Using Facial Electromyography to Test Competing Accounts of the Affective Consequences of Response Inhibition for Visual Stimuli

by

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ABSTRACT

USING FACIAL ELECTROMYOGRAPHY TO TEST COMPETING ACCOUNTS OF THE AFFECTIVE CONSEQUENCES OF RESPONSE INHIBITION

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Inhibition used to refrain from responding to undesirable or goal conflicting stimuli has affective consequences that alter the emotional evaluation of the inhibited item, resulting in relatively negative subjective ratings. Two competing explanatory accounts of this effect exist. These accounts differ by whether inhibition immediately elicits negative affect or only impacts emotion in subsequent evaluation. Here, using two facial electromyography (fEMG) methods, we investigate the feasibility of using an indirect-psychophysiological approach to define when affective correlates of inhibition occur. When facial muscle responses related to negative-affect happened was used as evidence for when inhibition likely has emotional consequences, extending previous findings that have relied primarily on subjective ratings. These negative emotion-related muscle responses were found at the time of inhibition, suggesting inhibition causes immediate negative affect. An overall assessment of the fEMG approaches, and the overall effectiveness of using this psychophysiological measure for this investigation are addressed.
Dedication

For my Jason. For inspiring me and putting up with me.

I only hope you one day may read it and understand.

Keep dreaming, aspiring, and questioning.
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Using facial electromyography to test competing accounts of the affective consequences of response inhibition for visual stimuli

Attention and emotion work together as the brain’s main prioritization systems. Emotion determines that which is good and therefore should be approached, and that which is bad and therefore should be avoided. Cognitive operations act to enhance the processing of objects and events most relevant to our goals, and suppress the processing of things that are irrelevant or that might otherwise interfere with those intentions. What is becoming clear is that these systems do not engage in these processes separately, but rather work together in an inter-related manner to ensure our thoughts and actions are focused on the most helpful information. Due to this increased understanding, recent research has been interested in how the linkage of these systems has ramifications for stimuli undergoing processing during attention-based tasks.

Previous findings demonstrate that the use of attention- and motor-response inhibition to refrain from responding to an undesirable or a goal conflicting stimulus has negative affective consequences for the withheld-from item (i.e., Doallo et al., 2012; Raymond et al., 2005; Wessel et al., 2014). Affective consequences for inhibited stimuli are implicated by demonstrated changes in our thoughts and behaviours towards these items (i.e. De Vito & Fenske, 2017; Driscoll, de Launay, & Fenske, 2017; Fenske, Raymond, Kessler, Westoby & Tipper, 2005; Ferrey, Frischen, & Fenske, 2012; Frischen, Ferrey, Burt, Pistchik & Fenske, 2012; Kiss et al., 2008; Raymond, Fenske & Westoby, 2005; Shonberg et al., 2014; Wessel, O’Doherty, Berkebile, Linderman, & Aron, 2014). This expanding area of research has shown that inhibition results in a relatively negative evaluation of stimuli to which the control was required (De Vito & Fenske, 2017; Fenske, et al., 2005; Frischen, et al., 2012; Raymond, et al., 2005) as well as aversion and decreases in approach responses (Driscoll, et al., 2017; Ferrey, et al., 2012;
Shonberg et al., 2014; Wessel, et al., 2014). These demonstrated negative consequences for stimuli previously associated with inhibition have been found using a variety of stimuli that vary in their affective significance, including abstract patterns, common objects, and images of real scenes, faces and bodies, and the negative stimulus ratings occur across a range of subjective emotional impressions (e.g., cheerfulness, liking, attractiveness, trustworthiness, etc.). These emotional consequences for inhibited stimuli likely are intended to aid in guiding our attention in future encounters with the previously-inhibited stimulus.

While previous research has revealed many of the fundamental characteristics of the links between basic cognitive processes and the subsequent rating of stimuli, several questions remain about the point at which inhibition’s emotional consequences impact the affective evaluation of stimuli. While there is evidence that affect plays a role in mediating these changed evaluations of affective qualities (i.e. Doallo et al., 2012; Frischen et al., 2012), the specific underlying affective characteristics, as well as when the affective responses involved throughout the cognitive control process occur, are not yet well understood. This inquiry begins to fill this gap; an attempt to identify measures that can delineate the time course of affective responses that result during inhibition; findings which could discern between competing explanations proposing different affective time courses for inhibition’s negative affective consequences.

Here, I investigate the feasibility of using a psychophysiological approach that employs facial electromyography (fEMG) to explore affective correlates of inhibition-related devaluation to test these accounts. The investigation tests and contrast the effectiveness of a paradigm that has been adapted to incorporate this indirect measure. The project also tested alternative approaches to collecting and analyzing fEMG within cognitive-affective tasks. The experiment employed two fEMG data collection methods, allowing a comparison that can be used to
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determine the utility of different experimental approaches and their related equipment. An
overall assessment of the revised paradigm, the different fEMG methods, and the overall
effectiveness of using this psychophysiological measure to answer questions about inhibition’s
affective correlates as a means for testing these competing accounts are addressed.

1.1 Inhibition-related devaluation.

As earlier described, previous findings demonstrate that when attention is diverted to
ignore or withhold a response from a distracting item we subsequently have a more negative
affective evaluation of that item (Raymond et al., 2003; for reviews, see Fenske & Raymond,
2006; Golwitzer et al., 2014; Raymond, 2009). This effect of inhibition-related devaluation is
robust across a variety of stimuli –for instance: abstract pictures, images of faces, real-world
objects, complex scenes, and emotionally salient stimuli –across a variety of affective
evaluations-for instance: how attractive, trustworthy, or cheerful a stimulus is (e.g., Driscoll et
al., 2017; Fenske et al., 2004, 2005; Frischen et al., 2012; Griffiths & Mitchell, 2008; Kihara et
al., 2011; Kiss et al., 2008; Veling et al., 2008). These findings have been previously interpreted
as reflecting affective consequences of inhibition that emerge through cooperation of attention
and emotion systems to facilitate avoidance of previously-problematic items in future encounters
(Fenske and Raymond, 2006; Frischen et al., 2012).

