

NEUROPHYSIOLOGICAL ACTIVITY IN RESPONSE  
TO PRE AND POST GOAL  
POSITIVE AFFECTS

by

DAVID ADAMS

PHILIP GABLE, COMMITTEE CHAIR  
MATTHEW JARRETT  
ANTHONY BUHR

A THESIS

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

TUSCALOOSA, ALABAMA

2015

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## ABSTRACT

Approach motivation is the impetus to move towards a stimulus. Most frequently, approach motivation is caused by positive affect, and has been repeatedly shown to influence a number of cognitive and behavioral outcomes. The present experiments investigate approach motivation, as induced by pre and post goal positive affects, and their relationship with neural correlates of physical activity, specifically beta and mu suppression. Participants completed a monetary incentive delay task while EEG data was recorded. Further, participants completed tasks that measured cognitive narrowing throughout both experiments. Results suggest that both beta and mu are related particularly to pre-goal positive affects, which are stronger in approach motivation than post-goal positive affects. Further, this effect was stronger for beta than it was for mu. Study two provides additional support of the relationship between beta and mu suppression and approach motivation by demonstrating that cognitive narrowing – an effect associated with strong approach motivations – is correlated with both beta and mu suppression. These results suggest that approach motivations produce the neurophysiological correlates of movement and prepare one for action.

## LIST OF ABBREVIATIONS AND SYMBOLS

$F$	Fisher's $F$ ratio: A ratio of two variances
$M$	Mean: a statistical average determined by the sum of a set of numbers divided by the number of measurements in that set
$SD$	Standard deviation: the average deviation from the mean of a set of numbers
$n$	Sample size for a study
$p$	Probability of a Type 1 error. Statistical significance is typically assumed at a less than .05 level
$\eta_p^2$	Partial eta squared: an effect size score for a repeated measures $F$ test
$t$	A t-score: a test of the difference of two continuous variables
$r$	A Pearson correlation: the relationship between two continuous variables
$<$	Less than
$=$	Equal to

## ACKNOWLEDGEMENTS

I would like to thank all of my teachers and friends throughout the years that have pushed me to challenge myself academically throughout the years. I would also like to thank my family who taught me the importance of academics and have supported and encouraged me to push myself and follow my dreams.

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## Chapter 1: INTRODUCTION

Imagine walking by an ice cream parlor on a hot summer day. You might look through the window to see others happily enjoying their ice cream and feel a strong, generally positive emotion to have an ice cream cone of your own. Such an experience might produce a relatively strong feeling of desire. In contrast, should you enter and enjoy an ice cream cone yourself, you would likely feel a different positive emotion such as joy or contentment.

This situation illustrates that positive emotions vary in their motivational intensity. Typically, researchers have classified emotions only on whether they are experienced as either negative or positive (e.g., Tomarken, Davidson, Wheeler & Doss, 1992). However, studying emotions only based on emotional valence neglects much of the emotional experience. One important dimension of positive emotion is approach motivational intensity, or the impetus to move towards (Harmon-Jones, Harmon-Jones & Price, 2013). Some positive emotions are high in approach motivational intensity (e.g., desire), but other positive emotions are low in approach motivational intensity (e.g., satisfaction).

While positive affects differ in their approach motivational intensity, they also differ in the degree of arousal they produce. Though these two factors tend to correlate – that is, high approach motivating affects tend to also be high in arousal, they are not the same. For example, humor might be highly arousing, yet cause low approach motivations. Gable and Harmon-Jones (2013) found that increased arousal did not influence typical measures of approach motivation. Furthermore, past research has shown that neurophysiological measures of approach motivation

differ for stimuli which vary in approach motivations, but not overall arousal (e.g., Schupp et al., 2004).

Illustrated by the opening scenario of acquiring or having consumed ice cream, positive affects high or low in approach motivation occur at different stages of goal pursuit. Positive affects high in approach motivational intensity often occur pre-goal. These positive affects may motivate one to move towards a goal (Knutson, Westdorp. Kaiser, & Hommer, 2000). In contrast, positive affects low in approach motivation often occur post-goal, or after the desired object or goal is obtained. Because these positive affects occur at different points in goal pursuit, positive affects high or low in approach motivation have distinct cognitive consequences.

#### *Cognitive Consequences of Positive Affects Varying in Emotional Intensity*

Much past work has found that low approach-motivated positive affects broaden cognitive scope. For example, Rowe, Hirsh and Anderson (2006) found that participants in a positive affective (vs. negative or neutral) state had broadened attentional scope as measured using a flankers task. Fredrickson and Branigan (2005) found that participants in an induced positive affective state were more likely to match a comparison to a standard figure based on global attributes (i.e., overall shape) than to local attributes (i.e., individual components; Kimchi & Palmer, 1982). This past work has led to the predominant view that all positive emotions broaden cognitive scope (Fredrickson, 2005). However, this past work did not examine positive affect high in approach motivation. Emotions within the same affective valence that vary in motivational intensity likely serve different functions, thus producing different cognitive and behavioral consequences.

Initial investigations examined whether positive affects high in approach motivation have distinct cognitive and perceptual consequences. Using the Kimchi and Palmer task (1982), Gable

& Harmon-Jones (2008) found that positive affects high in approach motivational intensity narrow cognitive scope, while positive affects low in motivational intensity broaden cognitive scope. That is, participants in a high approach-motivated state were quicker and more likely to identify the local components than were participants in a low approach motivated state, or a neutral state. The narrowing effect of attentional scope has also been found with memory recognition tasks. That is, in a high approach positive state, participants had better memory for words presented centrally on the screen than for words presented peripherally on the screen. On the other hand, in a low approach positive state, participants had better memory for words presented peripherally on the screen than for words presented centrally on the screen (Gable & Harmon-Jones, 2010a). Functionally, high approach motivating affects should serve to cause individuals to sustain attention and cognitions on task related domains. That is, narrowing cognitions in response to high motivational intensity positive affects may result in individuals remaining undistracted by task/goal-irrelevant factors.

#### *Neurophysiological Processes Associated with Approach Motivation*

Recent neurophysiological research has demonstrated that high approach-motivated positive affects are related to neurophysiological processes associated with approach motivation (Harmon-Jones, 2003; Harmon-Jones & Gable, 2009).<sup>1</sup> One neurophysiological measure associated with approach motivation is cortical asymmetry. For example, greater left-frontal cortical activity is associated with greater trait behavioral approach motivation (Coan & Allen,

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<sup>1</sup>Early demonstrations that frontal cortical activation was not simply due to affective valence included studies on anger, an approach motivated negative affect. Harmon-Jones and Sigelman (2001) demonstrated that induced anger produced greater left-frontal cortical activity than did a neutral condition (for a review, see: Harmon-Jones, Gable, & Peterson, 2010).

2003; Harmon-Jones & Allen, 1998). In contrast, greater right-frontal cortical activity is associated with greater trait behavioral withdrawal motivation (Sutton & Davidson, 1997). Consistent with the perspective that approach motivation in positive states drives attentional narrowing, research has demonstrated that left-frontal cortical activity is associated with cognitive narrowing caused by approach-motivated positive states (Gable & Harmon-Jones, 2010b; 2012; Harmon-Jones & Gable, 2009).

