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Motivated for movement: Beta activation over the motor cortex resulting from intrinsic and extrinsic motivators

Ricardo A. Wilhelm^{1,2}  | A. Hunter Threadgill³  | Philip A. Gable⁴

¹Department of Psychology, The University of Alabama, Tuscaloosa, Alabama, USA

²Laureate Institute for Brain Research, Tulsa, Oklahoma, USA

³Departments of Biomedical Sciences and Psychology, Florida State University, Tallahassee, Florida, USA

⁴Department of Psychological & Brain Sciences, University of Delaware, Newark, Delaware, USA

Correspondence

Ricardo A. Wilhelm, Department of Psychology, The University of Alabama, Tuscaloosa, AL, USA
Email: rwilhelm@laureateinstitute.org

Abstract

Past work on motivation has primarily studied dichotomous distinctions of motivation (e.g., extrinsic or intrinsic). However, focusing on the overall motivational intensity may be better at accentuating the unique differences within and between varying motivators as it pertains to the impetus to act. Specifically, motivational intensity influences neural patterns of beta band frequency (13–30 Hz) as measured by electroencephalography (EEG) that enable motor-action preparation, a neural correlate of motivated movement. The primary aim of across three experiments was to investigate neural motor-action preparation to modified flanker tasks within achievement (Experiment 1), autonomous (Experiment 2), and extrinsic vs. intrinsic (Experiment 3) motivational contexts. Experiment 1 revealed greater motor-action preparation for challenging trial cues and did not differ in behavioral attentional and performance measures across both trial types. Experiment 2 revealed no significant difference in motor-action preparation, did not differ in behavioral attentional narrowing and had worse behavioral performance in high autonomy relative to low autonomy trials. Experiment 3 revealed greater motor-action preparation for challenging trial cues, did not differ in behavioral attentional narrowing and had a faster performance for reward trials relative to high autonomy trials. These findings suggest motivators of the same category (i.e., intrinsic) may differ in motivational strength, as suggested by a neurophysiological measure of immediate motivated movement planning.

KEYWORDS

beta frequency activity, EEG, motivation

1 | INTRODUCTION

Motivation is the impetus to act. It aids in attaining biologically and socially important goals and resources. This means motivation is directional such that it drives an organism to move toward (approach) or away (withdraw). Past research on motivation has focused on categories of motivation based on the underlying reasons for why an object or activity is motivating, such that motivation may be elicited for the purpose of obtaining some external

outcome (e.g., extrinsic motivation), or for the sake of an activity itself and the enjoyment it provides (e.g., intrinsic motivation; Ryan & Deci, 2000a, 2000b). This differential treatment of the *type* of motivation has recently been challenged by the notion that a dichotomous view of motivation may not be applicable to all contexts requiring motivation or whether achievement-based motivators fit under the intrinsic-extrinsic motivation dichotomy (Locke & Schattke, 2019; Ryan & Deci, 2019; Vansteenkiste et al., 2014).

However, motivation also varies in intensity (low to high), which refers to the strength of the drive (Gable & Dreisbach, 2020; Gable & Harmon-Jones, 2010b). This view of motivational intensity views intensity as the amount of energy or the behavior that must be exerted to achieve or obtain a motivational goal or resource (Gable & Harmon-Jones, 2010b). This is not to be confused with *potential* motivation described in prior concepts, which determines the upper limit of effort based on benefits expected for a behavior (Brehm & Self, 1989). Whereas *potential* motivation for a goal or resource may be high motivational *intensity* for that goal or resource may be low if it is impossible to achieve (Harmon-Jones & Gable, 2018). Importantly, the motivational intensity may vary across different types of motivators regardless of the source of the motivation. This view suggests that intrinsic motivations varying in motivational intensity could have divergent neural patterns, depending on their motivational strength. Recent work finds evidence of high motivational intensity resulting from some intrinsic motivators, such as social competence comparisons (Wilhelm et al., 2019). However, past research has yet to investigate if other forms of motivation considered to be intrinsically oriented, such as achievement and autonomous motivators, also enhance motivational strength. We propose that motivational intensity within different sources of motivation is one of the primary mechanisms for understanding the role of motivation on the action and neural correlates of motor-action preparation. Importantly, considering distinctions of motivational strength by examining neural motor-action preparation may be more informative in understanding how eliciting motivational *types* may specifically influence the motivational intensity of intended actions rather than just appraisals of motivational potential. The current experiments sought to investigate motivational intensity behind distinct types of motivation by examining a neural correlate of motor-action preparation during intrinsic motivational states potentially differing in motivational intensity (e.g., achievement and autonomous choices) and extrinsic motivation (e.g., rewards).

1.1 | Types of motivation

Decades of research on motivation have contrasted motivation between its dichotomous extrinsic and intrinsic characteristics, or underlying reasons for why something is motivating (Ryan & Deci, 2000a, 2000b). Specifically, intrinsically oriented motivation is often influenced by enjoyment and perceived autonomy for an activity (Deci & Ryan, 1985, 1987, 2008; Di Domenico & Ryan, 2017; Ryan et al., 1991; Ryan & Deci, 2000a, 2000b). Extrinsic motivation results from motivators that also enhance energy

and effort, but for the purpose of obtaining some other external outcome or consequence (e.g., money or external reward; Deci et al., 1999, 2001, 2017).

Generally, achievement motivation contexts are thought to drive the energy or effort for an activity to compete against or achieve some standard (McClelland, 1985; McClelland et al., 1953). Research suggests that achievement motivation influences implicit thoughts (e.g., achievement imagery; Pang, 2010), drives occupational choices and performance (Collins et al., 2004), makes teachers more effective (Renata et al., 2018), and is related to achievement orientation (Köllner & Schultheiss, 2014). Current directions in motivation research suggest achievement motivation fits within the intrinsic motivation framework because achievement motives more closely resemble achievement-related *goals* of competence and internalized standards (Avila et al., 2012; Lewthwaite & Wulf, 2010; Ryan & Deci, 2019).

Other work on intrinsic motivation has often focused on enhancing intrinsic motivation by providing autonomous choices throughout performance-based tasks (Leotti & Delgado, 2011; Sanli et al., 2013; Tiger et al., 2006). Autonomy (or control) over an environment or situation enhance motivation by tapping into self-worth, competence, enjoyment, and a sense of control over a task or activity (Black & Deci, 2000; Deci & Ryan, 2008; Demir et al., 2011; Eitam et al., 2013; O'Donnell et al., 2013). For instance, performance is enhanced in laboratory tasks and classroom settings when individuals can choose their activities, reward types, and whether or not to receive feedback (Eitam et al., 2013; Sanli et al., 2013; Tiger et al., 2006; Wulf & Lewthwaite, 2016).

Despite the extensive past work examining intrinsic motivators, no past work has examined the motivational intensity of intrinsic motivators. Specifically, whether intrinsically oriented motivators are high or low in motivational intensity. For instance, achievement-related contexts enhance motivation by eliciting self-relevant goal-striving that may be useful for social desirability (i.e., getting attention from others) and social utility (i.e., being successful; Dompnier et al., 2009; Ehrlich, 2012; Urdan & Miranda, 2006; Vansteenkiste et al., 2014). These motivators may incite necessary competence-based pursuits that enhance attention and neural correlates of high motivational intensity (Elliot & Thrash, 2001; Wilhelm et al., 2019). Other types of intrinsic motivators may be low in motivational intensity. For instance, intrinsic motivators eliciting enjoyment (Black & Deci, 2000; Demir et al., 2011; Ryan & Deci, 2000b) may elicit positive states low in motivational intensity. Positive states low in motivational intensity may broaden attentional scope (Gable & Harmon-Jones, 2008, 2010b), which may improve cognitive flexibility to

switch between broad and narrowed attentional scope (Dreisbach, 2006; Dreisbach & Goschke, 2004; Liu & Wang, 2014; Marien et al., 2012).