Combined, the various previous findings demonstrate that the negative affective ratings
for previously inhibited stimuli reflects an increase in negative affect- regardless of these
stimuli’s pre-existing positive or negative qualities (Frischen, et al., 2012), that not only encodes
at a feature-based level but also can be linked to specific stimuli (Driscoll, Clancy, & Fenske, in
prep., cf. Goolsby et al., 2009), and appears not to be a result of other potential processes such as
an inhibition derived global brake on motor-response behaviour (Driscoll, et al., 2017), or
evaluative codes that become associated with inhibited items (Devito, Al Aidroos, & Fenske, 2017; cf., Dittrich & Klauer, 2012; Eder & Rothermund, 2008).

These findings have answered many questions, but many remain about how inhibition leads to negative affect for visual stimuli. Information is currently unknown about when and how negative emotional responses occur for inhibited items. Currently, two theoretical accounts propose two possible interpretations. One account proposes a later-indirect effect of inhibition where affect occurs due to disfluency related to reinstated inhibition at the time when the previously inhibited stimulus is encountered again in the context of an evaluation. The second account proposes immediate and direct affective consequences that encode representations of value during inhibition.

1.2 Competing explanations of inhibition-related devaluation.

Initial research suggested the Inhibition-Trace Account; an indirect explanation where the subsequently negative evaluation of inhibited items was related to memory-encoding of the stimulus-linked inhibitory episodes (e.g., Fenske et al., 2005; Raymond et al., 2005). This account proposed that when cognitive control was required, attentional inhibition would be applied and this inhibitory state would become encoded in memory with perceptual and response-related representations of the stimulus (Kessler & Tipper, 2004; Tipper, Grison, & Kessler, 2003). This account further suggested that retrieval of the memory of the inhibitory state during subsequent encounters with the stimulus led to inhibition’s re-instatement, and that the reinstated inhibitory state would impact the affective evaluation of the item. Here, stimulus devaluation is conceived to arise indirectly via connections between emotion-related fronto-limbic regions and areas involved in stimulus perception/response-activation to which top-down inhibitory signals are applied (e.g., extrastriate cortex).
The Inhibition-Trace Account of the cognitive-affective process suggests that stimulus devaluation is not the result of emotional reactions at the time inhibition is being applied, but rather stimulus devaluation derives later in the context of an evaluation. The evaluation elicits a negative affective rating because while re-encountering this stimulus the individual also retrieves the stimulus-linked inhibitory-status. This retrieval results in a reinstated inhibitory signal, and feelings of disfluency become applied to the current evaluation task.

However, more recent evidence has led to a reconceptualization that suggests alternative, direct, processes are at work. Formal neural-network models (Fragopanagos et al., 2009; Raymond, 2009) and related accounts (Frischen et al., 2012; Kiss et al., 2008) posit that value-encoding (the storage into stimulus-related memory a representation of the stimuli’s worth) at the time of inhibition, and thus a direct-route interpretation better describes the emotional implications of inhibition. The Inhibition-Altered Value Account proposes that inhibition of distracting items may have emotion-related signals that become encoded into memory as reduced encoded value during goal-conflicting perceptions (Doallo et al., 2011). From this perspective, inhibition applied to prevent interference from an item alters the coding of its stimulus-associated value at the time that inhibition is applied. Thus, stimulus devaluation is an immediate consequence of inhibition.

Although the Inhibition-Trace explanation has compelling reasoning about inhibition’s impact on stimulus ratings, and there is some support from evidence such as that found for how an item’s inhibitory state can be encoded into memory (Chiu, Aron, & Verbruggen, 2012; Kessler & Tipper, 2004b; Verbruggen & Logan, 2008), recent neuroimaging evidence supports the Inhibition-Altered Value Account. The neuroimaging evidence suggests that activity in
inhibition-related regions, including areas of lateral prefrontal cortex (lPFC), couples with activity in key emotion-related regions, including the orbitofrontal cortex (OFC) and amygdala (Berkman, Burklund, & Lieberman, 2009; Doallo et al., 2012). Thus, stimulus-devaluation could occur directly through connections between brain regions that generate top-down inhibitory signals (e.g., lPFC) and fronto-limbic areas that assess and encode stimulus value (e.g., OFC and amygdala). The dorsal anterior cingulate cortex (dACC) plays a fundamental role for detection of conflicting processes during task performance that might be associated with errors (Carter, Botnivik & Cohen, 1999). When a pre-potent response conflicts with intentions, signals concerning this conflict may activate the dACC (Bush et al., 2000). The dACC evaluates, and then communicates the detection to several network related regulatory regions (i.e. DLPFC) (Carter & van Veen, 2007). These regions subsequently may employ control mechanisms such as inhibition to resolve this concern and further evaluation of such inhibition may result in affective processing.

Doallo et al. (2012) using FMRI also found that the magnitude of changes in value- and affect-related regions (i.e. OFC and amygdala) for previously inhibited items was associated with the magnitude of stimulus devaluation evident in subsequent affective ratings. These results indicated an emotional response does correspond with activity in regions responsible for housing value representations during inhibitory processes. However, this emotional response is still not well characterized as there has been little previous research specifying the exact emotional reactions (i.e., increased negativity? disgust and aversion? reduced positivity?) which cannot be answered with FMRI measures. Additionally, while this evidence does demonstrate regional activations of the OFC -which is involved in affective processing and valuation- this region has multiple other functions. Thus, the interpretation that the results are affect or value related
remain only inferential.