While past work has focused largely on the effects of left-frontal cortical activation, it is likely there are additional neurophysiological processes associated with approach-motivated positive states. Because positive affects high in approach motivation are associated with neurophysiological processes of motivation, it seems likely that additional neurophysiological processes associated with action would be activated in such states. That is, positive affects high in approach motivation occur when one is motivated to move towards an object or goal. These states likely prepare the body for action and prime motor processes in order to achieve the goal.

#### *Beta Activity and Motor Preparation*

One neurophysiological process associated with action is the measure of beta wave activity over the motor cortex using electroencephalography (EEG). Motor-strip beta wave activity is typically measured at central-parietal sites corresponding to the motor cortex. Beta activity in the motor cortex is thought to be inversely related to motor movement, such that beta activity desynchronizes (decreases) during movement and then rebounds following the cessation of movement (Pfurtscheller, Neuper, Brunner, & da Silva, 2005; Pfurtscheller, Stancák, & Neuper, 1996). For example, McFarland, Miner, Vaughan and Wolpaw (2000) found that movement produced decreases in beta activity over the motor cortex in healthy humans. Later, researchers (Zhang, Chen, Bressler, & Ding, 2008) found that movement inhibition evoked

greater beta activity than movement activity. Using a Go/No-Go task, Zhang, Chen, Bressler and Ding (2008) found that macaques produced low levels of beta activity over the motor cortex at the onset of both Go and No-Go trials.<sup>2</sup> However, beta activity increased between 250-300 ms following the onset of No-Go trials, because subjects inhibited motor activity. No rebound was found for Go trials because go trials activated motor activity. Pogosyan, Gaynor, Eusebio and Brown (2009) found that enhancing beta activity using transcranial magnetic stimulation caused participants to make slower movements. This research indicates that decreased beta activity is highly correlated to movement. Importantly, McFarland, Miner, Vaughan and Wolpaw (2000) extended this work, demonstrating that both real and *imagined* movement increased beta suppression over the motor cortex in humans. Such results suggest that beta suppression not only occurs during active movement, but may also occur in response to stimuli which cause participants to prepare for real or imagined action.

Another measure similar to beta wave activity is the mu wave. Like beta activation, mu wave activity over the motor cortex tends to decrease during active movement (Cochin, Barthelemy, Roux & Martineau, 1999). In addition, mu wave activity also decreases when one is observing or simulating a motor behavior (Muthukumaraswamy, Johnson & McNair, 2004). Pfurtscheller, Brunner, Schlögl, and Lopes da Silva (2006) found that when participants imagined movement in one portion of their body, mu wave activity decreased in the corresponding motor cortex areas. However, mu wave activity in that area increased when participants began imagining movement in a different part of their body. Thus, mu suppression seems to occur for active movement, but also when observing or simulating motor behavior.

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<sup>2</sup> The Go/No Go task requires participants to repeatedly make an action in response to “Go” stimuli, but to inhibit action in response to infrequent “No-Go” stimuli.

Although mu and beta suppression correspond to movement, there appear to be some differences when movement is simulated vs. preformed. Jackson, Spinks, Freeman, Wolpert, and Lemon (2002) found that beta wave activity over the motor cortex was associated with electromyographical activity in the periphery (in this case, the hand specifically), but motor cortical mu wave activity was not. That is, beta activity related to actual motor neuron activity, but mu activity did not. Such results may indicate that beta is associated directly to (pre)motor activity, where as mu activity may not be directly associated with (pre)motor activity, but rather the mirror neuron system that may later influence (pre)motor activity (Rüther, Brown, Klepp, & Bellebaum, 2014). When one moves, they may also imagine the movement. Whereas the actual movement relates to beta suppression, only the simulation may relate to mu suppression.

Pre-goal, or high approach-motivated, positive affects likely prepare an organism for action. This preparation may involve both motor preparation as well as simulation. Tasks related to pre-goal positive affects may increase motor preparation as measured by decreased beta activity, and simulation of motor action, as measured by decreased mu activity. In contrast post-goal, or low approach-motivated, positive affects occur after a goal has been accomplished and are unlikely to enhance motor action. Tasks related to these affects are unlikely to increase motor-strip activation. Because high approach-motivated positive states have different cognitive consequences than low approach-motivated positive states, it is likely that neurophysiological effects related to approach motivations may be related to the neurophysiological correlates of approach motivation. Specifically, memory for centrally presented words (e.g., Gable & Harmon-Jones, 2010a) and narrowed attentional scope (e.g., Gable & Harmon-Jones, 2008) may be correlated with beta and mu activity in the motor cortex.

### *Trait Measures of Approach Motivation*

As with many psychological factors, general trait approach motivation can vary between participants. One common measure of this trait approach motivation is the Behavioral Approach System (BAS) scale (Carver & White, 1994). Behaviorally, BAS has been shown to be related to the cognitive narrowing in response to approach motivating stimuli (Gable & Harmon-Jones, 2008). Harmon-Jones and Peterson (2008) found that those high in BAS were more likely to express aggression – an approach motivation – than were those low in BAS. Further, investigations of individual differences in approach motivation using the BAS scale have repeatedly found greater left frontal cortical activity in those high in trait behavioral approach motivations (Coan & Allen, 2003, Harmon-Jones & Allen, 1997). The current studies will investigate the relationship between BAS and beta and mu suppression.

## Chapter 2: THE PRESENT EXPERIMENTS

Positive affects high in approach motivation (pre-goal) or low in approach motivation (post-goal) have been induced in the laboratory using the monetary incentive delay paradigm (Knutson, Westdorp, Kaiser, & Hommer, 2000). In the monetary incentive delay paradigm, participants are given a cue indicating whether or not they have a possibility of winning a reward on a subsequent reaction time task. Reward cues - indicating a reward can be earned - evoke high approach (pre-goal) positive affects as compared to neutral cues - indicating a reward cannot be earned. After the reaction time task, participants see the outcome of the trial on a feedback cue which is then followed by a subsequent reaction time task. Reward feedback cues - indicating a reward was received - evoke low approach (post-goal) positive affects as compared to neutral feedback cues - indicating a reward was not received (because it was a neutral trial).

Two experiments were used to investigate the effects of pre-goal (i.e., high approach motivational intensity) positive affect on the neurophysiological correlates of motivated action using a modified version of the monetary incentive delay paradigm. Where high motivational intensity should increase tendencies towards action, low motivational intensity should decrease tendencies towards action. It is predicted that action preparedness, as measured by beta and mu suppression over the motor cortex should correspond with pre-goal, high motivational intensity positive affects, but not for post-goal, low motivational intensity positive affects.

## Chapter 3: EXPERIMENT 1

### *Methodology*

#### Participants.

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

#### BIS/BAS Scales.

Trait approach motivation in this Experiment was measured by the BAS portion of the BIS/BAS scales (Carver & White, 1994). BAS is comprised of three separate subscales: fun seeking, drive, and reward responsiveness. Fun seeking is the general desire to seek out new and exciting opportunities and an example item is “I’m always willing to try something new if I think it will be fun.” Drive is the general motivation one has to complete a given goal and an example item is “I go out of my way to get things I want.” Finally, reward responsiveness is a measure of positive affect in response to winning a desired object and an example item is “When I get something I want, I feel excited and energized.” BIS is a single scale which is related to aversive motivations individuals have towards negative experiences and an example item is “Criticism or scolding hurts me quite a bit.”