1.2 | Beta activation

One potential consequence of increased motivational intensity is to drive an organism to act. The drive for action results in preparation for movement to approach resources or goals. The activation of beta oscillations (13–30 Hz) over motor regions of the cortex is a neural correlate of motor-action preparation (Pfurtscheller et al., 1996; Sanes & Donoghue, 1993). Cortical motor areas become more active during movement-related actions or thoughts (Pfurtscheller & Da Silva, 1999). This cortical activation suppresses beta oscillations over the motor regions (McFarland et al., 2000; Pfurtscheller et al., 2006). Specifically, this oscillatory beta activity decreases or is suppressed over motor strip regions during an organism's *preparation* for movement (McFarland et al., 2000; Pfurtscheller & Da Silva, 1999). Suppression of beta activity even occurs when an individual merely visualizes making motor movements (McFarland et al., 2000). In contrast, using transcranial alternating-current stimulation (tACS) to increase beta activity over motor strip regions diminishes motor movement readiness (Pogosyan et al., 2009; Wach et al., 2013). Similarly, rigidity and bradykinesia in Parkinson's Disease (PD) patients relate to greater beta activity at rest (Brown, 2007; Hammond et al., 2007), something which PD patients exhibit at chronically high levels (Uhlhaas & Singer, 2006). Overall, ample evidence suggests beta activity is an index of motor readiness, as it is a neural indicator of future motor movements toward resources (Doyle et al., 2005; Jenkinson & Brown, 2011), environmental cues that ultimately attract motivated attentional processing (Gable, Threadgill, & Adams, 2016), or linked to other physiological systems that facilitate movement when attending to events that implicate survival (e.g., heart rate; de Echegaray & Moratti, 2021).

As a neural indicator of motor-action preparation, beta activity is crucial for motivational intensity research. High-intensity motivators (e.g., rewards) activate cortical motor regions as preparation for future movement relative to no rewards (Babiloni et al., 2015; Cunnington et al., 2002; Sanes & Donoghue, 1993). Electroencephalography (EEG) research examining beta-band activity shows that suppression of beta activation is related to trait motivation (Threadgill & Gable, 2018a), associated with additional EEG correlates of motivation and trait motivation (Wendel et al., 2021), and occurs when motivational intensity is high for a potential reward (Doyle et al., 2005; Gable, Threadgill, Adams, 2016).

Importantly, research even suggests that the magnitude of beta activity is associated with the magnitude of rewards (Meyniel & Pessiglione, 2014), where greater rewards lead to decreased beta activity. Consistent with this view, beta activation is also associated with neural dopamine firing involved in future reward predictions to motivate future behavior (Schultz, 2016; Tobler et al., 2005). For instance, stimulation of dopaminergic areas of the basal ganglia in PD patients had a suppressing effect on beta activity in motor cortical regions and subsequently led to improved motor performance over time (Jenkinson & Brown, 2011; Kühn et al., 2008). High motivational intensity provided by extrinsic motivators (e.g., rewards), then, suppresses beta activity before quick physical movement is required to attain some goal or reward (Doyle et al., 2005; Gable, Threadgill, & Adams, 2016; Meadows et al., 2016; van Wijk et al., 2009).

In sum, cortical beta activity appears to be a reliable and more objective measure of motivational intensity, as it measures neural motor preparation immediately prior to movement. Past work examining extrinsic motivators high in motivational intensity shows enhanced motor-action preparation. In order to examine whether motivators of the same type have divergent motivational intensities, and thereby differing levels of motor preparation, beta activity should be examined during multiple motivational states. Finding that similar motivational types have different motivational intensities would suggest that motivational intensity may be a critical factor to examine when researching motivational states, regardless of the source of the motivation or *type*.

1.3 | The current experiments

The current experiments sought to investigate the influence of motor-action preparation across two types of intrinsic motivation (achievement and autonomy) by examining beta activation over motor cortical areas (Gable, Threadgill, Adams, 2016; Meadows et al., 2016; Wilhelm et al., 2019). Examining neural motor-action preparation (e.g., beta-band activity) may be a more reliable indicator of the motivational intensity of a motivator (Harmon-Jones & Gable, 2018), making it a core facet of motivation applicable to all motivational contexts during some type of action. As such, neural motor preparation is an important measure reflecting motivational intensity that seems critical to examine in varying motivational states, as it focuses on the strength of the motivation, instead of just the loci of the motivation. It is the aim of these experiments to investigate whether intrinsic motivators differ in the impetus to act. Examining neural correlates of motivation across

varying motivators can also help to elucidate differences in motivational states that would go undetected by behavioral studies exclusively.

2 | EXPERIMENT 1

Experiment 1 sought to examine neural motor-action preparation in achievement-based intrinsic motivation. Achievement motivation was elicited by giving participants the opportunity to outperform themselves in a reaction time game with varying degrees of perceived difficulty, as this creates motivation to best one's own efforts (Mento et al., 1992; Morisano et al., 2010; Urdan & Kaplan, 2020). Research on motivation largely suggests greater perceived task difficulty can enhance motivation, attention, and value for success (Inzlicht et al., 2018; Wilhelm et al., 2019, 2021). However, task difficulty is complex and may also enhance motivation for a task when individuals find that it is beneficial to engage in additional effort (i.e., reward or other motivating outcomes eliciting reasons for exerting more effort; Frömer et al., 2021; Milyavskaya et al., 2021). In light of this complex relationship, achievement motivation was elicited through a task where individuals perceived that beating their own past performance would be challenging or easy compared to prior practice trials. In other words, they would be attempting to outperform their prior practice trial performance in ostensibly varying trial difficulty. If achievement motivation, through greater interest for outperforming perceived difficult self-goals, is high in motivational intensity, beta activity should be reduced in the challenging relative to the easy condition.

Previous research on motivation suggests motivational intensity influences the allocation of attentional resources as a cognitive consequence of greater motivational intensity to attain goals or resources (Gable & Harmon-Jones, 2010b). Specifically, high motivational states narrow (vs. broaden) attentional scope as evidenced by faster response times (RTs) or better recall of stimuli in the local (vs. global) visual field in laboratory tasks (Gable & Harmon-Jones, 2008, 2010a, 2010b, 2011; Gable, Mechin, Neal, 2016; Hicks et al., 2012; Threadgill & Gable, 2019). Thus, attention was also measured. Similarly, performance was also measured using participant RTs to the game itself.

3 | EXPERIMENT 1 METHOD

3.1 | Participants

Fifty-six ($n = 56$) undergraduate introductory psychology students participated for partial course credit. Data

collection was pre-determined to start and stop at the beginning and end of one academic semester respectively.¹ To be included in the experiment, participants had to be at least 18 years old and be right-handed. Participant handedness was assessed using a 13-item checklist (Chapman & Chapman, 1987; Gable & Poole, 2014; Neal & Gable, 2017). Participants indicated which hand (right, left, or both) they used to perform day-to-day tasks (e.g., use scissors, write, draw, etc.). Participants were classified as right-handed if they reported doing no more than one activity with their left hand.

3.2 | Procedure

After applying the EEG stretch lycra cap to their scalp, participants were asked to play a flanker's task (Eriksen & Eriksen, 1974) reaction time game. Trials ($n = 96$) were broken up into eight blocks of 12 trials each. To create different conditions for which participants could demonstrate some motivation to achieve, participants were told four of these blocks would be "challenging" and the other four would be "easy." Unbeknownst to the participants, these blocks of trials did not actually differ in difficulty level. The different blocks of trials were presented in counterbalanced order.