Several other recent sources support the Inhibition-Altered Value Account. Results have demonstrated that inhibition can not only decrease approach motivation but also increase avoidance motivation (Driscoll, Quinn de Launay, & Fenske, 2017). This finding is better explained by a change in stimulus-related value than a reinstated inhibition signal. Other evidence from electroencephalography (EEG) data has shown that event related potential (ERP) components directly related to suppression of distractor representations are evident within inhibition tasks and have direct relationships to negative evaluation. The magnitude of the Pd component- a measure of suppression evident for distracting stimuli in cognitive control tasks- was found to be greater in trials with greater devaluation (De Vito, Al-Aidroos & Fenske, 2017). Since this component occurs at the time in which distractors are being inhibited, and prominently relates to how ratings are subsequently affected, this evidence better fares with the Inhibition-Altered Value interpretation. However, while this evidence is seemingly supportive- since it substantiates inhibition as the mechanism involved- this evidence does not completely preclude the possibility that inhibition (rather than affective consequences of inhibition) is what is stored in memory. No evidence exists as to whether at the time of the Pd an emotional co-activation occurs, which is believed to be essential for substantiating that immediate impacts on stimulus value-representation occur. Thus, ambiguity remains.

This research assesses these two competing accounts; investigating whether a change in stimulus- related value representations that are encoded in memory along with other stimulus aspects can be indicated by negative affect at the point of inhibition, thus explaining later more negative stimulus evaluations, or whether negative affect results during later assessments of the stimuli as the individual incorporates a reinstated inhibitory signal as evidence in their current
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appraisals. Considering the affective consequences already demonstrated for inhibition, it can be predicted that psychophysiological response systems that alert and respond to emotion related processing also become involved during inhibition. This may occur as the dACC relays inhibition signals to emotion related regions of the brain that process a further interpretation of the inhibition. Thus, psychophysiological measures may be able to substantiate (or reject) that this regional activation of the OFC is indeed emotion-based. Here, this is assessed by examining the time that psychophysiological indices reflective of affective response occur. If emotional responses are evident at the time of inhibition, there would be further support for the Inhibition-Altered Value Account. If emotional responses are absent at the time of inhibition, alternative OFC processes are likely at work and the Inhibition Trace Account may be supported.

1.3 fEMG as an indirect measure of affect

To be able to distinguish between these alternate accounts, an indirect measure of affect is needed that can measure subtle emotional responses at the time they are happening. Neither the type of emotional response that occurs nor the physiological correlates of this effect have yet been delineated in previous research. We have identified potential for obtaining such information through the measurement of facial muscle responses that are emotionally derived (Fridlund & Cacioppo, 1986). fEMG (the experimental technique for measurement of these muscle responses) may be able to demonstrate that emotional responses occur at the time of inhibition. However, its usefulness in the context of inhibition-related devaluation has not been established. Therefore, along with attempting to address the research questions of this investigation, it is additionally necessary to establish the feasibility of fEMG as a measure of inhibition-related change in stimulus affect. Thus, this project has employed additional experiments, and alternative fEMG methods to assess its practicality and efficacy.
Using an indirect method for addressing these questions has not been done in previous literature. However, substantial evidence from other results and the explanations posed by the two competing theoretical accounts indicate two primary working hypotheses concerning the affective consequences of inhibition. Either affect could be i) an immediate-direct consequence of inhibition, supporting a stimulus-linked value-related explanation, or ii) indirect and only evident later in the context of subsequent evaluations, supporting an encoded inhibitory state explanation. This research predicts these inhibition-related affective consequences are measurable through the relative changes in muscle engagements pertaining to positive and negative affective responses. These measures, by providing evidence about whether emotional responses occurred at the time of inhibition, or only later when encountered again, would provide evidence about how emotional responses contribute to altered subsequent evaluations of inhibited stimuli, providing evidence that would disentangle which of the two accounts better explain the effect.

Measurements of when alternative positive and negative affective responses occur in response inhibition tasks would also contribute to answering several related questions brought forth about the form of inhibition-related emotional impacts and inhibition’s consequences (i.e., Driscoll et al., 2017; Frischen et al., 2012). In this paradigm, we evaluate the emotional correlates evident within alternative periods of response inhibition tasks; examining whether emotional elicitation indicative of negative emotional response to stimuli occurs at the time inhibition is applied, or solely during the subsequent appraisal. It is also not known whether a general increase in non-specific negative emotional valence, or specific decreases in pleasantness, or increases in disgust, frustration/anger, etc. occur at the time of inhibition. fEMG may be able to make these emotional distinctions.
1.4 Facial expressions and affective states

Ekman (1984) proposes that emotion’s boundaries can be distinguished by patterned changes of visceral factors distinctive to emotional states. These patterns dissociate emotional processes from alternative constructs such as reflex and mood by the specific manner of information processing which organizes and brings these patterned changes. For instance, facial expressions have come to be known as innate, evolved behaviour that is responsive to the current affective state of an individual (Eibl-Eibesfeldt, 1972; Ekman, 1984; Lorenz, 1965).

Facial expressions are indicative of specific emotional states, and therefore make ideal expressive manifestations to employ in our paradigm. Coherence between facial expression and alternative indices of emotional experience has been established, and this holds both categorically as well as temporally (Rosenberg & Ekman, 1994). Facial expressions are likely the most characteristically emotional psychophysiological response that occurs during an emotional-state and likely will be most informative when trying to make conclusions across multiple different types of emotions.

What makes facial expressions so effective for discerning emotional responses is that they are highly defined by specific muscle actions that only occur in response patterns for one or the other alternative emotion (Ekman, 1982). Since facial expression is considered as being emotion-specific (Keltner & Ekman, 2000), this measure should be effective in going beyond just describing valence, but rather the discrete emotional states (i.e., anger, frustration, disgust) that occur during inhibition. Facial expressions are also a powerful method for discriminating the emotional state of an individual since distinctive universal facial expressions of emotion can be traced phylogenetically and are thus cross-cultural and innate (Darwin, 1872/1965; Ekman, 1984).
Even when individuals attempt to manage, falsify, or withhold expression, several characteristics of facial response can make emotional states detectable (Ekman, 1984; Ekman & Friesen, 1969). Muscle Action Potentials (MAPs), the underlying muscle engagement measured by fEMG, is not under conscious control. While these responses can be moderated, they will still be detectable if an emotional reaction occurred (Spink et al., 2010). Therefore, fEMG is an objective measure of facial expression that detects even subtle levels of muscle response (Ekman & Friesen, 1978; Izard, 1977). Since facial expressions are emotion specific and fEMG can measure emotional reaction at various levels, muscle responses can be used reliably for inferences across individuals and groups with a set of standardized expectations. It is predicted that facial expressions can be used in this investigation to determine whether an affective state is instantiated during inhibition, what these affective states are, and when these emotional influences appear to be impactful on stimulus evaluations.