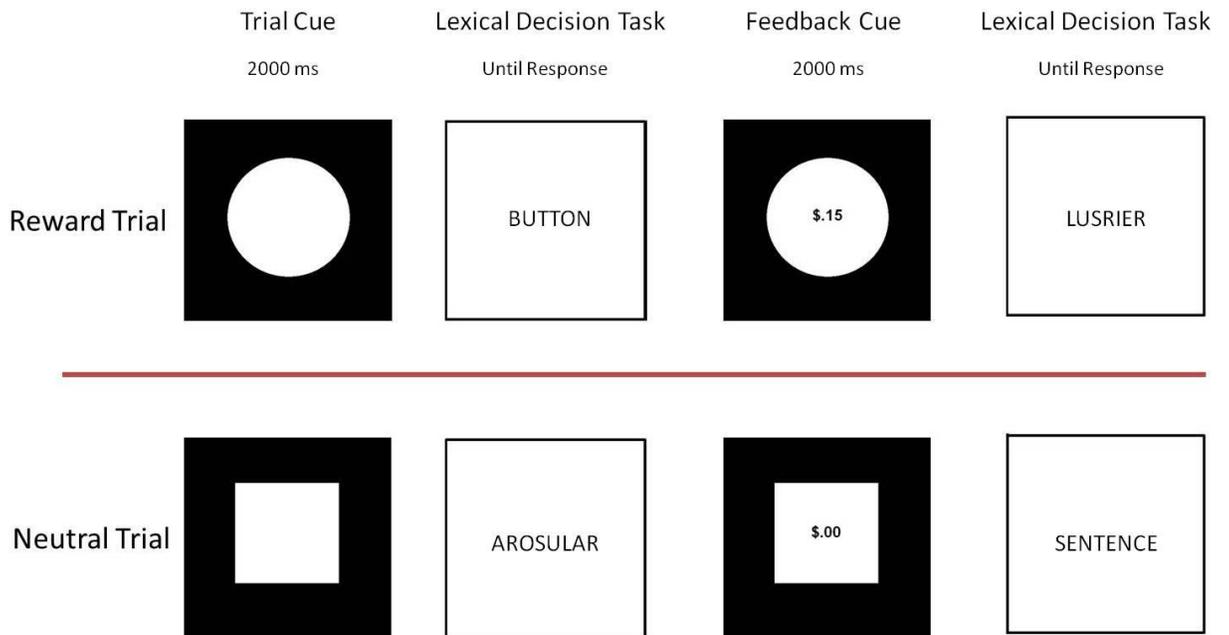
#### Procedure.

Participants first completed the BIS/BAS scales when they entered the lab. They were then told they would play a reaction time game where they would be able to win money on trials, which could later be spent on desserts at the end of the study. Rewards were ostensibly based on trial performance, such that participants believed they had to perform more quickly than average

on a trial to win. Participants completed 12 practice trials prior to beginning the study. Each trial began with either a white circle or a white square pre-goal (i.e., trial) cue (see Figure 1). Trials beginning with a circle indicated the chance to win a monetary reward based on trial performance. In contrast, trials beginning with a square indicated no chance to win a monetary reward based on performance. Cues were displayed for 2000 ms, and were immediately followed by a 500-900 ms inter stimulus interval (ISI). Following the ISI, a lexical decision task appeared, in which participants responded as to whether the word appearing on screen was a real or non-real word. After another 300-700 ms ISI, a final cue appeared indicating whether the participant did or did not gain money on the trial. In all trials, the shape following the lexical decision task was the same as the shape prior to the lexical decision task, however in the post lexical decision task shape, the amount of money won was presented in the shape (\$0.15 for successful reward trials, \$0.00 in no-reward trials). Following the post-goal (i.e., feedback) cue, another lexical decision task was presented, following the same procedures as the first. There was a 3-5s inter trial interval before the next trial began.

## Figure 1

*Example monetary incentive delay task.* Trial cue and feedback shapes appear for 2000 ms, followed by a 500-900 ms ISI. The reaction time task will appear on screen until feedback is received. Following another 300-700 ms ISI, feedback shapes will appear. An example reward trial appears above the red line, with an example neutral trial below the red line.



In order to assess attentional scope, a Navon letter picture appeared following some of the trial cues and feedback cues ( $n = 16$  per condition). The Navon letters task is one of the most prominent measures of attentional scope (Kimchi, 1992). It consists of a letter composed of several smaller letters (see Figure 2 for examples). Participants indicated whether the picture contains a T or H. The T or H could appear as the larger letter (i.e., global position), or as the smaller letters (i.e., local position). Quicker responses to identify the larger (global) T or H indicate a global attentional scope. In contrast, quicker responses to identify the smaller (local)

letter T or H indicate a local attentional scope. Half of the Navon letters included the target letter (i.e., T or H) at the local level, while the other half of the Navon letters included the target letter at the global level. Participants were told that the Navon letters are unrelated to the reward game, but that they should respond as quickly as possible. Reaction times to Navon stimuli were log transformed and any reaction time above or below three standard deviations on a given trial were removed. All reaction times for a trial type were then averaged together to create a separate local and global response time for each trial type.

**Figure 2**

*Example Navon letter.* A global letter (on the left, an H; on the right, an F) is composed of several local letters (on the left, Fs; on the right, Hs).

F	F	HHHHHH
F	F	H
FFFFF		HHHHHH
F	F	H
F	F	H

Half of all trials (n = 60) were reward trials, while the other half were neutral, no-reward trials. To manipulate the belief that performance affected outcome, one third of reward trials indicated the participant did not win a reward, while the other two-thirds indicated the participants won a reward. At the end of the experiment, participants were given candy and debriefed.

## EEG Assessment and Processing.

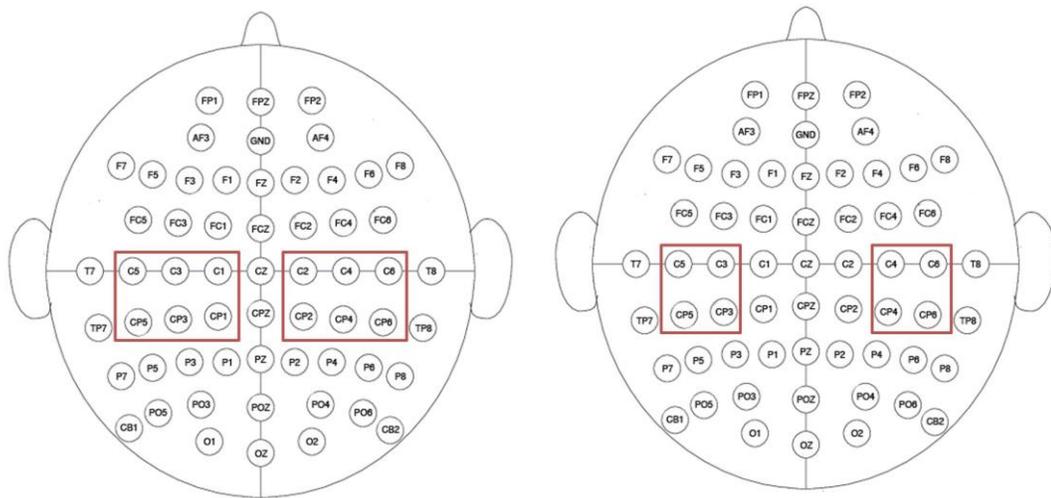
Electroencephalography was recorded from 64 tin electrodes mounted in a stretch lycra Quik-Cap (Electro-Cap, Eaton, OH) and referenced online to the left earlobe. A ground electrode was mounted midway between FPZ and FZ. The electrode cap used was based on the 10-20 system, and a sodium chloride based conductance gel was used to assist in the decrease of impedances. Electrode impedances were kept under 5,000  $\Omega$ . Signals were amplified with Neuroscan SynAmps RT amplifier unit (El Paso, TX), low-pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, notch filtered at 60-Hz, and digitized at 500 Hz. Artifacts (e.g., horizontal eye movement and muscle) were removed by hand. Then, a regression-based eye movement correction was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986), after which the data was visually inspected again to ensure proper correction.