Prior to the blocks of trials, participants had eight practice trials. They were told that it would be challenging to beat their performance from the practice trials in the challenging trials and easy to beat their performance from the practice trials in the easy trials. This was done in hopes that participants 1) had the practice trials as a point of reference for which to achieve and 2) were exposed to different conditions that may impact the achievement motivation context.

Each trial sequence began with a cue presented at the center of the screen for 2000 ms. White circles represented challenging trials. In contrast, white squares represented easy trials. Following each cue, a Navon (1977) letter was presented at the center of the computer screen to measure attentional scope. Identifying Navon letters involves locating local and global elements (only T's or H's) that make up the letter stimuli. Local elements are the small letters that make up a larger letter (e.g., small H's making up a large F). Global elements are the large letters that are made up of smaller letters (e.g., a large T made up of small F's). There was an equal number of letters containing global and local elements per block. Faster RTs when

¹To further examine the statistical power of samples for all three experiments, post hoc power analyses were included in the general discussion of this manuscript.

identifying local elements indicate a narrowed attentional scope, while faster RTs when identifying global elements indicate a broadened attentional scope. Participants were informed their responses to the letters would not have any influence on their trial success, but they were still asked to respond to them as quickly and accurately as possible. Responses were made by pressing the left or right shift keys on the keyboard.

Next, participants responded to a flanker. This involves identifying the direction of the center arrow among a series of five arrows. The center arrow was either congruent (pointing in the same direction; “>>>>”) or incongruent (pointing in the opposite direction; “>><>>”) to the other arrows. All blocks contained an equal number of congruent and incongruent flankers. This particular task was used because it is relatively simple and can be completed without unique competency. Responses to the flankers were also made by pressing the left or right shift keys on the keyboard.

After their responses to each flanker, feedback on whether they were successful or not appeared on the screen for 2000 ms. Feedback consisted of a green checkmark if they were successful on the trial or a red “X” if they were not successful on the trial (see Figure 1 for full sample trial sequence). To be successful in trials, participants were told they needed to be both fast and accurate with their responses to the flankers. Participants were told challenging trials would be more difficult than the practice trials, but easy trials would be easier than practice trials, although flanker difficulty was never altered. Feedback was also manipulated so that participants were successful in approximately 50% of trials in both conditions. As a manipulation check for perceived task difficulty, and since we were manipulating feedback, participants were asked to respond to questions regarding their predicted percentage of success prior to the start of each block and perceived percentage of success after completing each block (on a 9-point Likert scale). This would inform us of

their distinction between perceived difficulty for challenging vs. easy trials. Finally, participants were asked about the extent of their enjoyment and interest toward trials in each condition following each block (on a 7-point Likert scale).

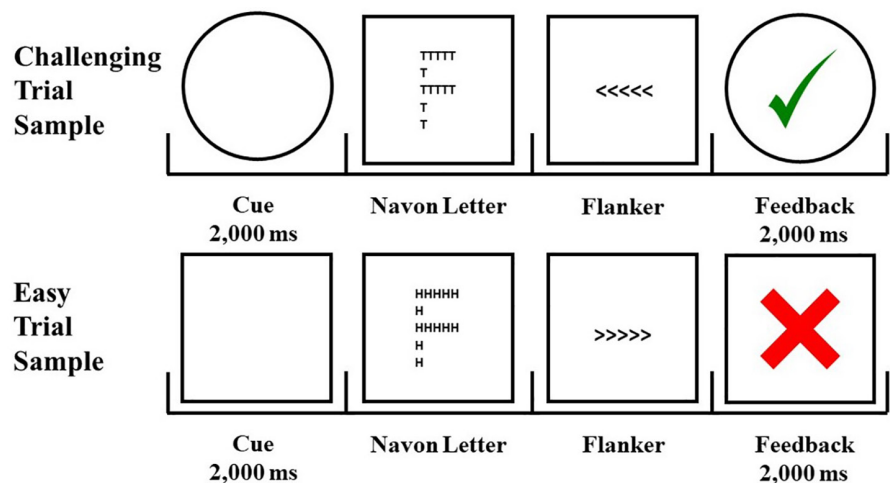
3.3 | Data collection and pre-processing

Experiment 1 was completed at a computer using Inquisit Lab stimulus presentation software (Inquisit 4.0.10, 2015). RTs to the Navon letters and flankers were logarithmically transformed. Trials with incorrect responses for the Navon letters and flankers (<15% and <14% respectively) were removed from reaction time analyses. Participants for whom RTs or beta activity were more than 3 standard deviations from the mean (<5% of the sample) were excluded from analyses on a listwise basis for that analysis (Fazio, 1990; Gable & Harmon-Jones, 2008; Threadgill & Gable, 2016). Moreover, due to this within-subject design, and subsequent repeated measures analyses, data were naturally listwise deleted.

3.4 | Electroencephalography processing

Electroencephalography (EEG) was recorded from 64 tin electrodes mounted in a stretch lycra Quick-Cap (Electro-Cap, Eaton, OH; Experiment 2) or a 64-channel actiCap (Brain Products GmbH, Gilching, Germany; Experiments 1 and 3) and referenced online to the left earlobe. A ground electrode was mounted midway between FPz and Fz (Quick-Cap) or at site FPz (actiCap). Electrode caps were 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 (Quick-Cap) or 30,000 Ω (actiCap). Electro-Cap recordings were amplified with NeuroScan SynAmps RT

FIGURE 1 Experiment 1 challenging and easy trial sample sequences. A variable ISI between 500 and 700 ms followed each cue, Navon letter, and flanker in each trial. Stimuli were presented over a black background on the computer screen.



amplifier units (El Paso, TX). Brain Products recordings were amplified with a Brain Vision actiCHamp amplifier (Brain Products GmbH, Gilching, Germany). All data were digitized at 500 Hz.

All recordings were analyzed offline using BrainVision Analyzer 2.1 (Brain Products, Gilching, Germany). Recorded data were low-pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, and notch filtered at 60 Hz (Butterworth zero-phase filters). A filter slope was set at 12 dB per octave. Eye blinks were corrected by using an ICA-based ocular artifact rejection function within the Brain Vision Analyzer software (electrode FP1 served as the VEOG channel). Individual channels were then artifact-inspected using an automated procedure, with artifacts defined as a step of 50 μV in a 100-ms interval, a 180 μV change within a 160-ms interval, a change $<0.5 \mu\text{V}$ within a 100-ms interval, and signals exceeding $\pm 180 \mu\text{V}$. After automatic artifact rejection, data were visually inspected again to ensure proper correction. Data were also re-referenced offline to an average ears reference. The duration of all epochs for beta frequency analyses was 1024 ms and was extracted during the cue time window (2000 ms) for each trial (i.e., when participants saw white circles and squares representing the start of each trial). These were extracted using a Hamming window, where consecutive epochs within the 2000 ms window where participants saw a cue overlapped by 50%, yielding 4 epochs per trial for both conditions. Each participant had a minimum of 150 epochs per condition. Power spectra were calculated using a fast Fourier transform and power values for the beta band (13–30 Hz) were averaged across all epochs and regions of the head at sites over the motor cortex: C1, C2, C3, C4, C5, C6, CP1, CP2, CP3, CP4, CP5, and CP6 (Gable, Threadgill, Adams, 2016; McFarland et al., 2000; Muthukumaraswamy et al., 2004; Pfurtscheller et al., 2005; R  ther et al., 2014; Threadgill & Gable, 2018a).