Facial expressions are also reciprocally connected and concordant to other aspects of the emotional experience. Ekman, Levenson, and Friesen (1983) used voluntary facial actions, in which their participants engaged the muscle actions used in natural universal facial expressions that arise during affective states, to explore alternative patterns of autonomic nervous system (ANS) activity for alternative emotional states. Through this procedure they could discern differential activity of both skin temperature and heart rate that were distinguishable for alternative discrete emotional expressions, not just for positive versus negative valences, and which corresponded to subjective ratings of emotional experience. This provides evidence that facial expressions could be an experimentally tangible technique for discerning specific affective responses that occur during inhibition and later evaluation periods that should align with subjective evaluations. Thus, fEMG would provide accurate converging information about the
period of processing at which affect arises and for how long it is endured in subsequent encounters with inhibited stimuli.

While other ANS changes involved in affect may last some duration, facial expressions are incredibly transient lasting only one-half to four seconds in most instances (Ekman, 1984). This characteristic necessitates experimental methods such as fEMG that can detect even the subtle actions of expression. Luckily, this transient element does have a tradeoff that can be taken advantage of in this investigation. Linking the duration of responsiveness of facial muscle movements, as well as their relative strength, can make cogent the robustness of emotion felt at any given time in response to a stimulus. Ekman, Friesen, and Ancoli (1980) established that the propensity of the felt emotion correlates with the duration of emotional expression and that variations in the strength of muscular action indicate intensity of emotion experienced. Rosenberg and Ekman (1994) also determined momentary-specific correspondence existed between the expressive components of emotion and the subjective experience of such emotion. Thus, throughout the time interval of stimulus presentation, several periods exist of high-degree correspondence between self-report and facial expression on even a momentary basis, indicating high temporal linkage and categorical agreement. Thus, muscle responses are temporally specific and this research predicts fEMG should therefore discern with a high degree of specificity when affective responses occur during inhibition-related devaluation.

However, recently the proposal that basic emotions are definable by patterned physiological changes is debated. Reviews such as Quigley and Barrett (2014) have concluded that the literature suggests that many additional factors must be considered in using measures of autonomic system response to characterize an emotional state. They propose consistency and specificity are not actually reliable across studies. Using the Conceptual Act Theory (CAT) as a
model, they propose that it is rather expected that concordance during emotional episodes would not be expected due to individual and situational differences. Rather than being driven by a basic biological program, they propose that consistency can only be expected when the specific context or situation can be highly expected to activate situational and embodied concepts. The individual uses affect-based predications through situated conceptualization of how one should prepare to act during a specified emotion within a specified context. This is instantaneous, ongoing, obligatory, and automatic and therefore no sense of agency, effort or control exists in construction of the emotion or its induction of a somatovisceral state. Thus, an overly dichotomous perspective of analysis for discrete emotional states would be inappropriate, and rather it is required to consider emotional response measures i) across individuals, ii) across contexts, and iii) as an emotional experience unfolds across time. In this study, every attempt has been made to mitigate analysis interpretation based on this new evidence.

As previously outlined, the exact emotional components of inhibition are still not understood; therefore, this investigation remained open about the nature of the expected increased negativity for inhibited items. An affective consequence that appears as an aversion to inhibited stimuli could be indicative of a signal for avoidance but it could also be an increased negative association encoded along with other stimulus attributes. Negative response to the stimuli could also rather be related to a decrease in positive affect in a relative sense to an individual’s expectations or other related exemplar stimuli. The findings of this research aim to characterize this emotional response by changes in muscle activations related to positive and negative emotional reaction. Currently, any of these possible explanations, or a combination of them, could characterize the emotional responses that occur throughout the alternative periods for inhibited stimuli since no empirical data has been procured that specifically addresses the
question. In addition, emotional responses which could be expected in a discrete emotion perspective (i.e. Ekman, 1984) may not characterize our results (Quigley & Barrett, 2014). Situational factors which arise as the individual updates affective predications, which could form an updated situated conceptualization of the emotion and context, may elicit alternative psychophysiological responses across the alternative contexts of the task (e.g., indirect emotional reaction during inhibition, versus direct emotional processing during evaluation).

1.5 fEMG as a tool for measuring the inter-relationship of emotion and cognition

While emerging evidence indicates that psychophysiological measures may not always be reliable in the form of discrete emotional responses (Quigley & Barrett, 2014), fEMG within this investigation of inhibition-related devaluation should be a successful measure because it replicates an indirect method of investigation which has been highly successful for discerning the affective consequences of other indirect cognitive processes. Many sources of previous evidence suggest that indirect influences on emotional reactions are measurable by psychophysiological reactions.

For instance, Harmon-Jones and Allen (2001) have determined that affect-related changes in the zygomatic Major are evoked in the mere-exposure effect. Specifically, with increased exposure to stimuli there is an increase in positive emotional response. Although there was no explicit awareness of this increased exposure, or the expected effect that such exposure would have on stimulus liking, positive affective reactions to non-reinforced stimuli were still apparent and corresponded to relatively positive subjective ratings.