Data was re-referenced to the average of the mastoid sensors. During trial and feedback cues data was epoched every 200 ms using a Hamming window (50% taper of distal ends). Consecutive epochs were overlapped by 50% to avoid data loss. Power values of the beta wave (12-30 Hz) and mu (8-13 Hz) were then extracted with a Fast Fourier Transformation from the cue shapes for each reward and neutral trial and feedback condition for the entire 2 seconds of cue display. Data was then averaged across regions of the head corresponding with the motor cortex. Beta and mu areas of interest were chosen corresponding to the motor strip (e.g., McFarland et al., 2000; Muthukumaraswamy, Johnson & McNair, 2004; Pfurtscheller et al., 2005). Specific sites were chosen because they demonstrated the areas of greatest suppression within-conditions. Beta suppression was maximal at sites: C1, C2, C3, C4, C5, C6, CP1, CP2, CP3, CP4, CP5, CP6. Mu suppression was maximal at sites: C3, C4, C5, C6, CP3, CP4, CP5, CP6 (see Figure 3). Differences in maximal suppression may reflect the different neurological

functions (e.g., motor preparation vs. simulation) of the beta and mu waves (e.g., Jackson et al., 2004; R  ther, Brown, Klepp, & Bellebaum, 2014).

**Figure 3**

*Layout of the 64 Channel head map. Sensors used to analyze beta (left) and mu (right) activity are inside the red boxes.*



*Results*

Beta.

A 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA revealed a significant main effect of reward compared to neutral trials,  $F(1,43) = 10.05, p = .003, \eta_p^2 = .19$ .<sup>3</sup> These results suggest that reward trials produce overall greater beta suppression than

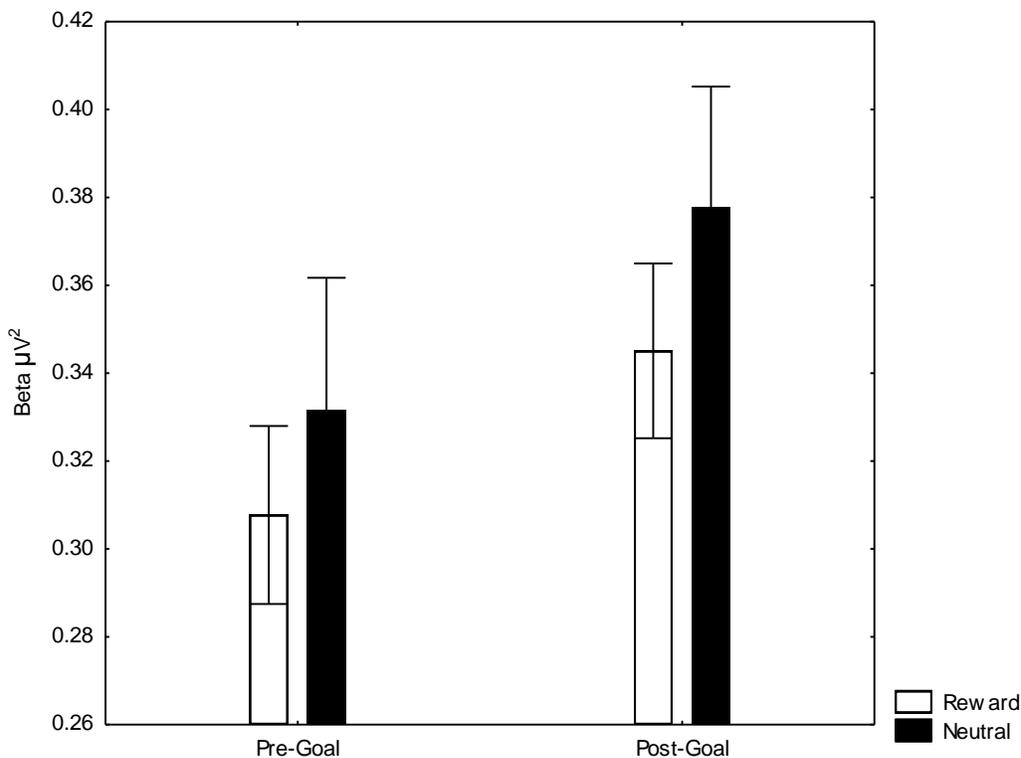
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<sup>3</sup> All tests of the beta and mu interactions with reward/neutral and pre/post-goal were first considered with an additional factor of left hemisphere versus right hemisphere. It was predicted that there should be no effect, as action preparedness should not be asymmetric for the experimental tasks used. In all cases, the interactions of left/right by reward/neutral by pre/post-

neutral trials. There was also a significant main effect of pre-goal compared to post-goal trials,  $F(1,43) = 3.93, p = .045, \eta_p^2 = .08$ . These results suggest that pre-goal trials produce overall greater beta suppression than post-goal trials. However, the interaction was not significant,  $F(1,43) = 0.08, p = .778, \eta_p^2 = .002$  (see Figure 4).

**Figure 4**

*Results of the 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA examining beta suppression. Bars represent within subjects confidence intervals.*



Mu.

A 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA revealed a trending effect of reward compared to neutral trials,  $F(1,43) = 3.19, p = .081, \eta_p^2 = .07$ .

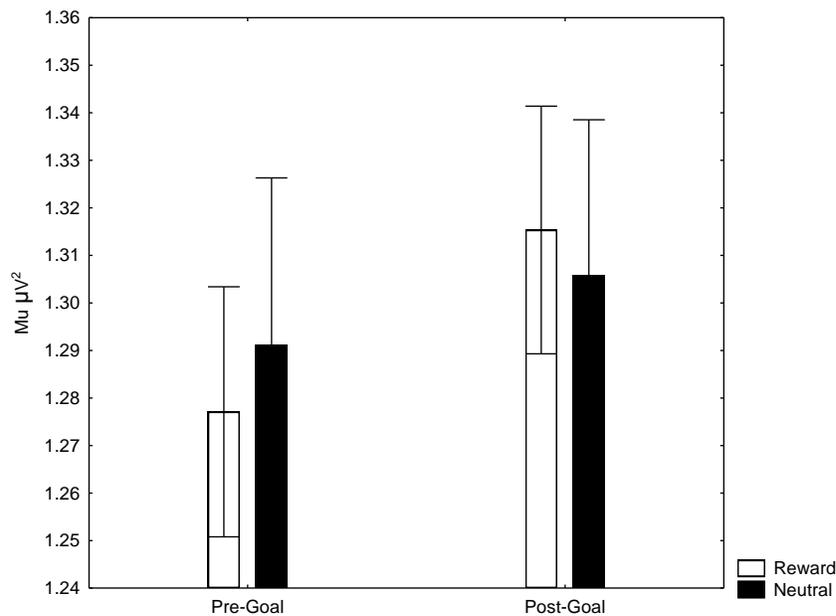
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goal were non-significant,  $F^2s < 2.36, p^2s > .136$ . As such, hemispherical asymmetries were not included in further analyses.

