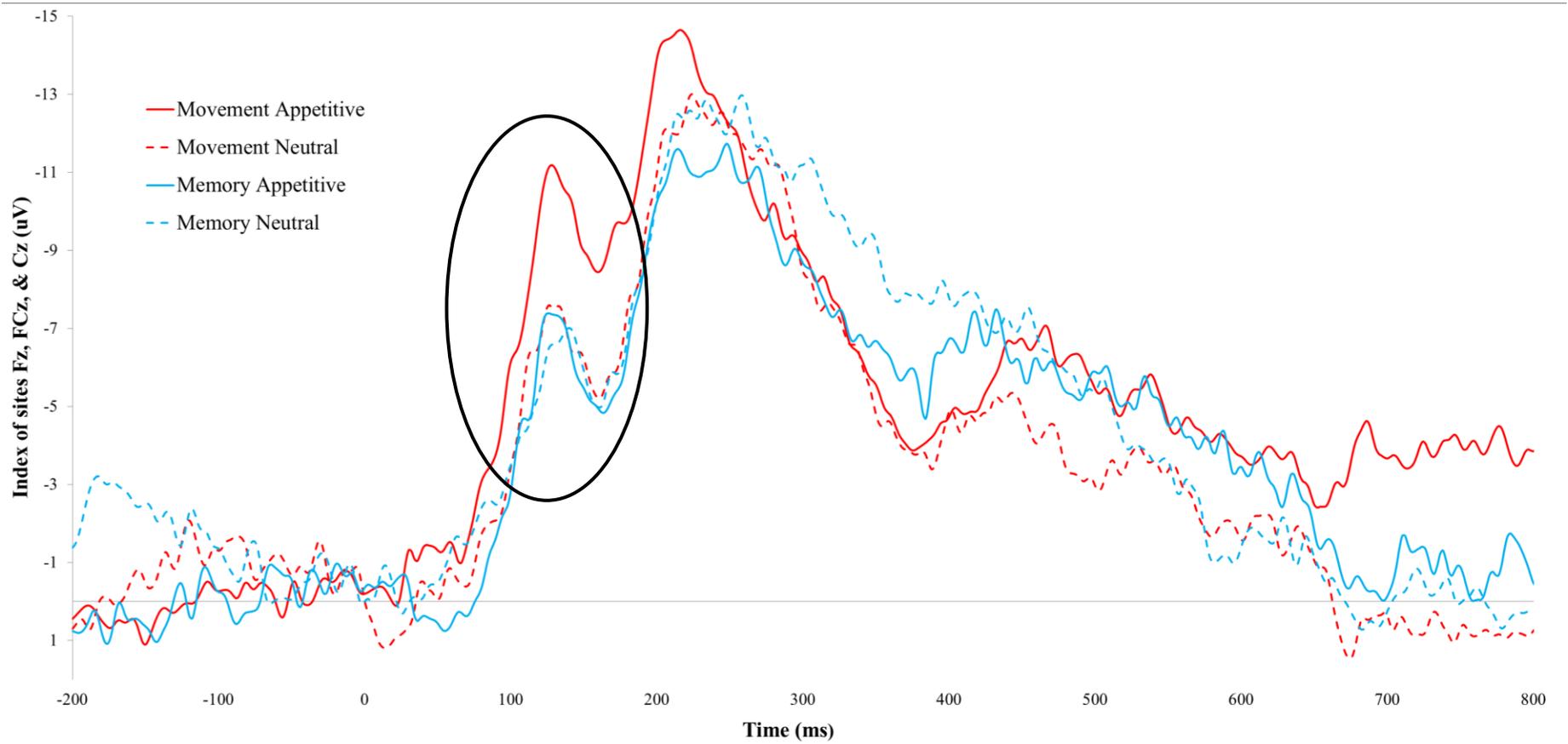


Figure 7. ERP waveforms for appetitive and neutral pictures during movement and memory trials at an index of sites Fz, FCz, and Cz. The N1 is circled.