Topolinski, Erle, and Reber (2015) found that interference at an unconscious level during early visual stages in the gestalt completion of necker cubes reduced the positive affective response of stimuli. This was demonstrated by both facial expression and subjective report. They
further demonstrated that this expressive behaviour discriminated per the presentation of possible versus impossible necker cubes. This finding indicates that even early perceptual processing at an unconscious level can have emotional consequences that induce expressive behaviour.

Sims et al., (2012), used an implicit-conditioning game to assign socially-rewarding individuals with happy-faced expressions to either high or low reward values. They found alterations of facial mimicry and a reduction in positive emotion-related response based on whether the face had been in the high or low reward conditions. Thus, processing different levels of stimulus-associated value can have impacts on facial expression behaviour during subsequent encounters with a stimulus. It appears facial expressions can reflect the emotional components of encoded value. This re-elicitation of an affective state may also contribute to the ongoing encoding of stimulus worth.

Thus, several examples indicate that expressive components of emotion seem to be representative, or have some influence from perception, cognition, and performance even when an individual is not aware of the emotion-eliciting event or introspection of any current emotional state. Further, these findings all imply that emotional reactions at the time of a cognitive event may have encoded an alteration of stored stimulus value, and that this was measurable in facial expression behaviour.

1.6 Current research

Due to the multitude of stimuli we are exposed to, resource limitations often necessitate that we manage our cognitive resources by prioritizing goal-relevant stimuli and inhibiting inappropriate responses that might result in interference from distracting objects and events. Evidence indicates that inhibition under such types of circumstances has affective consequences that impact affective ratings of the inhibited stimuli. In the research reported here, the interplay
between cognition and affect during cognitive control processes is evaluated by assessing the occurrence and timing of affect-related physiological responses (fEMG) during inhibition.

According to the Inhibition-Altered Value Account, inhibition applied to prevent interference from an item elicits negative affect at the time inhibition is applied, which immediately alters the coding of its stimulus-associated value. This process may stem from a cascade of inter-related cognitive-affective processing. The Inhibition Trace Account would predict that affective reactions should not be evident in this manner, possibly only later evident while making evaluations.

Affective processing is typically characterized by several physiological responses (e.g., change in heart rate, skin conductance, and facial expression (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). Psychophysiological responses are elicited since emotions are embodied as tangible bodily reactions (Cacioppo, et al., 2000). Thus, if the relationship between inhibition and negative affective evaluations is mediated through affective responses arising at the time of inhibition, or at the time of later evaluation, then it should be reflected in some sort of concurrent physiological reaction. This reaction may also provide evidence of the specific emotional components involved at distinct periods in the corresponding sequence of events.

In the present research, any potential emotional response that may occur during inhibition is investigated using fEMG. Because fEMG has the capability to be both temporally precise and provide selective information about different types of emotion, it may tell when affect occurs, as well as be useful for characterizing the type of emotion that may be evoked during inhibition. For instance, if the negative affective ratings of previously inhibited stimuli arise because of a negative emotional response elicited at the time of inhibition, then psychophysiological indices of negative emotion should be evident when inhibition is applied, as well as during subsequent
encounters. The physiological indices should be characterized by a decrease in positive response alongside an increase in negative response. Therefore, activation of the positive-emotion related muscle engagement of the M. Zygomaticus Major should decrease, and an activation in muscle engagement of the M. Corrugator Supercilii, known for activity during negative affective states, should occur. Alternatively, if the change in stimulus ratings is better characterized as a decrease in positive emotion at the time of inhibition, then changes in the psychophysiological indices of positive emotion should be evident during inhibition, as well as during subsequent encounters. This would include reduced activity of the M. Zygomaticus Major, known for its role in smiling, compared to otherwise equivalent stimuli.

Due to the highly-defined characteristics of these physiological measures they should be useful in defining the specific affective processes of inhibition, the period of processing at which affective components occur, and ultimately the manner that the affective components associated with inhibition are influencing subjective evaluations in future encounters. By investigating the pattern of affective response during periods of inhibition this research intends to aid understanding for the underlying manner through which the effect derives as well as make insights as to its purpose and function.

Here we extend prior investigations of cognitive control and prioritization by moving beyond subjective affective impressions. We use a converging evidence paradigm which incorporates psychophysiological measures of emotion-related facial-muscle engagement (e.g. Electromyography) along with standard subjective measures (e.g., Self-report) of stimulus affect. Facial electromyography (fEMG) has been shown in previous research to provide a reliable physiological index of emotion- and motivation-related responses (i.e., Cacioppo, Martzke, Petty, & Tassinary, 1988; Cacioppo, Petty, Losch, & Kim, 1986; Kron et al., 2014; Lang,
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Greenwald, Bradley, & Hamm, 1993; Larsen, Norris, & Cacioppo, 2003), but has yet to be used in investigations concerning inhibition-related devaluation. Here, alongside discussion of our results, we discuss the utility of employing this measure within our current paradigm and its feasibility for use in future similar cognitive control research.

Section 2: Confirmation of fEMG methods for measurement of affective responses

Before investigating affective response during inhibition, it was important to ensure that the fEMG equipment used in the experiment was an indirect measure of emotional response. This was especially important because the equipment being employed was never used for this purpose, had several limitations for initial hardware setup, and while the equipment was tested by the manufacturer, its functioning remained ambiguous in our current experimental setup. Here, the equipment’s ability to measure affective response was tested in tasks adapted from previous research.

2.1 Experiment 1.

During Experiment 1, psychophysiological measures were recorded during a stimulus presentation task. This task was intended to verify our ability to measure emotion-specific facial electromyograms (e.g., engagement of key different face muscles involved in smiling, frowning, disgust, etc.) toward emotional visual stimuli. During the stimulus presentation task, participants were presented with visual images from the International Affective Picture System developed by the National Institute of Mental Health Center for Emotion and Attention at the University of Florida (2005) and the Warsaw Set of Emotional Facial Expression Pictures (WSEFEP). Images varied in the specific emotion they are known to elicit (e.g., joy, anger, disgust). Similar images have been shown in previous literature to elicit alternative muscle activations specific to their affective content (i.e., Lang, Greenwald, Bradley, & Hamm, 1993). Additionally, participants
performed an explicit facial expression task. During the explicit task, participants were shown an emotionally descriptive word and asked to perform the facial expression they would make while experiencing that affective state. Thus, Experiment 1 recorded stimulus-driven affective reactions as well as explicit mimicry of emotion-related facial muscle movements.