However, there was no effect of pre-goal compared to post-goal trials,  $F(1,43) = 0.01$ ,  $p = .913$ ,  $\eta_p^2 < .01$ , or an interaction of the effects,  $F(1,43) = 0.51$ ,  $p = .478$ ,  $\eta_p^2 = .01$  (see Figure 5).

### Figure 5

*Results of the 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA examining mu suppression. Bars represent within subjects confidence intervals.*



### Relationship Between Mu and Beta.

The relationship between beta and mu was examined at the sites used in the primary analyses. Pearson correlations revealed a strong relationship between beta and mu in the pre and post-goal reward and neutral conditions,  $r^2s > .844$ ,  $p^2s < .001$ .

### Cognitive Narrowing.

Logged reaction times were then entered into a 2 (Local vs. Global) x 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA, which revealed a three-way interaction,  $F(1,42) = 11.93$ ,  $p = .001$ ,  $\eta_p^2 = .22$ . This three-way interaction was unpacked by

examining the 2 (Local vs. Global) X 2 (Reward vs. Neutral) interactions within the pre-goal vs. post-goal conditions.

In the pre-goal conditions, a 2 (Local vs. Global) X 2 (Reward vs. Neutral) revealed a marginal interaction,  $F(1,42) = 3.08, p = .087, \eta_p^2 = .07$ . In the post-goal conditions, a 2 (Local vs. Global) X 2 (Reward vs. Neutral) revealed a significant interaction,  $F(1,42) = 13.06, p < .001, \eta_p^2 = .24$ . Follow up t-tests revealed that participants responded significantly more quickly to global ( $M = 6.80, SD = 0.20$ ) than local ( $M = 6.85, SD = 0.22$ ) Navon letters following reward trials,  $t(43) = 2.92, p = .005$ , and that participants responded more quickly to local ( $M = 6.80, SD = 0.20$ ) than to global ( $M = 6.85, SD = 0.23$ ) Navon letters following neutral trials,  $t(43) = 2.20, p = .033$ . Participants also responded more quickly to local Navon letters following neutral trials than reward trials,  $t(43) = 2.28, p = .028$ , and more quickly to global Navon letters following reward trials than neutral trials,  $t(43) = 2.51, p = .016$ .

These results reveal that in the post-goal conditions, participants were quicker to respond to local Navon letters following neutral compared to reward trials and were quicker to respond to global Navon letters following reward compared to neutral trials. Results suggest that participants had a broadened attentional scope in the post-goal positive condition. In contrast, participants did not show a statistically significant narrowed attentional scope in the positive pre-goal condition.

#### Relationship Between Mu/Beta and Cognitive Narrowing.

To test the relationship between mu and beta and cognitive narrowing, a difference score was created for the logged reaction time to local Navon minus the reaction time to global Navon for each trial type (reward and neutral pre-goal and post-goal). Smaller scores reflect greater narrowing of attentional scope, whereas larger scores reflect greater broadening of attentional

scope. This difference score will be referred to as attentional broadening or narrowing, depending on the direction of the effect. Pearson correlations were then run between attentional narrowing and mu and beta activity for each cue type.

Results revealed that mu and beta suppression during post-goal reward cues predicted greater attentional narrowing after post-goal reward cues,  $r(44) = .314, p = .038$ , and,  $r(44) = .322, p = .033$ , respectively. These results suggest that both beta and mu suppression in response to the post-goal reward condition was related to attentional narrowing during this condition. Neither mu nor beta was related to attentional breadth in any other condition,  $r's < .233, p's > .131$  (see Table 1 for correlations between beta /mu suppression and attentional breadth).

**Table 1**

*Correlations between beta and mu suppression and cognitive narrowing*

Frequency	Trial Type			
	Pre-Goal Reward	Post-Goal Reward	Pre-Goal Neutral	Post-Goal Neutral
Beta Suppression	.065	.348*	.078	.234
Mu Suppression	.177	.322*	.218	.205

\* $p < .05$

Relationship Between Mu/Beta and BAS.

To test the relationship between mu and beta suppression and trait approach motivation (BAS), Pearson correlations were run between beta/mu and overall BAS scores as well as each BAS subscale (fun seeking, reward responsiveness, and drive). Results revealed that post-goal reward condition mu was related to BAS fun seeking,  $r(44) = .299, p = .049$ . Post-goal reward condition beta was related to BAS reward responsiveness,  $r(44) = -.298, p = .049$ . All other

relationships were non-significant (see Table 2 for correlations between beta/mu suppression and BAS). These results suggest that participants who have greater approach motivation to reward cues experienced greater beta suppression in response to those cues. Further, BAS fun seeking was related to less mu suppression in response to post-goal reward cues, possibly indicating that those who seek new and exciting experiences are less likely to express approach motivation after receiving a monetary reward.

**Table 2**

*Correlations between beta and mu suppression and trait approach motivations (BAS)*

	Trial Type			
	Pre-Goal Reward	Post-Goal Reward	Pre-Goal Neutral	Post-Goal Neutral
<b>Beta</b>				
BAS	-.056	-.064	-.076	-.080
BAS Drive	-.170	-.173	-.207	-.230
BAS Fun Seeking	.279	.290	.277	.285
BAS Reward Responsiveness	-.269	-.298*	-.274	-.264
<b>Mu</b>				
BAS	-.006	.027	.003	-.011
BAS Drive	-.162	-.116	-.164	-.198
BAS Fun Seeking	.236	.299*	.258	.284
BAS Reward Responsiveness	-.101	-.150	-.099	-.125

\* $p < .05$

## *Discussion*

In Experiment 1, reward trials produced greater beta suppression than neutral trials, and pre-goal trials produced greater beta suppression than post-goal trials. Trial type did not influence mu. Reward trials, when general approach motivation is greatest, produced greater beta suppression than neutral trials. These results provide support to the hypothesis that beta is related to motor preparation during approach states. Nevertheless, pre-goal beta and mu suppression was not related to cognitive narrowing during pre-goal cues or BAS. However, post-goal reward condition mu correlated with BAS fun-seeking, and post-goal reward condition beta correlated with BAS reward responsiveness. Further, beta and mu suppression only correlated with post-goal cognitive narrowing, but not pre-goal. These results were not predicted, but may indicate that personality differences are capable of increasing beta and mu suppression during post-goal positive states

## Chapter 4: EXPERIMENT 2

Experiment 2 employed a similar paradigm as Experiment 1 with two key differences. Firstly, the Navon letters task was replaced with a memory task designed to measure memory for centrally and peripherally presented words. Instead of a Navon letter appearing, a word was presented in the center or periphery of the screen. Participants were told that the words are unrelated to the task. However, a surprise recognition at the end of the experiment was used to assess memory for centrally and peripherally presented information. Secondly, the lexical decision task was replaced by a flanker task. Because words were presented in the memory task, we did not want words in the lexical decision task to interfere. Finally, in order to enhance reward motivation, participants in Experiment 2 were told they would receive \$0.05 each trial they win, with the possibility of winning a total of \$10.