4 | EXPERIMENT 1 RESULTS

4.1 | Manipulation checks

A pair of dependent-samples *t*-tests were used to test for participants' perceived difficulty. Participants expected to perform worse in the challenging condition ($M = 3.782$, $SD = 1.683$) than in the easy condition ($M = 5.778$, $SD = 1.886$), $t(52) = -7.971$, $p < .001$, $d = 1.105$. Participants also perceived doing worse in the challenging condition ($M = 4.360$, $SD = 1.637$) than in the easy condition ($M = 5.171$, $SD = 1.672$), $t(52) = -5.669$, $p < .001$, $d = 0.787$. These results suggest participants perceived challenging trials to be more difficult than the easy trials before trials and after trials. Based on this evidence, this

was a strong manipulation of perceived difficulty even though task difficulty was not altered across conditions. Participants did not differ in enjoyment and interest between conditions ($ps = .790$ and $.862$, respectively).

4.2 | Beta activation

A repeated measures ANOVA revealed beta activity was significantly more suppressed in the challenging condition ($M = 1.723$, $SD = 0.797$) than in the easy condition ($M = 1.773$, $SD = 0.828$), $F(1, 53) = 7.12$, $p = .010$, $\eta_p^2 = .118$. These results suggest participants engaged in greater motor-action preparation prior to challenging vs. easy trials, indicative of greater motivational intensity toward the more challenging task (see Figure 2a and Figure 2b for bar and paired observation plot graphs of challenging versus easy trial cues; see Figure 3a for beta-band topographic difference map between challenging and easy trial cues).

4.3 | Attentional narrowing and reaction time performance

A 2 (Challenging vs. Easy) \times 2 (Global vs. Local) repeated measures ANOVA on Navon letter RTs did not reveal any significant main effects ($ps = .095$ and $.284$, respectively). There was no interaction ($p = .617$). A 2 (Challenging vs. Easy) \times 2 (Congruent vs. Incongruent) repeated measures ANOVA on flanker RTs revealed only a significant main effect for congruent vs. incongruent, $F(1, 51) = 33.330$, $p < .001$, $\eta_p^2 = .395$, where participants were faster at responding to congruent vs. incongruent trials. A 2 (Challenging vs. Easy) \times 2 (Congruent vs. Incongruent) repeated measures ANOVA on flanker accuracy revealed a significant main effect for congruent vs. incongruent, $F(1, 51) = 9.208$, $p = .003$, $\eta_p^2 = .152$, where participants were more accurate at responding to congruent vs. incongruent trials. These results suggest that participants were faster and more accurate at responding to the congruent flankers vs. incongruent flankers altogether but did not differ by achievement condition-type.

5 | EXPERIMENT 1 DISCUSSION

Results for Experiment 1 revealed that the degree of *perceived* difficulty in beating one's past performance was greater for the challenging trials than the easy trials. This perceived difficulty remained at the end of the task, indicating the manipulation was effective at creating achievement motivation throughout the experiment. In addition,

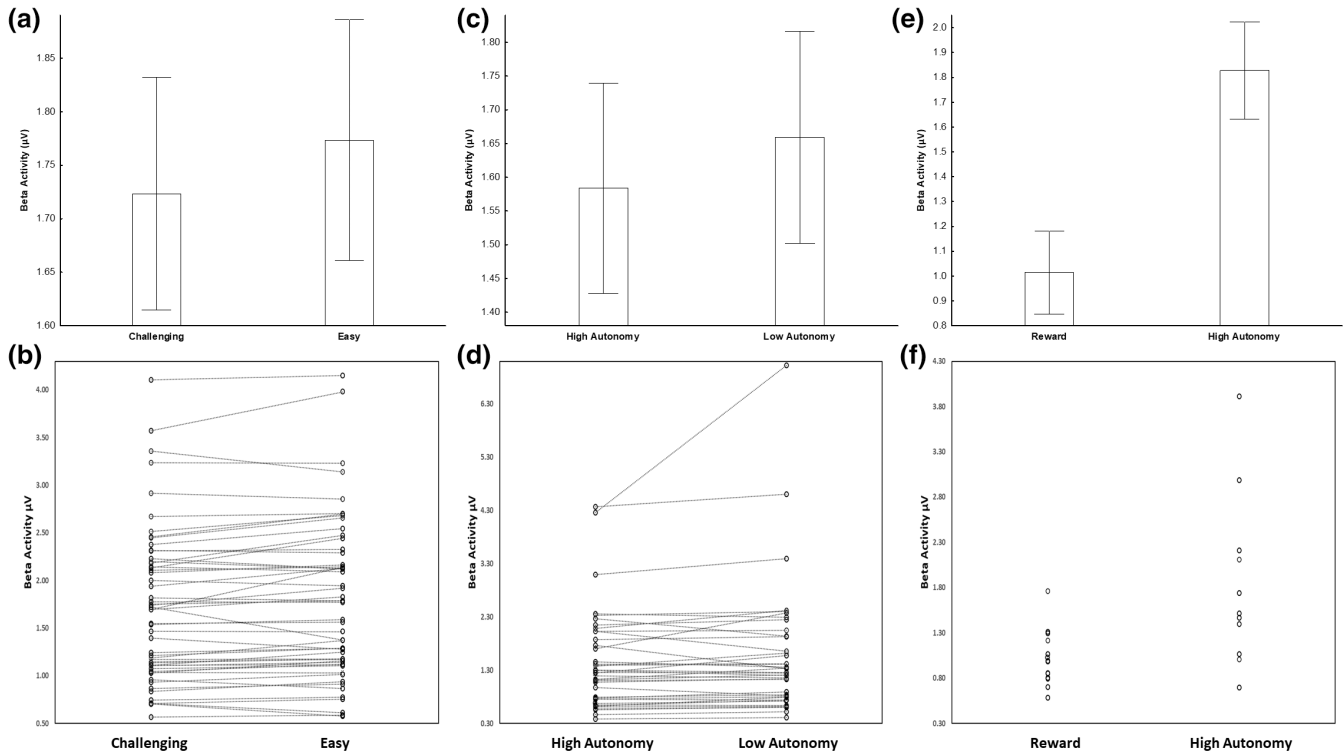


FIGURE 2 Bar and paired observation plot graphs for beta activity between trial cues for experiments 1–3. For bar graphs, all error bars indicate standard errors from the mean (a, c, and e). (a). Experiment 1: Beta activation bar graph between challenging and easy trial cues. (b) Experiment 1: Beta activation paired observation plot between challenging and easy trial cues. (c). Experiment 2: Beta activation bar graph between high autonomy and low autonomy trial cues. (d). Experiment 2: Beta activation paired observation plot between high autonomy and low autonomy trial cues. (e). Experiment 3: Beta activation bar graph between reward (extrinsically oriented) and high autonomy (intrinsically oriented) trial cues. (f). Experiment 3: Beta activation plotted observations. These were not paired since experiment 3 was between-subjects, but these were nevertheless plotted to reflect the consistency of individual observations with results.

achievement-based intrinsic motivation toward challenging trials enhanced neural motor-action preparation by suppressing cortical beta activation. This is in line with past research suggesting that intrinsic motivators can enhance motivational intensity (Wilhelm et al., 2019). Although this form of intrinsic motivation was motivationally intense to sufficiently evoke motor-action preparation, the motivational intensity may not have been high enough to narrow the attentional scope. Additionally, there was no change in self-reported enjoyment or interest, suggesting that this type of motivation did not enhance positive affect, per se. Overall, an achievement paradigm to outperform one's self in challenging vs. easy trials significantly enhanced difficulty and neural correlates of motor-action preparation. These results suggest that achievement motivation increased motivational intensity, as reflected by neural motor-action preparation.