Facial EMG signals from each recording site were obtained during each image presentation. Thus, fEMG were recorded for critical regions demonstrated in previous research to have patterns of change related to increased positive or negative affect during exposure to emotion-eliciting visual stimuli. For positive response, fEMG of the M. Zygomaticus Major were measured, previously shown to indicate positive affect and to fluctuate in positive emotional responses to stimuli. (e.g., Scherer & Ellgring, 2007; Winkielman & Cacioppo, 2001). For negative responses, fEMG of the Corrugator Supercilli, which indicates negative affect and mental effort (Waterink & van Boxtel, 1994), and has been demonstrated to show engagement during negative emotional responses to stimuli (Cacioppo et al., 1986; Fridlund & Cacioppo, 1986) were measured. These same muscles are expected to show patterns of engagement when employed in our fEMG investigation during Experiment 3, while testing the competing hypothesis of inhibition-associated devaluation. Experiment 1 would substantiate that the equipment can record the activations of these facial expression-related muscles, and that these muscle activations are related to emotion-specific responses, before carrying forward with using this measure in Experiment 3.
2.2 Methods.

Participants.

17 individuals (29% male) between the ages of 18 and 35 participated (M=19.76). Participants were recruited through the undergraduate Psychology Participant Pool and given course credit as compensation.

Materials.

Stimuli.

28 photograph images of affective content consist of visual stimuli in our task. The images were selected from the International Affective Picture System developed by the National Institute of Mental Health Center for Emotion and Attention at the University of Florida (2005) (15 images) and the Warsaw Set of Emotional Facial Expression Pictures (WSEFEP) (12 images). Images varied in the specific emotion they are known to elicit (e.g., joy, anger, disgust). Exact pictures are recorded and described for stimulus categories in Table 1 and Table 2.

Equipment.

Activities over the M. Zygomaticus Major and the M. Corrugator Supercillii were recorded on the left side of the face using bipolar placements of 8 mm Ag/AgCl surface-electrodes (as per the recommendations of Fridlund and Cacioppo (1986)). fEMG signals were collected in a data sweep for each trial with sweeps of data beginning 300 ms prior to stimulus onset and lasting 1650 ms following onset. The fEMG raw signal was measured with a V-Amp amplifier (Intronix Technologies Corporation) amplified by a factor of 2,000 with AC differential amplified (bandpass 0.2 and 500 Hz), digitalized by a 16-bit analogue-to-digital converter (Cambridge Electronic Design Limited 2008), and stored with a sampling frequency of 1000 Hz. Raw data were filtered with a 30 Hz low cutoff FIR filter, a 500 Hz high cutoff FIR
filter, a 60 Hz notch FIR filter, rectified and baseline corrected with the software program Signal 2.16.

**Stimuli Presentation Task.**

**Design and Procedure.**

**Stimuli.**

During the stimulus presentation task, participants were presented with the visual stimuli from the International Affective Picture System developed by the National Institute of Mental Health Center for Emotion and Attention at the University of Florida (2005) and the Warsaw Set of Emotional Facial Expression Pictures (WSEFEP). Stimuli consisted of one 10.4° x 10.4° item presented at a time at a viewing distance of 57 cm centrally presented on a grey background.

During the explicit facial expression component, the emotional word was centrally presented in 18 pt. Arial font.

Stimuli presentation and time-stamping of fEMG data collection was performed using psychopy (Pierce, 2009).

**Procedure.**

Participants were informed of the task procedures and consent was requested before beginning the task. Participants were seated at a computer screen in an individual testing room. fEMG equipment was affixed and prepared for data procurement. Participants were informed that they will be shown various images with affective content. During the presentation of the stimulus they were to simply view the images. They are told that it is ok to have emotional responses to the images, some of which are pleasant and some of which are not. However,
irrespective of how much the image is liked or not liked the image is to be continued to be viewed for the entire stimulus presentation duration.

The stimuli presentation task lasted approximately 10 minutes. The task began with the instructions followed by a black fixation cross in the center of the screen for 2000 ms. Following the fixation cross one image of the stimulus set was presented for 1650 ms. This image duration was selected to ensure emotional responses were evident in the time window corresponding to trial lengths to be used in Experiment 3. Images were fully randomized in presentation order. A 2000 ms fixation cross separated each image presentation. Finally, five emotion-descriptive words (anger, frustration, disgust, happiness, joy) were presented in randomized order. The participant was told to make the most reflective facial expression they could to that which they would be making if they were feeling the emotion presented on the screen. They were to make these facial expressions as expressively as possible when the word appeared on the screen. The text was presented for 1650 ms and separated by a 2000 ms central fixation cross.

**Measures.**

The fEMG scores represent the difference in activity that occurred as a response during stimulus presentation compared to a baseline of 300 ms pre-stimulus onset. Stimulus presentation of affective images had initial responses begin 500 ms post stimulus onset. Explicit facial expression responses began at 400 ms post-stimulus onset. These time periods were determined by visual inspection of the averaged waveform and accord with several other experiments which have found differential muscle activations beginning at similar time points (Gentsch, Grandjean & Scherer, 2013; Kunecke, Hildebrandt, Sommer & Wilhelm, 2014; Oberman, Winkielman, & Ramachndran, 2009). Thus, the data are averaged for analysis from
these periods respectively. Before statistical analysis, fEMG data were collapsed over trials by affect-elicitation condition. The analysis was separated by three categories of the stimuli used; negative, disgusting, and positive. For an example of the stimulus presentation see Appendix Figure 1.