It is hypothesized that the mu and beta wave suppression should be greater for pre-goal reward trials than for post-goal reward trials. It is expected that a general cognitive narrowing effect will be seen as evidenced by better memory for centrally presented words in the pre-goal reward condition than pre-goal neutral condition. Furthermore, as indices of motor action, mu suppression and beta wave suppression should serve as predictors for recognition of centrally presented words, such that greater motivation should predict higher recognition of centrally presented words.

## *Methodology*

### Participants.

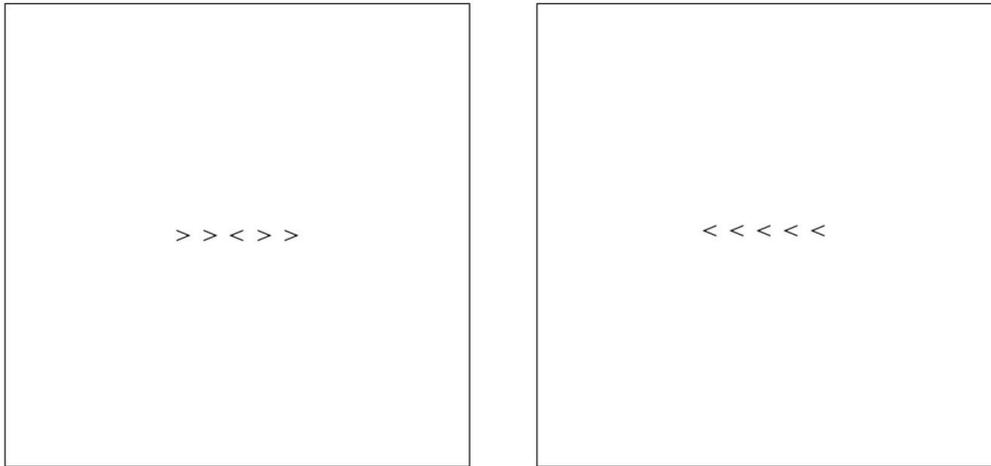
Twenty-eight introductory psychology students participated in exchange for partial course credit.

### Procedure.

The procedure of Experiment 2 largely followed the procedure of Experiment 1; pre- and post-goal positive affects were manipulated in the same manner, with the exception that participants believe they would win money instead of desserts. Further, instead of a lexical decision task, trial outcome was based on a flanker task. Participants responded to the direction (i.e., left or right) of a center arrow surrounded by either four compatible arrows (i.e., the arrows pointed the same direction), or four incompatible arrows (i.e., the arrows pointed the opposite directions; see Figure 6). In addition, immediately following 40 trial and 40 feedback cues, a word was presented either centrally or peripherally (i.e., the word was presented directly in the center of the screen, or in one of the four corners of the screen). This task replaced the Navon stimuli task in the first experiment and resulted in 10 centrally and 10 peripherally presented words for each trial/feedback reward/neutral cue condition. Participants were told that the words were unrelated to the game and to make no response to the words. Following completion of the reward game task, participants completed a surprise recognition task. Each word was presented again, along with 80 foil words, one at a time. Participants responded whether they recognized the word or not. EEG assessment and processing followed the same procedures as Experiment 1.

## Figure 6

*Example flankers task.* Participants response indicated whether the center arrow pointed left or right; an incompatible trial is on the left, a compatible trial is on the right.



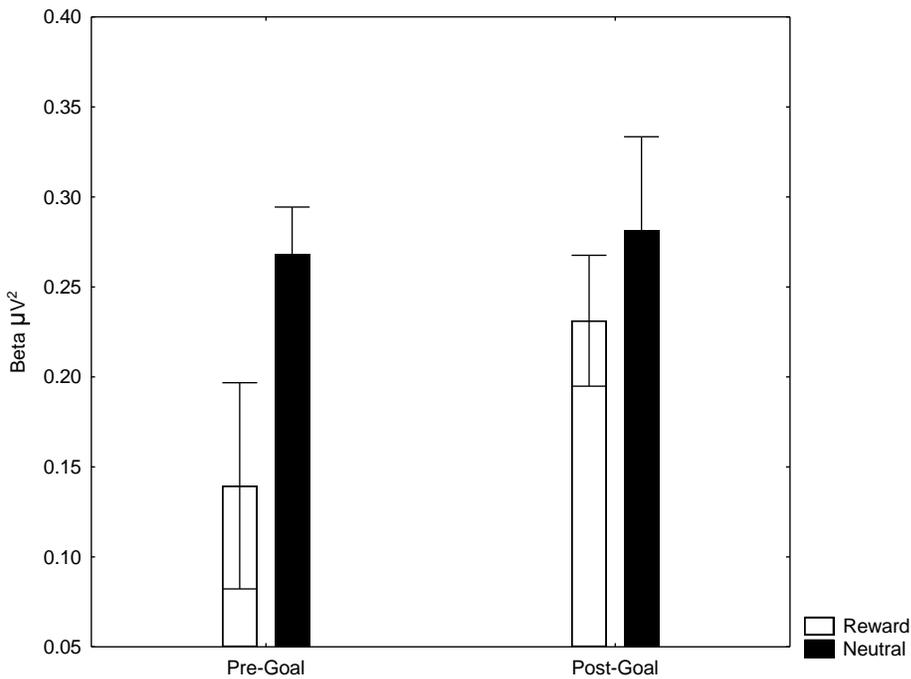
## Results

Beta.

A 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA revealed a significant main effect of reward compared to neutral trials,  $F(1,27) = 5.44, p = .027, \eta_p^2 = .17$ . These results suggest that reward trials produce overall greater beta suppression than neutral trials. There was also a main effect of pre-goal compared to post-goal trials,  $F(1,27) = 7.47, p = .011, \eta_p^2 = .22$ . These results suggest that pre-goal trials produce overall greater beta suppression than post-goal trials. Finally, there was a significant interaction,  $F(1,27) = 4.76, p = .038, \eta_p^2 = .15$  (see Figure 7).

**Figure 7**

*Results of the 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA examining beta suppression. Bars represent within subjects confidence intervals.*



Follow up t-tests indicated that beta was significantly smaller in the pre-goal reward condition than the pre-goal neutral condition,  $t(28) = 2.75, p = .011$ , and smaller in the pre-goal reward condition than the post-goal reward condition,  $t(28) = 3.47, p = .002$ . Beta during pre-goal neutral condition did not differ from beta in the post-goal neutral condition,  $t(28) = 1.33, p = .194$ . Similarly, beta during the post-goal reward condition did not differ from beta in the post-goal neutral condition,  $t(28) = 0.56, p = .581$ . These results suggest that the pre-goal reward condition had the greatest influence on beta suppression.

Mu.