6 | EXPERIMENT 2

Experiment 2 sought to examine neural motor-action preparation from a different intrinsic motivator: Autonomy.

Autonomy was created by giving participants autonomous choices over tasks and feedback, manipulations shown to enhance intrinsic motivation (Legault & Inzlicht, 2013; Leotti & Delgado, 2011; Sanli et al., 2013; Wulf & Lewthwaite, 2016). Similar to Experiment 1, this experiment assessed neural motor-action preparation by measuring cortical beta activation, attentional scope using Navon letters, and performance to a modified flanker task. If an autonomous intrinsic motivator increases motivational intensity, we expected to see reduced beta activity, narrowed attention, and faster RTs in a high autonomy, relative to a low autonomy condition.

7 | EXPERIMENT 2 METHOD

7.1 | Participants

Forty-five ($n = 45$) undergraduate introductory psychology students participated for partial course credit. Data collection was pre-determined to stop at the end of one academic semester. To be included in the study, participants had to be at least 18 years old and be right-handed (same 13-item checklist from Experiment 1).

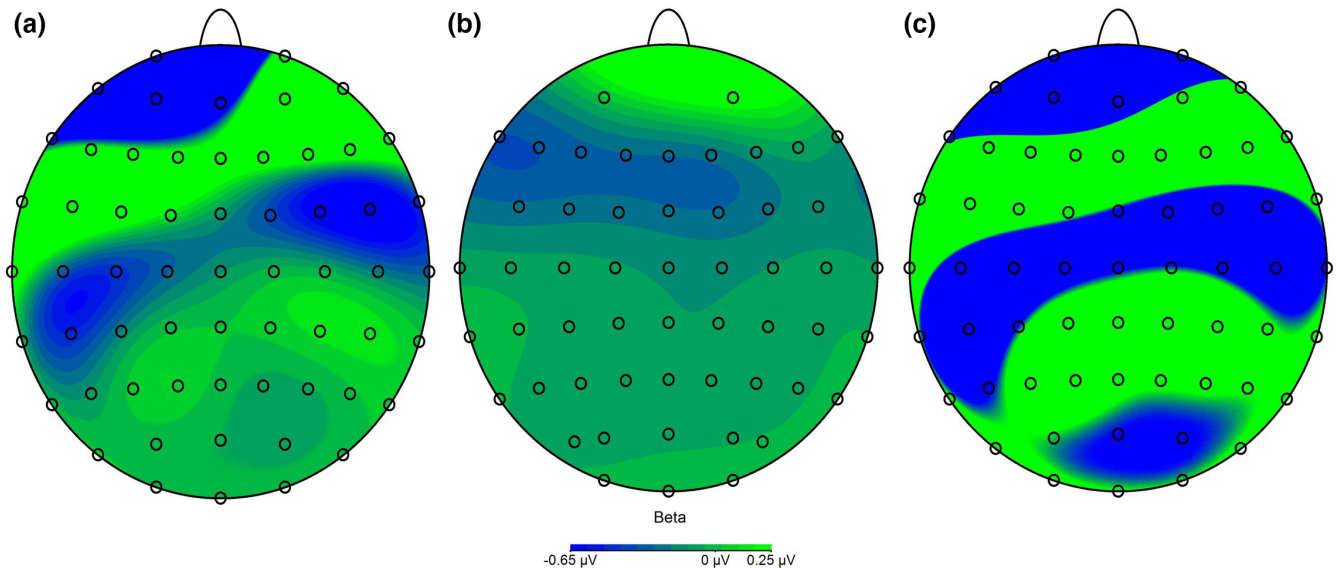


FIGURE 3 Beta band frequency (13–30 Hz) difference maps depicting topography differences between conditions. (a). Experiment 1: Topography difference map (challenging—easy) where darker blue over motor cortical regions suggests greater motor preparation (suppression of beta activation) for challenging versus easy trial cues. (b). Experiment 2: Topography difference map (high autonomy—Low autonomy) where darker blue over motor cortical regions would suggest greater motor preparation for high autonomy versus low autonomy trial cues. More positive values (green) would indicate greater suppression of beta activity for low autonomy versus high autonomy trial cues. (c). Experiment 3: Topography difference map (high autonomy—Reward) where darker blue over motor cortical regions suggests greater motor preparation for reward (extrinsically-oriented) versus high autonomy (intrinsically-oriented) trial cues.

7.2 | Procedure

After applying the EEG stretch lycra cap to their scalp, participants were asked to play a “*brain game*” consisting of a modified flanker’s task (Eriksen & Eriksen, 1974). Trials ($n = 120$) were broken up into 2 different games, with 3 blocks of 20 trials in each game. In the high autonomy condition, participants were given a choice over which task they could do. Regardless of which task they chose, participants unknowingly completed the same task. In addition, the high autonomy condition gave participants the choice of whether they wanted feedback on how well they did after every trial before the start of each of the 3 blocks. In the low autonomy condition, participants were told the experimenter picked the game for them and they were automatically assigned whether or not they would receive feedback.

In the high autonomy condition, participants were given a list of four games they could choose from that ostensibly described four different games (Legault & Inzlicht, 2013). The list of games was as follows: (1) The Mental Distraction Game. (2) A Game of Reactions. (3) Ignore Your Impulses. (4) Cognitive Response Test. Regardless of what choice the participant made, all participants unknowingly completed the same task. For the low autonomy game, participants were shown the same list but were told the experimenter had chosen a game for them.

Each trial sequence contained a cue, a Navon letter, a flanker, and feedback (just like in Experiment 1 (see

Figure 1 for a similar trial sequence). With this game, however, white circle cues indicated high autonomy trials, and white squares indicated low autonomy trials. In this experiment, participants had to respond to two different flanker tasks for the autonomy manipulation to appear real. In one of the flanker tasks, participants had the same flankers as those in Experiment 1. The other flanker task was similar; however, instead of using arrow flankers, it presented words on the left or right side of the computer screen that said “RIGHT” or “LEFT.” Congruent stimuli appeared on the correct side of the screen (e.g., “RIGHT” appearing on the right side of the screen), but incongruent stimuli appeared on the other opposite side of the screen (e.g., “LEFT” appearing on the right side of the screen). Participants pressed the right or left shift key to indicate the direction of the center arrow or what the word said. It was necessary to have participants complete different types of flanker’s tasks to create perceived high autonomy (choice) on one of the tasks, but low (no choice) on the other task. Task order (i.e., high autonomy task first or high autonomy task second) was counterbalanced between participants. Because both tasks were flanker-type tasks, task type was collapsed for RT analyses.

Once again, feedback consisted of a green checkmark if they were successful on the trial or a red “X” if they were not successful on the trial. These were displayed inside the same shape as the initial cue for that trial: white circles or white squares. To be successful on the trials,

participants were told they had to be both fast enough and accurate with their responses. Unbeknownst to the participants, feedback was manipulated so that participants won approximately 50% of trials in both conditions to ensure a similar number of wins and losses across conditions (see [Figure 1](#) for a sample trial sequence). After each game, participants were asked to report how much of a choice they had over the task and feedback on scales ranging from 1 (*It was entirely out of my hands*) to 7 (*It was entirely up to me*). Finally, participants were asked their degree of effort and enjoyment (on a 7-point Likert scale).