2.3 Results

Corrugator

A paired sample (Affect: Negative, Positive) t-test was performed to ensure stimuli when conditions were distinguished between general Negative and Positive Affect had significantly different negative-emotion muscle engagement. The main effect of Affect was significant [$t(17) = 3.67, p=.001$; one tailed, see Figure 1].

Figure 1. Corrugator activation for stimuli of “Negative” and “Positive” affective content (Experiment 1). (Error Bars = SE) ($n = 17$).
A 3 level (Affect: Negative, Disgusting, Positive) repeated measure ANOVA was performed with planned comparisons carried out using t-tests to determine if we could record negative-emotion muscle activations that were emotion specific. There was a main effect of Affect \( F(2, 17) = 14.42, p = .000, \eta^2 = .46 \); see Figure 2. Pairwise comparisons revealed that negative stimuli had significantly higher Corrugator activation than Positive stimuli \( t(17) = 4.21, p = .0005 \); one tailed) and Disgust stimuli \( t(17) = 3.87, p = .0005 \); one tailed), Disgust had significantly higher Corrugator activation than Positive \( t(17) = 2.75, p = .007 \); one tailed).

Figure 2. Corrugator activation for stimuli of “Negative”, “Disgusting”, and “Positive” affective content (Experiment 1). (Error Bars = SE) \( n = 17 \).

Zygomaticus

A paired sample (Affect: Negative, Positive) t-test was performed to examine whether stimuli when conditions were distinguished between general Negative and Positive Affect
differentiations would significantly differ in positive-emotion muscle engagement. The main effect of Affect was significant \[ t(17) = -1.78, p=.045; \text{ one tailed, see Figure 3}. \]

![Zygomaticus Activation](image)

*Figure 3. Zygomaticus activation for stimuli of “Negative” and “Positive” affective content (Experiment 1). (Error Bars = SE) (n = 17).*

A 3 level (Affect: Negative, Disgusting, Positive) repeated measure ANOVA was performed with planned comparisons carried out using t-tests. There was no main effect of Affect \[ F(2, 17) = 1.48, p=.24, \eta^2 =.08; \text{ see Figure 4}. \] Pairwise comparisons revealed that Negative stimuli had marginally lower Zygomaticus activation than Positive stimuli \[ t(17) = -1.39, p =.09, \text{ one tailed} \] and no difference to Disgust stimuli \[ t(17) = 1.01, p=.16, \text{ one tailed} \]. Disgust had no differences in Zygomaticus activation than Positive \[ t(17) = -1.13, p =.14, \text{ one tailed} \].
Figure 4. Zygomaticus activation for stimuli of “Negative”, “Disgusting”, and “Positive” affective content (Experiment 1). (Error Bars = SE) \( n = 17 \).

2.4 Discussion.

Experiment 1 confirms that positive and negative-emotion related muscle responses are reliably measured by our fEMG methods. The Corrugator, associated with negative emotion, showed a quantitative difference in activation level for stimuli of negative, disgusting, and positive emotion categories. This difference indicates emotion-specificity. The data show valence specificity for Zygomaticus activations (positive compared to negative stimuli), but not emotion specificity. Zygomaticus activations did not significantly differ from negative or disgust
stimuli when emotion categories were further dissociated. Thus, we cannot reliably record 
Zygomaticus activation reflective of specific emotions, but we can use Zygomaticus activation to 
dissociate between negative and positive valences. This corresponds with other research which 
has also shown that Zygomaticus activation can often not be discernably emotion specific, 
possibly due to the high inter-participant variability of the morphology of the muscle (i.e., 
Aguado, et al., 2013; Kunecke, et al., 2014). Thus, this measure remained for Experiment 3 
because it has been highly used in previous research to measure positive emotional responses; 
but we interpret the results of this muscle in Experiment 3 under knowledge of this caveat.

Emotion specificity was not recorded as well as hoped, which is typically reliably found 
in other fEMG methods. It is believed to be related to limitations of our equipment setup. It was 
evident that issues with noise in the data recordings existed. This noise may have been 
introduced by using un-shielded electrodes, electrode movement from heavy leads attached to 
this equipment, or other general issues with equipment set-up. Therefore, it was decided to 
employ an additional methodology with newer equipment in Experiment 3. This equipment has a 
larger breadth of previous fEMG research applications and several additional features that may 
overcome these limitations. Experiment 3 data was collected with both equipments to compare 
and contrast these methods and their viability for fEMG applications in our investigation.

**Section 3: The cognitive-affective process of ‘inhibitory-related devaluation’**

Experiment 2 and 3 aim to characterize the time-course of psychophysiological 
responses that arise from mechanisms of emotion and cognition throughout inhibition-associated 
devaluation. One account, the Inhibition-Altered Value Account, proposes that reduced 
affective-evaluations of inhibited stimuli occur from aversion signals of affect-processing brain
regions to areas of the brain that encode and store value-representations. Performing cognitive processes such as inhibition may have emotional ramifications that contribute to the development of devalued representations which reward-related regions store for future processing. Thus, inhibition may reduce the perceptions of value of an inhibited item from that which would form during a neutral presentation of that same item. Previous research indicates this aversion signal has an affect-basis (Doallo et al., 2012) and thus should be measureable through psychophysiological responses, such as facial expressions, that characterize emotional states (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). Thus, fEMG, a measure of both expressive, covert, and inhibited facial reactions which are characteristic of emotional states (Fridlund & Cacioppo, 1986) is employed in our paradigm to determine if affective response does become evident during inhibition. If affective responses are not evident at the time of inhibition, support for the competing hypothesis, the Inhibition Trace Account, which proposes a later-indirect effect on affective-ratings would be supported.