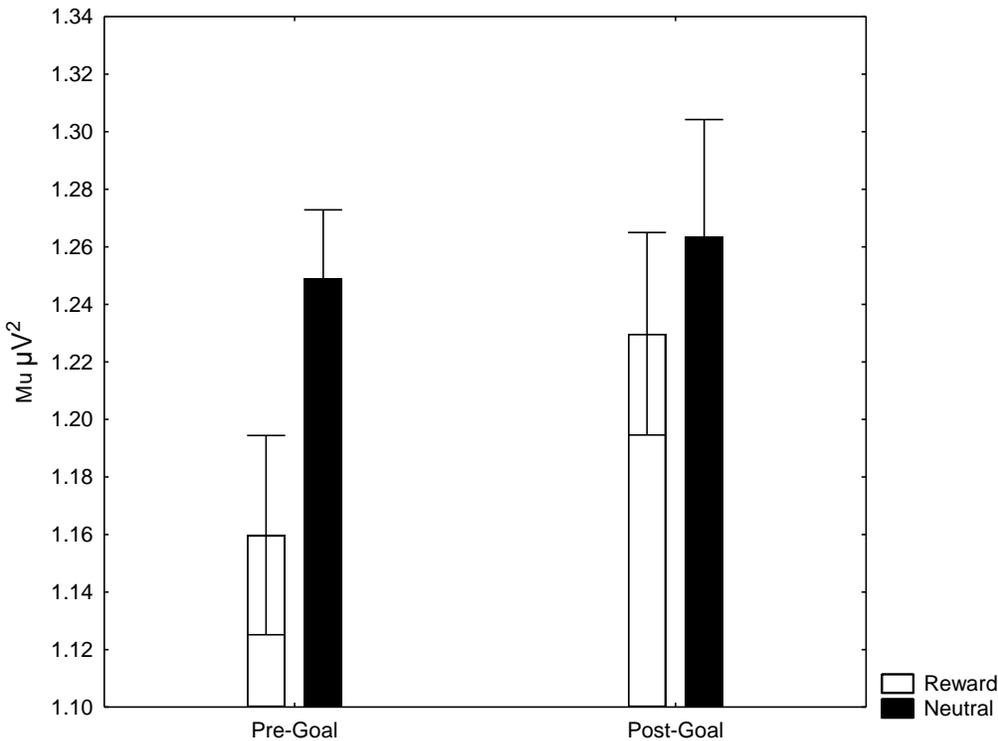
A 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA revealed a significant main effect of reward compared to neutral trials,  $F(1,27) = 5.68, p = .024$ ,

$\eta_p^2 = .17$ . These results suggest that reward trials produce overall greater mu suppression than neutral trials. There was also a main effect of pre-goal compared to post-goal trials,  $F(1,27) = 6.89, p = .014, \eta_p^2 = .20$ . These results suggest that pre-goal trials produce overall greater mu suppression than post-goal trials. Finally, there was a moderately significant interaction,  $F(1,27) = 3.50, p = .072, \eta_p^2 = .11$  (see Figure 8).

Follow up t-tests indicated that mu was significantly smaller in the pre-goal reward condition than the pre-goal neutral condition,  $t(28) = 2.96, p = .006$ , and smaller in the pre-goal reward condition than the post-goal reward condition,  $t(28) = 3.71, p = .001$ . Mu during pre-goal neutral condition did not differ from mu in the post-goal neutral condition,  $t(28) = 1.13, p = .269$ . Similarly, mu during the post-goal reward condition did not differ from mu in the post-goal neutral condition,  $t(28) = 0.69, p = .498$ . These results suggest the pre-goal reward condition had the greatest influence on mu suppression.

**Figure 8**

*Results of the 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA examining mu suppression. Bars represent within subjects confidence intervals.*



#### Relationship Between Mu and Beta.

The relationship between beta and mu was examined at the sites used in the primary analyses. Pearson correlations revealed a strong relationship between beta and mu at pre and post-goal reward and neutral times,  $r's > .756$ ,  $p's < .001$ .

#### Cognitive Narrowing.

To test the general effect of cognitive narrowing in response to pre-goal reward trials, participants responded to whether or not they recognized the words presented during the experiment. Responses were then entered into a 2 (Central vs. Peripheral) x 2 (Reward vs. Neutral) X 2 (Pre-goal vs. Post-goal) repeated measures ANOVA, which revealed a three-way interaction,  $F(1,25) = 4.81$ ,  $p = .038$ ,  $\eta_p^2 = .16$ . This three-way interaction was unpacked by

examining the 2 (Central vs. Peripheral) X 2 (Reward vs. Neutral) interactions within the pre-goal vs. post-goal conditions.

In the pre-goal window, a 2 (Central vs. peripheral) X 2 (Reward vs. Neutral) also revealed a significant interaction,  $F(1,25) = 5.45, p = .028, \eta_p^2 = .18$ . Follow up t-tests revealed participants recognized more words following the centrally presented reward condition ( $M = 6.23, SD = 2.21$ ) than the centrally presented neutral condition ( $M = 4.42, SD = 2.44$ ),  $t(25) = 3.91, p < .001$ . Participants recognized more words after the centrally presented reward condition than the peripherally presented reward condition ( $M = 2.50, SD = 2.12$ ),  $t(25) = 3.73, p < .001$ . Participants also recognized more words presented after the centrally presented neutral condition than the peripherally presented neutral condition ( $M = 2.23, SD = 2.16$ ),  $t(25) = 2.24, p < .001$ . There were no difference in responses to peripherally presented words in the reward and neutral conditions,  $t(25) = 0.59, p = .557$ . In the post-goal window, a 2 (Central vs. peripheral) X 2 (Reward vs. Neutral) revealed no significant interaction,  $F(1,25) = 1.44, p = .242, \eta_p^2 = .05$ .

These results indicate that in the pre-goal condition, participants were more likely to recognize centrally presented words after reward trials than after neutral trials. In the post-goal condition, however, participants were more likely to recognize centrally presented words than peripherally presented words with no effect of reward compared to neutral trials. This pattern of results indicates that pre-goal reward trials caused a cognitive narrowing effect in which participants were more likely to recognize centrally presented words.

#### Relationship Between Mu/Beta and Cognitive Narrowing.

To test the relationship between mu and beta and cognitive narrowing, a difference score was created for the total number of words presented in the center of the screen correctly recognized minus the total number of words presented in the periphery of the screen correctly

recognized. Lower scores indicate greater levels of cognitive narrowing. Pearson correlations were then run between mu and beta for each cue and the degree of cognitive narrowing for words presented immediately following that cue.

Results revealed that both mu and beta suppression during the pre-goal reward cue were significantly correlated with cognitive narrowing after this cue,  $r(28) = -.463, p = .012$ , and,  $r(28) = -.540, p = .003$ , respectively. These results indicate that mu and beta suppression during pre-goal reward trials correlated with greater recognition of centrally, compared to peripherally, presented words following pre-goal reward trials. Mu suppression was also correlated with cognitive narrowing after post-goal neutral cues,  $r(28) = -.390, p = .040$ , indicating mu suppression during post-goal neutral trials correlated with greater recognition of centrally, compared to peripherally, presented words following post-goal neutral trials. However, neither mu nor beta suppression was significantly related to cognitive narrowing at any other cue,  $r's > -.300, p's > .120$ , (see Table 3 for correlations between beta/mu suppression and cognitive narrowing).