7.3 | Data collection, pre-processing, and EEG processing

Experiment 2 was completed at a computer using Inquisit Lab stimulus presentation software (Inquisit 4.0.10, 2015). RTs to the Navon letters and flankers were logarithmically transformed. Trials with incorrect responses for the Navon letters and flankers (<30% and <16% respectively) were removed from reaction time analyses. Participants for which RTs or beta activation were more than 3 standard deviations from the mean (<13% of the sample) were excluded from analyses on a listwise basis for that analysis (Fazio, 1990; Gable & Harmon-Jones, 2008; Threadgill & Gable, 2016). EEG processing was kept consistent with that of Experiment 1 (see Section 3.4).

8 | EXPERIMENT 2 RESULTS

8.1 | Manipulation checks

A series of dependent-samples *t*-tests were used to test perceived choice over tasks, choice over feedback, self-reported effort, and task enjoyment in the high autonomy vs. low autonomy conditions. Participants felt they had more task-choice during the high autonomy ($M = 6.288$, $SD = 1.516$) than the low autonomy condition ($M = 2.288$, $SD = 2.252$), $t(44) = 9.681$, $p < .001$, $d = 1.444$. Participants also felt they had more feedback-choice during the high autonomy ($M = 5.755$, $SD = 1.798$) than the low autonomy condition ($M = 2.755$, $SD = 2.112$), $t(44) = 7.370$, $p < .001$, $d = 1.099$. When asked about enjoyment, participants reported more enjoyment for the high autonomy ($M = 3.911$, $SD = 1.534$) than the low autonomy condition ($M = 3.400$, $SD = 1.513$), $t(44) = 2.859$, $p = .006$, $d = 0.426$. Participants did not report putting more effort in the high autonomy than the low autonomy condition ($p > .560$). These results suggest the manipulation of high autonomy was consistent with making participants feel like they had

a choice over the task and feedback and that participants enjoyed the high autonomy condition more.

8.2 | Beta activation

A repeated measures ANOVA revealed beta activity did not differ between the high autonomy condition ($M = 1.58$, $SD = 0.97$) and low autonomy condition ($M = 1.66$, $SD = 0.98$), $F(1, 38) = 2.834$, $p = .100$, $\eta_p^2 = .069$. High autonomy did not significantly influence motor-action preparation relative to the low autonomy condition (see [Figure 2c](#) and [Figure 2d](#) for bar and paired observation plot graphs of high autonomy versus low autonomy trial cues; see [Figure 3b](#) for beta-band topographic difference map between high autonomy and low autonomy trial cues).

8.3 | Attentional narrowing and reaction time performance

A 2 (High autonomy vs. Low autonomy) \times 2 (Global vs. Local) repeated measures ANOVA on Navon RTs revealed no significant main effects for autonomy or letter type ($ps = .166$ and $.092$ respectively). There was no interaction ($p = .089$). A 2 (Autonomy Task: Arrows vs. Words) \times 2 (Arrows vs. Words) \times 2 (Congruent vs. Incongruent) mixed ANOVA on the flanker RTs revealed no three-way interaction ($p = .581$), suggesting there was no RT difference in the flanker-type task (arrows or words). Because there was no three-way interaction as a function of task type, task type was collapsed. A 2 (High autonomy vs. Low autonomy) \times 2 (Congruent vs. Incongruent) repeated measures ANOVA on flanker RTs revealed a significant main effect for high autonomy vs. low autonomy, $F(1, 44) = 6.520$, $p = .014$, $\eta_p^2 = .129$, where participants were faster to respond to the low autonomy vs. high autonomy flankers. There was a significant main effect for congruent vs. incongruent flankers, $F(1, 44) = 126.080$, $p < .001$, $\eta_p^2 = .741$, such that participants responded faster to the congruent vs. incongruent flankers. The interaction was not significant ($p = .271$).

A 2 (Autonomy Task: Arrows vs. Words) \times 2 (Arrows vs. Words) \times 2 (Congruent vs. Incongruent) mixed ANOVA on flanker accuracy revealed no three-way interaction ($p = .428$), suggesting there was no accuracy difference in the flanker-type task (arrows or words). Because there was no three-way interaction as a function of task type, task type was collapsed. A 2 (High autonomy vs. Low autonomy) \times 2 (Congruent vs. Incongruent) repeated measures ANOVA on flanker accuracy revealed a significant main effect for high autonomy vs. low autonomy,

$F(1, 44) = 6.614, p = .013, \eta_p^2 = .130$, such that participants were more accurate to low autonomy vs. high autonomy flankers. There was a significant main effect for congruent vs. incongruent flankers, $F(1, 44) = 45.320, p < .001, \eta_p^2 = .507$, such that participants were more accurate at responding to the congruent vs. incongruent flankers. The interaction was not significant ($p = .392$). Altogether, these results suggest that participant performance was slower and less accurate in the high autonomy relative to the low autonomy condition.

9 | EXPERIMENT 2 DISCUSSION

Participants reported greater perceived autonomy over the task and feedback in the high autonomy vs. low autonomy condition. This is consistent with past research on manipulating autonomy motivation (Legault & Inzlicht, 2013). In addition, the high autonomy condition elicited greater enjoyment than the low autonomy condition, another key component of autonomous motivation (Black & Deci, 2000; Deci et al., 2001; Demir et al., 2011). Overall, results for Experiment 2 revealed the high autonomy condition evoked a strong manipulation of autonomy.

Results of beta activity did not reveal differences between the high and low autonomy conditions; this type of intrinsic motivator did not enhance motor-action preparation. Perhaps indicative of this finding, participants were slower and less accurate at responding to a simple flanker task in the high autonomy condition as compared to the low autonomy condition. Together, these results suggest that autonomy increased perceived control and enjoyment but did not elicit neural motor-action preparation. This would suggest that autonomy may be low in motivational intensity.

Despite evidence that intrinsic motivation is low in motivational intensity, it may be difficult to interpret the null effect with beta activity, as the potential for an effect may depend on a measure sensitive enough to detect such an effect (Gable & Harmon-Jones, 2013; Harmon-Jones, 1999). It is important to note that participants not only self-reported feeling more control in the high autonomy condition, but also more enjoyment, relative to the low autonomy condition. These are central factors in promoting intrinsic motivation (Deci & Ryan, 2008; Demir et al., 2011) and are also consistent with similar manipulations that elicit autonomy and effort (Legault & Inzlicht, 2013). One potential explanation is that the low autonomy condition may have also elicited reactance motivation in which individuals sense a lack of control (i.e., low autonomy) and react to it with enhanced motivation (e.g., to finish a task/game; see Brehm & Brehm, 1981 for

a more in-depth description of reactance motivation). Recent evidence suggests this reactance to freedom restrictions does elicit psychophysiology indicative of greater approach motivation (i.e., greater left frontal asymmetry; Mühlberger et al., 2020). Another alternative explanation is that motivational intensity may have been high in both high and low autonomy conditions, thus causing the null effect. Regardless of these speculations, it is not possible to interpret the causes of the observed null effect. In light of these results, we sought to partially test one of these alternative explanations by comparing high autonomy to an extrinsic motivator known to be high in motivational intensity: the reward of winning candy.

10 | EXPERIMENT 3

In light of the beta activation results in Experiment 2, Experiment 3 sought to further compare the role of motivational intensity across motivational contexts by examining high autonomy, an intrinsic motivator, directly compared to extrinsic motivation toward winning a reward: candy. Winning candy, sweets, or points have been shown to enhance neural motivated processing similar to monetary rewards in prior lab experiments (i.e., Clithero et al., 2011; Threadgill & Gable, 2018b; Tunison et al., 2019). To examine whether high autonomy was low in motivational intensity, it is necessary to compare it to a condition high in motivational intensity.