Experiment 2 Discussion

The purpose of Experiment 2 was to investigate the bi-directional relationship between motor-action preparation and emotional responding. Experiment 2 revealed that participants experienced more arousal, positive valence, and desire during appetitive pictures than neutral pictures, suggesting that participants experienced more approach-motivated affect during appetitive pictures than neutral pictures. Additionally, movement trial cues elicited more beta suppression than memory trial cues, suggesting that motor-action preparation, independent of motivation, was successfully manipulated. Together, these manipulation checks indicate that the task successfully manipulated motor-action preparation and emotional states as intended.

The present experiment found that manipulating motor-action preparation, independent of motivational state, increased rapid motivated attentional processing of appetitive pictures. This is seen by increased N1 amplitudes to appetitive pictures during movement trials, as opposed to appetitive pictures during memory trials or neutral pictures during movement trials. Furthermore, there was no difference in N1 amplitude between appetitive pictures during memory trials and neutral pictures during memory trials. Together, this suggests that increasing neural activity associated with motor-action preparation increases emotional responding to approach-motivated stimuli.

Increases in motor-action preparation should lead to increases in emotional responding to appetitive stimuli. Individuals who have heightened levels of motor-action preparation are more likely to commit more errors in a go/no-go task (Alegre et al., 2006; Zhang et al., 2008). While typically interpreted as showing deficits in control, these results also suggest that individuals who have increases in motor-action preparation are faster to respond to salient stimuli (Jenkinson & Brown, 2011). When an appetitive stimuli appears while experiencing heightened levels of

motor-action preparation, it may be the case that individuals would be more sensitive to that emotional stimuli. Functionally, it would be beneficial for individuals to have greater levels of motor-action preparation when appetitive stimuli appear. When individuals have greater levels of motor-action preparation, they are more vigilant to what is around them. When an appetitive stimulus that the organism desires appears, the organism is in a state in which they could more quickly pursue and obtain the desired goal. By already being prepared to make a general movement, organisms can quickly adapt to the task at hand and increase the likelihood of obtaining the desired goal or object. Increasing motor-action preparation before viewing an object with motivational relevance likely enhances the desirability of the object, since the organism may believe that they would expend less energy, given that the organism is already prepared to pursue the goal or object, as opposed to having to both prepare to pursue the goal and actually pursue the goal.

GENERAL DISCUSSION

In Experiment 1, I examined how performance feedback on previous trials influenced neural correlates of motor-action preparation by creating a reward paradigm in which participants would win and lose multiple trials in a row. Participants reported experiencing increases in positive affect, arousal, and desire during consequence blocks as compared to neutral blocks. Additionally, participants indicated increases in positive affect, arousal, and desire during consequence block wins than consequence block losses and neutral block wins. Finally, participants were faster to respond to the flankers task during consequence blocks than during neutral blocks. Together, these results suggest that approach-motivation was increased during consequence blocks as compared to neutral blocks. However, Experiment 1 did not elicit the hypothesized coasting or disengagement effects when examining neural correlates of motor-action preparation. Nevertheless, replicating past work, consequence blocks did exhibit greater beta suppression during trial cues than trial cues during neutral blocks. This relationship is consistent with past work suggesting that increases both trait and state approach motivation increases neural activity associated with motor-action preparation (Meadows et al., 2016b; Threadgill & Gable, 2018a, 2019c; Gable et al., 2016). As approach motivation increases, beta suppression increases, suggesting that approach motivational responding increases motor-action preparation.