**Table 3**

*Correlations between beta and mu suppression and cognitive narrowing*

	Trial Type			
	Pre-Goal Reward	Post-Goal Reward	Pre-Goal Neutral	Post-Goal Neutral
Mu Suppression	$-.540, p = .003$	$-.247, p = .205$	$-.278, p = .151$	$-.301, p = .120$
Beta Suppression	$-.466, p = .012$	$-.1215, p = .538$	$-.140, p = .479$	$-.390, p = .040$

### Relationship Between Mu/Beta and BAS.

To test the relationship between mu and beta suppression and trait approach motivation (BAS), Pearson correlations were run between beta/mu and overall BAS scores as well as each BAS subscale (fun seeking, reward responsiveness, and drive). Results revealed that pre-goal reward beta was related to BAS,  $r(28) = .396, p = .07$ . All other relationships were non-significant (see Table 4 for correlations between beta/mu suppression and BAS). These results suggest that those who are naturally high in approach motivation experienced less beta suppression to pre-goal reward cues.

**Table 4**

*Correlations between beta suppression and trait approach motivations (BAS)*

	Trial Type			
	Pre-Goal Reward	Post-Goal Reward	Pre-Goal Neutral	Post-Goal Neutral
<b>Beta</b>				
BAS	.396*	.248	.237	.179
BAS Drive	.324	.265	.240	.219
BAS Fun Seeking	.306	.172	.178	.066
BAS Reward Responsiveness	.162	.067	.062	.066
<b>Mu</b>				
BAS	.318	.273	.266	.188
BAS Drive	.253	.228	.209	.204
BAS Fun Seeking	.296	.295	.267	.204
BAS Reward Responsiveness	.077	.044	.045	.013

\* $p < .05$

## *Discussion*

In Experiment 2, both beta and mu were suppressed to the greatest extent during pre-goal reward cues. Beta and mu suppression did not differ between all other time points. These results would suggest that both beta and Mu are psychophysiological markers of movement related to approach motivation. These results further suggest that beta and mu are specifically related to pre-goal positive affects (i.e., high approach motivations). To support this, both beta and mu were related to the degree of cognitive narrowing when approach motivation was strongest. Nevertheless, beta suppression was inversely related to trait approach motivation (BAS) during pre-goal reward cues. This result was not expected. However, it may be that participants who regularly experience approach motivation simply need less neurological activation in order to respond to approach motivating stimuli. As such, the motor cortical areas may have strengthened neural connections to the periphery, which allow less beta suppression to occur.

## Chapter 5: GENERAL DISCUSSION

Two experiments tested the effect of approach motivation on the suppression of beta and mu – neurophysiological markers of real and imagined movement. While pre-goal positive states have been shown to narrow cognitive scope (see Gable & Harmon-Jones, 2010b), no studies have found neurophysiological substrates related to pre-goal positive states and cognitive narrowing. The results from these two experiments provide general evidence that beta and mu suppression are indicators of pre-goal positive affect. Moreover, both beta and mu were closely related in both experiments. However, the effects of pre-goal positive affect were generally stronger in beta than mu.

The current pattern of results suggests that beta suppression particularly, and mu suppression to a lesser extent, are related to pre-goal positive states. Further, such results suggest that pre-goal positive affective stimuli cause neurophysiological reactions preparing individuals to act. While Experiment 1 suggests a general approach motivating effect on the neurophysiological processes associated with movement, Experiment 2 suggests that only pre-goal positive affective (i.e., strong approach motivating) stimuli influence these neurophysiological processes. One potential reason for this difference in the observed findings might be the reward motivator of money (\$10 in Experiment 2) was greater than the reward of desserts used in Experiment 1.

### *On the Difference of Beta and Mu Suppression*

The results from two experiments suggest both beta and mu were related to pre-goal states. However, in both experiments, the relationship with pre-goal positive states was stronger for beta

than for mu. Past research indicates both beta and mu suppression relate to real and imagined movement in both humans and primates (e.g., Pfurtscheller et al., 2006; Zhang et al., 2008). However, recent research has suggested that there may be distinct neurological differences between beta and mu, such that the mirror neuron system is, at least in part, responsible for mu suppression (Frenkel-Toledo, Bentin, Perry, Liebermann, & Soroker, 2014; R  ther, Brown, Klepp, & Bellebaum 2014; Woodruff, Martin, & Bilyk, 2011). Little research, though, has suggested a link between beta suppression and typical mirror neuron effects. In the current studies, it appears that beta is more sensitive to reward-motivated pre-goal states. Beta activity may be directly responsible for motor and pre-motor activity, whereas mu may only represent mental representation of a planned action, causing overall effects of intended approach behavior to appear more weakly in the mu wave.

### *Conclusions*

Two studies provided evidence that manipulations of pre-goal vs. post goal states, and reward vs. neutral states modulate beta and mu suppression. Further experimentation may help elucidate how strong the approach motivating affect needs to be in order to produce beta and mu suppression. Studies typically investigating positive affect generally, and approach motivating positive affects specifically, generally use only pictorial stimuli of motivating objects and scenes. However, the current experiments used a manipulation wherein the stimuli alone are not naturally motivating, but rather are motivating in the context of the experiment. This approach has the benefit of being more generalizable to the real world, where opportunities to win prizes or money occur often. However, future research could determine whether affective pictures of biological motivators (e.g., food) produce similar findings to those presented here. It is likely that pictorial stimuli of strongly approach-motivating objects would cause beta and mu suppression.

Nevertheless, the current studies demonstrate that both beta and mu suppression occurs in response to approach motivating stimuli. These results give us a greater neurological understanding of the effects of approach motivation. Ultimately, these findings demonstrate that approach motivation itself prepares one neurologically for physical action and that these neurological preparations facilitate cognitive narrowing in such states. In addition, the current studies help to clarify the roles of mu and beta wave activity, demonstrating that beta suppression may be more sensitive to approach-motivated motor preparation than mu suppression. This demonstration may bear on future research to consider beta and mu suppression as reflecting separate psychophysiological processes.

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## APPENDIX A

November 19, 2013

Office for Research  
Institutional Review Board for the  
Protection of Human Subjects

THE UNIVERSITY OF  
**ALABAMA**  
RESEARCH

[REDACTED]  
Department of Psychology  
College of Arts and Sciences  
The University of Alabama

Re: IRB # 12-OR-076-R2 "Personality and Physiology"

Dear [REDACTED]

The University of Alabama Institutional Review Board has granted approval for your renewal application.

Your renewal application has been given expedited approval according to 45 CFR part 46. You have also been granted the requested waiver of informed consent. Approval has been given under expedited review category 7 as outlined below:

*(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.*

Your application will expire on November 18, 2014. If your research will continue beyond this date, complete the relevant portions of the IRB Renewal Application. If you wish to modify the application, complete the Modification of an Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, complete the appropriate portions of the IRB Study Closure Form.

Should you need to submit any further correspondence regarding this proposal, please include the above application number.

Good luck with your research.

Sincerely,



358 Rose Administration Building  
Box 870127  
Tuscaloosa, Alabama 35487-0127  
(205) 348-5461  
fax (205) 348-7189  
toll free (877) 820-3066

[REDACTED]  
Director & Research Compliance Officer  
Office for Research Compliance  
The University of Alabama