Like Experiments 1 and 2, Experiment 3 assessed performance, attention, and motor-action preparation using a modified flanker task. The motivational context that enhances motivational intensity should show enhanced performance, attention, and neural motor-action preparation. Based on results from Experiment 2, we expected autonomy to be lower in motivational intensity as compared to winning a reward and pre-registered this prediction (<https://aspredicted.org/r7yc5.pdf>). As such, winning points for candy should enhance performance, attention, and neural motor-action preparation, relative to a high autonomy intrinsic motivator.

11 | EXPERIMENT 3 METHOD

11.1 | Participants

Thirty-one ($n = 31$) undergraduate introductory psychology students participated in this optional experiment that followed a different study for which they received partial course credit. Data collection for this study began about halfway through the academic year and ran until in-person data collection was no longer

possible due to the Covid-19 pandemic. To be included in the study, participants had to be at least 18 years old and be right-handed (the same 13-item checklist from Experiments 1 and 2).

11.2 | Procedure

Participants were run in a between-subjects design because past research suggests that extrinsic motivators can diminish intrinsic motivation (Deci et al., 1999, 2001). After applying the EEG stretch lycra cap, participants were randomly assigned to either the extrinsic (reward) or intrinsic (autonomy) condition. In both conditions, participants were asked to play a reaction time game consisting of shortened modified flanker tasks similar to the ones used in Experiments 1 and 2 (i.e., an arrows flanker task). To elicit high motivational intensity for both conditions, those in the extrinsic condition completed trials to win points for candy, while those in the intrinsic condition completed trials where they had high autonomy over the task (control over game and feedback). Each trial sequence for each condition ($n = 48$) consisted of a cue, a Navon letter, a flanker, and feedback (see Figure 1 for a similar trial sequence). In the reward (extrinsic) condition, participants were told they would get “+5” points for every successful trial and “+0” points for every unsuccessful trial. They could then exchange their points at the end of the study for candy. Their feedback included the “+5 or 0 points” in addition to the green checkmark or red “X.” In the autonomy (intrinsic) condition, participants were asked to complete the same task as participants in the high autonomy condition in Experiment 2. Because participants were only exposed to the *high autonomy* condition, it meant they only had to complete one task when assigned to the autonomy (intrinsic) condition. This also meant the conventional arrow flankers (>>>>>; >><>>) were used in both reward and autonomy conditions. Feedback was once again manipulated so that participants were successful on approximately 50% of trials for both conditions as well. Finally, participants were asked their degree of effort and enjoyment (on a 7-point Likert scale).

11.3 | Data collection, pre-processing, and EEG processing

Experiment 3 was completed at a computer using Inquisit Lab stimulus presentation software (Inquisit 4.0.10, 2015). RTs to the Navon letters and flankers were logarithmically transformed. Trials with incorrect responses for the Navon letters and flankers (<20% and <19% respectively)

were removed from reaction time analyses. Participants for which RTs or beta activation were more than 3 standard deviations from the mean (<15% of the sample) were excluded from analyses on a listwise basis for that analysis (Fazio, 1990; Gable & Harmon-Jones, 2008; Threadgill & Gable, 2016). EEG processing was kept consistent with that of Experiments 1 and 2 (see Section 3.4).

12 | EXPERIMENT 3 RESULTS AND DISCUSSION

12.1 | Beta activation

A one-way ANOVA revealed beta activity was significantly more suppressed in the reward condition ($M = 1.014$, $SD = 0.293$) than in the autonomy condition ($M = 1.828$, $SD = 0.942$), $F(1, 24) = 9.980$, $p = .004$, $\eta_p^2 = .293$. These results suggest participants who received points candy in the extrinsic reward condition had greater motor-action preparation than participants who were given autonomous control (i.e., over task and feedback in the intrinsic condition; see Figure 2e for bar graph and Figure 2f plotted observation graphs of reward versus high autonomy trial cues; see Figure 3c for beta-band topographic difference map between reward and high autonomy trial cues).

12.2 | Manipulation check, attentional narrowing, and reaction time performance

Independent sample t tests were conducted for self-reported effort and enjoyment. These revealed no difference in effort ($p = .193$) and enjoyment ($p = .849$) between reward and autonomy conditions, suggesting similar motivational intensity between these two conditions of interest. A 2 (Reward vs. Autonomy) \times 2 (Global vs. Local) mixed ANOVA on Navon RTs revealed no significant main effects or interaction ($p = .686$, $p = .230$, and $p = .326$, respectively). This indicated that participants' attentional narrowing did not differ between conditions. A 2 (Reward vs. Autonomy) \times 2 (Congruent vs. Incongruent) mixed ANOVA on flanker RTs only revealed a significant main effect for congruent vs. incongruent flankers, $F(1, 29) = 22.820$, $p < .001$, $\eta_p^2 = .440$, such that participants were faster to the congruent vs. incongruent flankers (main effect for condition and interaction were not significant, $p = .554$ and $p = .109$ respectively). This suggests participants were just as fast in both the reward and autonomy conditions. A 2 (Reward vs. Autonomy) \times 2 (Congruent vs. Incongruent) mixed ANOVA on flanker accuracy only revealed a significant main effect for condition, $F(1, 29) = 10.119$, $p = .003$, $\eta_p^2 = .258$, such that

participants were significantly more accurate to flankers in the reward condition vs. autonomy condition (main effect for flanker type and interaction were not significant, $p = .776$ and $p = .398$, respectively). Altogether, these results suggest that participants had better performance in the reward condition (vs. autonomy).

13 | GENERAL DISCUSSION

Taken together, the results of three experiments indicate that motor-action preparation, as reflected by beta activation, is different across types of intrinsic motivators. Some types of intrinsic motivators increase the motivational intensity, but other types of intrinsic motivators may not alter motivational intensity. Specifically, Experiment 1 demonstrated that high (vs. low) achievement motivation suppressed beta activation. Experiment 2 found no difference in beta activity and reaction times between a high (vs. low) autonomy motivation. Finally, Experiment 3 showed that high autonomy motivation (intrinsic) was higher in beta activation relative to potential reward outcomes (extrinsic), suggesting that intrinsic autonomy motivation was lower in approach motivational intensity than extrinsic rewards.

Neural movement preparation is beneficial for the study of motivation as an indicator of potential energy or action that can be allocated toward the pursuit of an activity or object, a core facet of motivation (Harmon-Jones & Gable, 2018). Recent work on motivation finds beta activation is suppressed when motivational intensity is high (Gable, Threadgill, Adams, 2016; Meadows et al., 2016; Meyniel & Pessiglione, 2014; Wilhelm et al., 2019, 2021). Experiment 1 results indicate that the opportunity to outperform oneself during difficult trials (vs. easy trials) within an achievement motivation context may have been more motivating, as reflected by enhanced neural motor preparation. These results are also consistent with prior work on achievement motivation and task difficulty leading to enhanced motivation (Inzlicht et al., 2018; Morisano et al., 2010; Urdan & Kaplan, 2020).

Experiment 3 investigated whether high autonomy was low in motivational intensity relative to an extrinsic reward condition. Results revealed that high autonomy has reduced motor-action preparation, as compared to an extrinsically oriented condition. This suggests that autonomy evoked weaker motivational intensity relative to an extrinsic reward. However, additional studies may consider additional comparative conditions and higher-powered within-subjects samples that may further replicate this effect. Doing so could also provide additional physiological evidence for whether extrinsic motivators also undermine intrinsic motivators (Murayama

et al., 2010) when motivated motor movement is necessary, as these undermining effects are not universal in those eliciting diminished preferences for intrinsic motivators (Marsden et al., 2015).