Building on the results of Experiment 1, Experiment 2 was conducted to examine whether there was a bi-directional relationship between neural correlates of motor-action preparation and approach-motivated emotion. More specifically, Experiment 2 sought to

examine whether increasing motor-action preparation, independent of motivational state, would elicit increased emotional responding sensitivity. Using a novel modified monetary incentive delay paradigm, participants were required to complete a goal task by either making a movement toward a goal or indicating characteristics of the target stimulus in a memory task. While preparing to make a movement or preparing for the target stimulus, affective and neutral pictures were shown to measure emotional responding. Replicating past work, results indicated that participants experienced increased motor-action preparation during movement trials as compared to memory trials (as indicated by greater beta suppression during trial cues in movement trials than in memory trials). Additionally, results indicated that appetitive pictures elicit more positive valence, arousal, and desire than neutral pictures, suggesting that the appetitive stimuli were viewed as approach-motivating. The main hypothesis, which was that greater motor-action preparation would lead to greater emotional responding sensitivity, was confirmed. More specifically, appetitive pictures during movement trials elicited larger N1 amplitudes than both neutral pictures during movement trials and, most importantly, appetitive pictures during memory trials. Together, these results suggest that the increasing neural correlates of motor-action preparation independent of motivation increases neural correlates of rapid motivated attentional processing of appetitive stimuli.

The present work builds upon past work examining beta suppression in three ways. First, replicating past work, motor-action preparation enhances beta suppression (Pfurtscheller et al., 1996; Sanes & Donoghue, 1993). This is important because movement towards a goal requires motor planning. Without motor planning, an organism is less likely to successfully complete some action. Experiment 2 found that increasing motor-action preparation, independently of motivational state, increases beta suppression. Because the paradigm elicited similar levels of

motivation across both trial types (i.e., movement and memory trials) by asking participants to successfully respond to a motor or memory task, this held motivation constant across both trial cues. However, results indicated that movement trials elicited greater levels of beta suppression than neutral trials. Thus, the present work provides further evidence that increasing motor-action preparation causes greater levels of beta suppression over the motor cortex.

Second, past work has found that increases in state (Gable et al., 2016; Threadgill & Gable, 2019d) and trait (Threadgill & Gable, 2018a) approach motivation is related to increases in beta suppression over the motor cortex. This likely occurs because appetitive approach-motivated states occur during the pursuit of a goal, including when an individual is preparing to act upon some goal. Objects of goal pursuit have high value (Mirabella, 2014). Presumably, objects of value would elicit strong levels of approach motivation as the organism pursues the object, which should generate robust neurophysiological signals related to goal pursuit processes. Replicating past work, the results of Experiment 1 found that consequence trials (i.e., approach-motivated trials) increased beta suppression relative to neutral trials. Therefore, the present work provides further evidence that approach motivation enhances beta suppression.

Third (and most importantly), the present experiments demonstrate that the relationship between beta suppression and approach motivation is bi-directional. While past work has found that increasing levels of approach motivation leads to increases in beta suppression (Experiment 1; Meadows et al., 2016b), the present work found that increasing beta suppression independently of motivational state leads to increases in emotional responding sensitivity (Experiment 2). This makes sense given that previous research has shown that activity in the motor cortex begins before conscious decisions have been made to make movements towards a goal (Libet et al., 1983; Soon et al., 2008). It may be the case that unconscious motor-action

preparation aids in eliciting decisions to make movements towards a target stimulus. From this, it seems that participants exhibited greater emotional responding to appetitive pictures because they were more ready to actually be able to pursue that object (if the object were to actually present itself). By increasing motor-action preparation, participants narrowed their focus to the task at hand and were more acute to motivationally-relevant stimuli, and, therefore, displayed increased levels of emotional responding sensitivity.

Functionally, it makes sense that there would be a bi-directional relationship between motor-action preparation and approach-motivated affects. Increases in approach motivation should lead to increases in motor-action preparation during goal pursuit. This should occur because approach-motivated states generate action tendencies within organisms to pursue some reward (Kaplan et al., 2012; Larsen & Steuer, 2009). If an individual is not motivated to pursue a reward, then he or she is unlikely to begin cognitive processes that would increase the likelihood of attaining that reward. Greater motor-action preparation represents a preparatory state in which the organism is ready to pursue some goal or object. It seems that, without motivation to approach some object, organisms would have no reason to prepare to make a movement; however, when someone sees a desirable object, he or she begins to devise an action plan that would bring about successfully attaining that goal. Thus, increasing levels of approach motivation should elicit greater motor-action preparation.

Conversely, increasing motor-action preparation independently of motivational state should lead to increases in approach-motivated responding. This likely occurs because motivational and cognitive (such as motor-action preparation) are connected via functional loops between the prefrontal cortex, basal ganglia, and motor cortex (Gray, 2001; Gray, Braver, & Raichle, 2002; Peterson, Shackman, & Harmon-Jones, 2008). Functionally, increasing motor-

action preparation may enhance attention toward desirable goals. By increasing general readiness, individuals may be more prepared for deliberative motivated action towards a goal (Threadgill & Gable, 2018a, 2019c). When a goal arises, the individual is better prepared to make a movement towards that goal (since they are already equipped to make a movement, increasing the likelihood of successfully attaining that goal (Davidson, 2004). By increasing motor activity preparedness, individuals are better able to zero-in on appetitive objects and pursue them more quickly and efficiently. Thus, increased levels of motor-action preparation should promote acute responding to appetitive stimuli.

Much of human behavior is predicated on the motivation to act. Inherent within this motivation is motor-action preparation while one is preparing to move towards some goal. The current studies indicate that motor-action preparation and approach motivation have a bi-directional relationship: approach motivation causes increases in motor-action preparation (Experiment 1; Gable et al., 2016), and motor-action preparation causes increases in approach motivation (Experiment 2). These results indicate that emotion and movement are not merely related, but are enhanced by this bi-directional relationship.

REFERENCES

- Abramson, L. Y., Seligman, M. E. P., & Teasdale, J. D. (1978). Learned helplessness in humans: Critique and reformulation. *Journal of Abnormal Psychology, 87*(1), 49-74.
- Alegre, M., Imirizaldu, L., Valencia, M., Iriarte, J., Arcocha, J., & Artieda, J. (2006). Alpha and beta changes in cortical oscillatory activity in a go/no-go randomly-delayed-response choice reaction time paradigm. *Clinical Neurophysiology, 117*(1), 16-25.
- Androulidakis, A. G., Doyle, L. M. F., Yarrow, K., Litvak, V., Gilbertson, T. P., & Brown, P. (2007). Anticipatory changes in beta synchrony in the human corticospinal system and associated improvements in task performance. *European Journal of Neuroscience, 25*(12), 3758-3765.
- Angus, D. J., Kemkes, K., Schutter, D. J., & Harmon-Jones, E. (2015). Anger is associated with reward-related electrocortical activity: Evidence from the reward positivity. *Psychophysiology, 52*(10), 1271-1280.
- Angus, D. J., Latham, A. J., Harmon-Jones, E., Deliano, M., Balleine, B., & Braddon-Mitchell, D. (2017). Electrocortical components of anticipation and consumption in a monetary incentive delay task. *Psychophysiology, 54*(11), 1686-1705.
- Bauldauf, D., & Deubel, H. (2009). Attentional selection of multiple goal positions before rapid hand movement sequences: An event-related potential study. *Journal of Cognitive Neuroscience, 29*(1), 18-29.
- Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The Self-Assessment Manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49-59.
- Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106-113.
- Bress, J. N., & Hajcak, G. (2013). Self-report and behavioral measures of reward sensitivity predict the feedback negativity. *Psychophysiology, 50*(7), 610-616.
- Carver, C. S. (2003). Pleasure as a sign you can attend to something else: Placing positive feelings within a general model of affect. *Cognition & Emotion, 17*(2), 241-261.
- Carver, C. S., & Scheier, M. F. (1998). *On the self-regulation of behavior*. New York: Cambridge University Press.

- Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS Scales. *Journal of Personality and Social Psychology*, *67*(2), 319-333.
- Chiel, H. J., & Beer, R. D. (1997). The brain has a body: Adaptive behavior emerges from interaction of nervous system, body and environment. *Trends in Neurosciences*, *20*(12), 553-557.
- Cuthbert, B. N., Schupp, H. T., Bradley, M., McManis, M., & Lang, P. J. (1998). Probing affective pictures: Attended startle and tone probes. *Psychophysiology*, *35*, 344-347.
- Davidson, R. J. (2004). What does the prefrontal cortex “do” in affect: Perspectives on frontal EEG asymmetry research. *Biological Psychology*, *67*(1-2), 219-234.
- Doyle, L. M. F., Yarrow, K., & Brown, P. (2005). Lateralization of event-related beta desynchronization in the EEG during pre-cued reaction time tasks. *Clinical Neurophysiology*, *116*(8), 1879-1888.
- Ekman, P., Friesen, W. V., & Ancoli, S. (1980). Facial signs of emotional experience. *Journal of Personality and Social Psychology*, *39*(6), 1124-1134.
- Elliot, A. J. (1999). Approach and avoidance motivation and achievement goals. *Educational Psychologist*, *34*(3), 169-189.
- Eriksen, B. A., & Eriksen, 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.
- Foti, D., Hajcak, G., & Dien, J. (2009). Differentiating neural responses to emotional pictures: Evidence from temporal-spatial PCA. *Psychophysiology*, *46*(3), 521-530.
- Foti, D., Weinberg, A., Dien, J., & Hajcak, G. (2011). Event-related potential activity in the basal ganglia differentiates rewards from nonrewards: Temporospatial principal components analysis and source localization of the feedback negativity. *Human Brain Mapping*, *32*(12), 2207-2216.
- Frijda, N. H. (1994). Emotions are functional, most of the time. In P. Ekman & R. J. Davidson (Eds.), *The nature of emotion: Fundamental questions* (pp. 112-126). New York: Oxford University Press.
- Gable, P. A., & Harmon-Jones, E. (2008a). Approach-motivated positive affect reduces breadth of attention. *Psychological Science*, *19*(5), 476-482.
- Gable, P. A., & Harmon-Jones, E. (2008b). Relative left frontal activation to appetitive stimuli: Considering the role of individual differences. *Psychophysiology*, *45*(2), 275-278.

- Gable, P. A., & Harmon-Jones, E. (2010a). The effect of low vs. high approach-motivated positive affect on memory for peripherally vs. centrally presented information. *Emotion, 10*(4), 599-603.
- Gable, P. A., & Harmon-Jones, E. (2010b). The motivational dimensional model of affect: Implications for breadth of attention, memory, and cognitive categorization. *Cognition and Emotion, 24*(2), 322-337.
- Gable, P. A., & Harmon-Jones, E. (2011a). Attentional consequences of pre-goal and post-goal positive affects. *Emotion, 11*(6), 1358-1367.
- Gable, P. A., & Harmon-Jones, E. (2011b). Attentional states influence early neural response associated with motivational processes: Local vs. global attentional scope and N1 amplitude to appetitive stimuli. *Biological Psychology, 87*(2), 303-305.
- Gable, P. A., & Harmon-Jones, E. (2012). Trait behavioral approach sensitivity (BAS) relates to early (<150 ms) electrocortical responses to appetitive stimuli. *Social, Cognitive, and Affective Neuroscience, 8*(7), 795-798.
- Gable, P. A., & Harmon-Jones, E. (2016). Assessing the Motivational Dimensional Model of emotion-cognition interaction: Comment on Domachowska, Heitmann, Deutsch et al., (2016). *Journal of Experimental Social Psychology, 67*, 57-59.
- Gable, P. A., Hart, W., Threadgill, A. H., & Adams, D. L. (2019). *High approach-motivated positive affect enhances goal performance*. Manuscript in preparation.
- Gable, P. A., Neal, L. B., & Threadgill, A. H. (2018). Regulatory behavior and frontal activity: Considering the role of revised-BIS in relative right frontal asymmetry. *Psychophysiology, 55*(1), e12910.
- Gable, P. A., Threadgill, A. H., & Adams, D. L. (2016). Neural activity underlying motor-action preparation and cognitive narrowing in approach-motivated goal states. *Cognitive, Affective, and Behavioral Neuroscience, 16*(1), 145-152.
- Gehring, W. J., & Willoughby, A. R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science, 295*(5563), 2279-2282.
- Gray, J. R. (2001). Emotional modulation of cognitive control: Approach-withdrawal states double-dissociate spatial from verbal two-back task performance. *Journal of Experimental Psychology: General, 130*, 436-452.
- Gray, J. R., Braver, T. S., & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceedings of the National Academy of Sciences USA, 99*, 4115-4120.