Results for Experiment 2 revealed that the autonomy manipulation had its intended effect, such that a high autonomy manipulation increased self-reported enjoyment and self-reported control over task parameters (i.e., task choice and feedback choice) relative to low autonomy manipulation. These findings are consistent with past work suggesting that autonomous control and enjoyment are important components that foster intrinsic motivation (Black & Deci, 2000; Demir et al., 2011; O'Donnell et al., 2013). However, greater autonomy did not reveal relative differences in greater motor action preparation as measured by beta activity and better behavioral performance.

Some past literature investigating autonomy suggests that autonomy fosters self-regulation and self-efficacy to promote learning to increase performance (Legault & Inzlicht, 2013; Sanli et al., 2013; Wulf & Lewthwaite, 2016). If autonomy manipulations also enhance self-control, it may be possible that suppression of beta activity may become less sensitive or immediate on tasks that require quick reaction performance but do not require learning or motor learning prior to impending movement. Additional studies are needed to further replicate these findings to be able to more confidently rule out the possibility that both low and high autonomy manipulations are low in motivational intensity.

One limitation in these experiments may be a lack of consistent attentional and performance differences within or across motivation types. Presumably, if beta activation relates to motivation (i.e., faster RTs), then suppression of beta activity should also cause faster RTs. However, beta activation is related to tendencies for planned or purposeful movement, rather than just mere impulsive or reflexive behavior (Threadgill & Gable, 2018a). Decreased beta activity may not always lead to physical or observable movement reflected in behavioral responses. This is in line with prior work suggesting that suppression of cortical beta activity over the motor cortex reflects *potential* neural preparation for *future* cell firing and may not always occur concurrently with observable motor movements (Grammont & Riehle, 2003; van Wijk et al., 2012). Beta activity, then, is thought to reflect a crucial “gating” role in physical movement, as greater beta activity slows movement activation (Chen et al., 2007; Engel & Fries, 2010; Pogosyan et al., 2009). Because this gating role of beta activation is the precursor to potential cell firing, it reflects the first signs of neural activation toward the potential for required movement. This makes beta activation potentially one of the most immediate indicators of motivational

intensity; as beta activity suppression seemingly must occur for enhanced motor movement, but enhanced motor movements do not always follow suppressed beta activity. In the case of this body of work, the beta activation results seem to reflect this immediate neural preparation necessary for motivational strength processes (i.e., movement).

Another potential limitation of this work stems from the observed power from the sample size available for these experiments during the academic semesters they were each collected. Post-hoc power analyses using the WebPower package in R (version 0.6; Zhang et al., 2021) suggest experiments 1 and 2 had an adequate degree of power ($1-\beta$) to detect medium effects (Cohen, 1988). Importantly, experiment 1 had adequate power (.776) to detect an effect between two beta activation conditions of achievement (calculated $f^2 = 0.25$, $\alpha = 0.05$, $n = 54$, n of tested groups = 1, n of measurements = 2, $r = 0.5$). Similarly, experiment 2 also had adequate power (.732) to detect a medium effect between two beta activation conditions of autonomy (calculated $f^2 = 0.25$, $\alpha = 0.05$, $n = 39$, n of tested groups = 1, n of measurements = 2, $r = 0.5$). Although results for beta activity in experiment 3 were in line with our pre-registered predictions (<https://aspre dictated.org/r7yc5.pdf>), this post hoc power analysis did not reveal ideal power under the same conventions (.203; calculated $f^2 = 0.25$, $\alpha = 0.05$, $n = 26$, n of tested groups = 2). Because of this, results should be interpreted with caution and should be replicated in future research. Although experiment 3 was primarily run to examine if high autonomy manipulations would differ from a conventional high motivation condition (i.e., reward), future research should attempt this to examine potential modulations that added extrinsically neutral and low autonomy conditions may reveal. However, results for experiment 3 seem to provide subsequent confirmatory evidence that high autonomy may not necessarily enhance motivational intensity. This is similar to our findings in experiment 2 which suggested high autonomy did not enhance motor preparation over a low autonomy condition. Moreover, several studies have already indicated that a reward condition significantly enhances motivation and its motor preparation processes as compared to no-reward conditions (Gable, Threadgill, & Adams, 2016; Meadows et al., 2016; Threadgill & Gable, 2018b).

Across all studies, attentional breadth did not differ between conditions. Perhaps the manipulated intrinsic motivators were not intense enough to influence attentional breadth. These motivational paradigms, however, may still influence other forms of attention that may not require actions, like a cognitive breadth of memory (Gable & Harmon-Jones, 2010a; Gable, Threadgill, & Adams, 2016). Further research should explore attentional differences within the scope of different motivators, as these are

conceptually important within motivation and learning frameworks (Wulf & Lewthwaite, 2016).

Lastly, it is important to note that these experiments examined neural preparation for a few seconds prior to motor movement. As a result, prolonged levels of neural motor preparation were not examined. Future studies should examine whether different manipulations of motivation moderate neural motor preparation over prolonged periods, especially since intrinsic motivation literature suggests intrinsic factors promote sustained motivation (Deci et al., 1999, 2001; Deci & Ryan, 2008; Demir et al., 2011; Ryan & Deci, 2000a, 2000b). Future research examining motor preparation through beta activation would also benefit from additional metrics of frequency bands. For example, time-frequency analyses which enable examination of a broader frequency range within time windows to better inform researchers on the activation strength of individual frequency bins within the wide range of beta-band activity (13–30 Hz) activity (Glazer et al., 2018). Additionally, further examination of beta activation as a measure of motor-action planning is still needed and could prove useful in motivation research. Specifically, examining beta activity provides a venue to investigate an objective physiological precursor to motivated actions which can complement extant theories of motivation (Di Domenico & Ryan, 2017; Gable & Harmon-Jones, 2010b; Ryan & Deci, 2000a, 2000b), as well as inform new questions and developing theories relevant to motivational research and additional physiological systems of movement (de Echegaray & Moratti, 2021; Kelley et al., 2019; Legault & Inzlicht, 2013; Locke & Schattke, 2019; Wulf & Lewthwaite, 2016).

13.1 | Conclusion

The current experiments sought to investigate motivational intensity within differing intrinsic motivators by examining neural motor-action preparation. Our results found that an achievement manipulation of motivation enhanced motor-action preparation (Experiment 1), but manipulation of autonomy had no effect relative to lower autonomy manipulation (Experiment 2). In addition, autonomy motivation was relatively weaker than more extrinsically oriented manipulation of motivation (Experiment 3). Together, these results demonstrate that motivational intensity varies within motivators of the same category (e.g., extrinsic and intrinsic). These experiments are some of the first, to examine the dimension of motivational intensity across various types of motivators. Using a neurophysiological measure of action preparation, a correlate of motivational intensity, to examine differences in motivational states may help to detect changes

in motivational intensity that may otherwise go undetected by behavioral or even cognitive measures. These results are part of a growing body of work demonstrating the need for research on motivation and its physiological underpinnings (Di Domenico & Ryan, 2017; Wilhelm et al., 2019). Together, this work may suggest a new focus in the ways motivation categories and dimensions are examined in the research.

AUTHOR CONTRIBUTIONS

Ricardo A. Wilhelm: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; supervision; validation; visualization; writing – original draft; writing – review and editing. **A. Hunter Threadgill:** Formal analysis; software; writing – review and editing. **Philip A Gable:** Conceptualization; methodology; project administration; supervision; validation; visualization; writing – original draft; writing – review and editing.

ORCID

Ricardo A. Wilhelm  <https://orcid.org/0000-0003-2600-0263>

A. Hunter Threadgill  <https://orcid.org/0000-0003-3620-5959>

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