- Harmon-Jones, E., Harmon-Jones, C., Fearn, M., Sigelman, J. D., & Johnson, P. (2008). Action orientation, relative left frontal cortical activation, and spreading of alternatives: A test of the action-based model of dissonance. *Journal of Personality and Social Psychology, 94*, 1-15.
- Holroyd, C. B., Hajcak, G., & Larsen, J. T. (2006). The good, the bad and the neutral: Electrophysiological responses to feedback stimuli. *Brain Research, 1105*(1), 93-101.
- Holroyd, C. B., & Krigolson, O. E. (2007). Reward prediction error signals associated with a modified time estimation task. *Psychophysiology, 44*, 913-917.
- Jenkinson, N., & Brown, P. (2011). New insights into the relationship between dopamine, beta oscillations and motor function. *Trends in Neurosciences, 34*(12), 611-618.
- Kaplan, R. L., Van Damme, I., & Levine, L. J. (2012). Motivation matters: Differing effects of pre-goal and post-goal emotions on attention and memory. *Frontiers in Psychology, 3*, 404.
- Keil, A., Müller, M. M., Gruber, T., Wienbruch, C., Stolarova, M., & Elbert, T. (2001). Effects of emotional arousal in the cerebral hemispheres: A study of oscillatory brain activity and event-related potentials. *Clinical Neurophysiology, 112*(11), 2057-2068.
- Klinger, E. (1975). Consequences of commitment to and disengagement from incentives. *Psychological Review, 82*(1), 1-25.
- Klinger, E. (1977). *Meaning and void: Inner experience and the incentives in people's lives*. Minneapolis: University of Minnesota Press.
- Klug, H. J. P., & Maier, G. W. (2014). Linking goal progress and subjective well-being: A meta-analysis. *Journal of Happiness Studies, 16*(1), 37-65.
- Krigolson, O. E., Hassall, C. D., & Handy, T. C. (2014). How we learn to make decisions: Rapid propagation of reinforcement learning prediction errors in humans. *Journal of Cognitive Neuroscience, 26*(3), 635-644.
- Lange, S., Leue, A., & Beauducel, A. (2012). Behavioral approach and reward processing: Results on feedback-related negativity and P3 component. *Biological Psychology, 89*(2), 416-425.
- Larson, C. L., & Steuer, E. L. (2009). Motivational relevance as a potential modulator of memory for affective stimuli: Can we compare snakes and cakes? *Emotion Review, 1*(2), 116-117.
- Lau, H. C., Rogers, R. D., Haggard, P., & Passingham, R. E. (2004). Attention to intention. *Science, 303*, 1208-1210.

- Levinson, A. R., Speed, B. C., Infantolino, Z. P., & Hajcak, G. (2017). Reliability of the electrocortical response to gains and losses in the doors task. *Psychophysiology*, *54*(4), 601-607.
- Libet, B., Gleason, C. A., Wright, E. W., & Pearl, D. K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness potential): The unconscious initiation of a freely voluntary act. *Brain*, *106*, 623-642.
- McFarland, D. J., Miner, L. A., Vaughan, T. M., & Wolpaw, J. R. (2000). Mu and beta rhythm topographies during motor imagery and actual movement. *Brain Topography*, *12*(3), 177-186.
- Meadows, C. C., Gable, P. A., Lohse, K. R., & Miller, M. W. (2016a). The effects of reward magnitude on reward processing: An averaged and single trial event-related potential study. *Biological Psychology*, *118*, 154-160.
- Meadows, C. C., Gable, P. A., Lohse, K. R., & Miller, M. W. (2016b). Motivation and motor cortical activity can independently affect motor performance. *Neuroscience*, *339*, 174-179.
- Meyniel, F., & Pessiglione, M. (2014). Better get back to work: A role for motor beta desynchronization in incentive motivation. *Journal of Neuroscience*, *34*(1), 1-9.
- Mirabella, G. (2014). Should I stay or should I go? Conceptual underpinnings of goal-directed actions. *Frontiers in Systems Neuroscience*, *8*, 206.
- Nieuwenhuis, S., Holroyd, C. B., Mol, N., & Coles, M. G. H. (2004). Reinforcement-related brain potentials from medial frontal cortex: Origins and functional significance. *Neuroscience and Biobehavioral Reviews*, *28*(4), 441-448.
- Peterson, C. K., Shackman, A. J., & Harmon-Jones, E. (2008). The role of asymmetrical frontal cortical activity in aggression. *Psychophysiology*, *45*, 86-92.
- Pfurtscheller, G., & Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: Basic principles. *Clinical Neurophysiology*, *110*(11), 1842-1857.
- Pfurtscheller, G., Neuper, C., Brunner, C., & da Silva, F. L. (2005). Beta rebound after different types of motor imagery in man. *Neuroscience Letters*, *378*(3), 156-159.
- Pfurtscheller, G., Stancák, Jr., A., & Neuper, C. (1996). Post-movement beta synchronization: A correlate of idling motor area? *Electroencephalography and Clinical Neurophysiology*, *98*(4), 281-293.
- Picazio, S., Veniero, D., Ponzio, V., Caltagirone, C., Gross, J., Thut, G., & Koch, G. (2014). Prefrontal control over motor cortex cycles at beta frequency during movement inhibition. *Current Biology*, *24*(24), 2940-2945.

- Poole, B. D., & Gable, P. A. (2014). Affective motivational direction drives asymmetric frontal hemispheric activation. *Experimental Brain Research*, *232*(7), 2121-2130.
- Proudfit, G. H. (2015). The reward positivity: From basic research on reward to a biomarker for depression. *Psychophysiology*, *52*(4), 449-459.
- Pogosyan, A., Gaynor, L. D., Eusebio, A., & Brown, P. (2009). Boosting cortical activity at beta-band frequencies slows movement in humans. *Current Biology*, *19*(19), 1637-1641.
- Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian condition: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 64-99). New York: Appleton-Century-Crofts.
- Ryerson, N. C., Neal, L. B., & Gable, P. A. (2017). Attenuating the alcohol allure: Attentional broadening reduces rapid motivational response to alcohol pictures. *Psychopharmacology*, *234*(8), 1247-1254.
- Sambrook, T. D., & Goslin, J. (2015). A neural reward prediction error revealed by a meta-analysis of ERPs using great grand averages. *Psychological Bulletin*, *141*(1), 213-235.
- Sanes, J. N., & Donoghue, J. P. (1993). Oscillations in local field potentials of the primary motor cortex during voluntary movement. *Proceedings of the National Academy of Sciences*, *90*(10), 4470-4474.
- Santesso, D. L., Steele, K. T., Bogdan, R., Homes, A. J., Deveney, C. M., Meites, T. M., & Pizzagalli, D. A. (2008). Enhanced negative feedback responses in remitted depression. *Neuroreport*, *19*(10), 1045-1048.
- Semlitsch, H. V., Anderer, P., & Schuster, P., & Presslich, O. (1986). A solution or reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology*, *23*(6), 695-703.
- Shankman, S. A., Klein, D. N., Tenke, C. E., & Bruder, G. E. (2007). Reward sensitivity in depression: A biobehavioral study. *Journal of Abnormal Psychology*, *116*(1), 95-104.
- Soon, C. S., Brass, M., Heinze, H., & Haynes, J. A. (2008). Unconscious determinants of free decisions in the human brain. *Nature Neuroscience*, *11*(5), 543-545.
- Sutton, R. S., & Barto, A. G. (1998). *Reinforcement learning: An introduction*. Cambridge, MA: MIT Press.
- Swann, N., Tandon, N., Canolty, R., Ellmore, T. M., McEvoy, L. K., Dreyer, S., ... Aron, A. R., (2009). Intracranial EEG reveals a time- and frequency-specific role for the right interior frontal gyrus and primary motor cortex in stopping initiated responses. *The Journal of Neuroscience*, *29*(40), 12675-12685.

- Threadgill, A. H., & Gable, P. A. (2016). Approach-motivated pregoal states enhance the reward positivity. *Psychophysiology*, *53*(5), 733-738.
- Threadgill, A. H., & Gable, P. A. (2018a). Resting beta activation and trait motivation: Neurophysiological markers of motivated motor-action preparation. *International Journal of Psychophysiology*, *127*, 46-51.
- Threadgill, A. H., & Gable, P. A. (2018b). The sweetness of successful goal pursuit: Approach-motivated pregoal states enhance the reward positivity during goal pursuit. *International Journal of Psychophysiology*. Advance online publication. doi: 10.1016/j.ijpsycho.2017.12.010
- Threadgill, A. H., & Gable, P. A. (2019a). Negative affect varying in motivational intensity influences scope of memory. *Cognition & Emotion*, *33*(2), 332-345.
- Threadgill, A. H., & Gable, P. A. (2019b). *Approach-motivated anger makes revenge sweeter and losses more aggravating: Investigation of the reward positivity in a novel aggression paradigm*. Manuscript in preparation.
- Threadgill, A. H., & Gable, P. A. (2019c). Intertrial variability in emotive reactions to approach-motivated positive pictures predicts attentional narrowing: The role of individual differences. *Biological Psychology*, *142*, 19-28.
- Threadgill, A. H., & Gable, P. A. (2019d). *Neural activity underlying motor-action preparation increases in approach-motivated anger states*. Manuscript in preparation.
- Trevena, J. A., & Miller, J. (2002). Cortical movement preparation before and after a conscious decision to move. *Consciousness and Cognition*, *11*, 162-190.
- Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology*, *37*, 190-203.
- Wach, C., Krause, V., Moliadze, V., Paulus, W., Schnitzler, A., & Pollok, B. (2013). Effects of 10Hz and 20Hz transcranial alternating current stimulation (tACS) on motor functions and motor cortical excitability. *Behavioural Brain Research*, *241*, 1-6.
- Weinberg, A., & Hajcak, G. (2010). Beyond good and evil: The time-course of neural activity elicited by specific picture content. *Emotion*, *10*(6), 767-782.
- Wessman, A. E., & Ricks, D. F. (1966). *Mood and personality*. Oxford, England: Holt, Rinehart, & Winston.
- Whiteside, S. P., Lynam, D. R., Miller, J. D., & Reynolds, S. K. (2005). Validation of the UPPS impulsive behaviour scale: A four-factor model of impulsivity. *European Journal of Personality*, *19*(7), 559-574.

Yeung, N., Holroyd, C. B., & Cohen, J. D. (2005). ERP correlates of feedback and reward processing in the presence and absence of response choice. *Cerebral Cortex*, *15*(5), 535-544.

Zhang, Y., Chen, Y., Bressler, S. L., & Ding, M. (2008). Response preparation and inhibition: The role of the cortical sensorimotor beta rhythm. *Neuroscience*, *156*(1), 238-246.