This inquiry intends to increase our understanding of the previous research that has relied primarily on subjective evaluations of stimuli after inhibition. In this investigation, we extended the traditional paradigm that has been previously used to incorporate psychophysiological response variables. Thus, whereas past investigations of inhibitory devaluation have combined attention- or response-inhibition tasks with an affective rating task that assesses one of a variety of subjective affective impressions (e.g., liking, cheerfulness, etc.), this research replaces the affective- rating task as the primary measure of affective consequences. Rather this research employs a widely used psychophysiological measure of affective states in response to visual stimuli, (fEMG), as its primary indication of affective consequences.
fEMG has been shown in previous research to provide a reliable physiological index of emotion- and motivation-related responses to visual stimuli. If attentional processing is generating negative affect towards an item and this negative affect in turn plays a role in the processes which encode and store representations of value, individuals should demonstrate more negative-or less positive- facial responses indicative of these negative emotional states both at the time of inhibition and in future encounters. This method, a commonly employed index of current emotional state, will reflect this change in affect through detected modifications in electrophysiological response in affect-related facial muscles. These measures have high temporal resolution and thus can provide accurate measures of time-locked affect-related response changes (Fridlund & Cacioppo, 1986). It is predicted that this measure can be used to define the time course of the affective components of inhibitory-related devaluation. I began the examination of this measure’s utility through a pilot task (Experiment 1) that ensured our capacity to record muscle activity generated from emotional responses. Here, I subsequently assess the measure’s feasibility for this investigation in two experimental approaches which used alternative fEMG equipment for data collection.

If the measures of fEMG demonstrate reliable affect-related muscle recordings, then results of this inquiry should clarify the form of affective response that is elicited throughout inhibitory processes and whether it corresponds to the later affective response of an inhibited stimulus. If inhibition of a distractor has immediate-direct affective consequences that alter representations of stimulus value, it is assumed that these affective responses will become encoded along with other aspects of the stimulus representation. During future encounters its expected the encoded affective response will become re-elicited along with the other aspects of the value-representation. Thus, affective response will be evident at both the time of inhibition
and during subsequent encounters. Therefore, analogous fEMG measures should be procured between periods of inhibition and the time-points of later stimulus appraisal if the Inhibition-Altered Value Account explains inhibitory devaluation. If the Inhibition Trace Account explains inhibition-related devaluation, then emotional reactions should only be evident in the context of the evaluation during the later encounter and not during inhibition.

It’s believed that these affective responses are used to heuristically inform current perspectives of stimulus value and that this provides explanation of the reduced subjective evaluations obtained in previous results. Correspondence between psychophysiological responses and devaluation evident in self-reported measures is therefore expected. We anticipate that fEMG measures will indicate negative emotion–related muscle responses that correspond to relatively negative stimulus evaluations, or positive emotion related muscle responses that correspond to relatively positive stimulus evaluations.

3.1 Experiment 2.

Once the ability to record and analyze emotion-related electromyograms was established in Experiment 1, the next step in using fEMG was to develop a behavioural task which was amenable to using this measure while testing the two competing hypothesis about inhibition-related devaluation. This task is tested in Experiment 2. The task to be used needed to produce the same behavioural results of previous literature (more negative ratings for No-go than Go stimuli), therefore replicating previous methods as closely as possible was desirable. However, fEMG recording and interpretation required several modifications be made. The task also needed to be designed to preclude possible confounds in fEMG data interpretation. Therefore, I modified the standard Go/No-go task used in previous research in several ways that were conducive to
using implicit (fEMG) measures of affect. In Experiment 2, I tested a version of the experiment without fEMG recording to validate the use of the intended behavioural paradigm.

**Go/No-go Task modifications.**

It was important that the task could replicate previous findings of inhibition-related stimulus devaluation but also allowed periods of time in which inhibition was applied (or not) that lasted a long enough duration and were explicit enough to record implicit measures of affect. fEMG requires longer time windows for each trial, and between each trial, than many previous experiments are designed to have. In the modified task, we adopted procedures from previous experiments (Driscoll et al., in prep) that facilitated longer trial durations. In this task, the stimulus was presented and a motor response about perceptual features of a stimulus was prepared, but whether inhibition was to occur on the trial was only cued later by a stimulus-unrelated cue-presentation.

It was also important to test the competing hypothesis that participants were not aware that they would need to make any explicit ratings of the stimuli while engaging in the Go/No-go task. The ability to test between the competing hypotheses depends on having an indirect measure of participants’ affective responses to stimuli in the absence of explicit affective evaluations. Thus, while employing this implicit measure of affect we needed to maintain the participants’ naïveté to the experimental expectation that emotional and/or evaluative processing may be occurring throughout the experiment. Therefore, the typical method of interspersing Go/No-go trial blocks with evaluation trial blocks was not conducive because it couldn’t ensure participants’ affective reactions at the time of employing inhibition were not already indicative of evaluative processing. Thus, in this task, it was opted to delay all explicit stimulus ratings until the very end of the experiment (Driscoll et al., in prep; Martiny-Huenger, et al., 2014). This
ensured that participants did not know that they would be asked to make explicit ratings until after all Go/No-go trials were over, and thus prevented them from inadvertently making stimulus evaluations during the Go/No-go task.

fEMG also requires a baseline measure; thus, I added an initial task which exposed the participants to the stimuli without any cognitive control requirements. Therefore, the paradigm begins with a perceptual-feature sorting task in which motor responses are made about perceptual features of the images presented, but no other task demands are involved.

Lastly, to ensure stable measures in fEMG data were obtained for each stimulus, several trials of each stimulus were repeated in both the initial baseline task and in the Go/No-go task.

In Experiment 2, a sample of behavioural data was collected to ensure devaluation was still evident in subsequent evaluations of inhibited items in the adapted task. It was expected that the modified paradigm would demonstrate negative subjective evaluations of visual stimuli that had been inhibited, replicating previous research. If results replicated previous findings, this task would serve as a reliable paradigm for simultaneously recording fEMG during Experiment 3.

3.2 Methods

Participants.

28 individuals (34% male) between the ages of 18 and 35 participated (M=19.62). Participants were recruited through the undergraduate Psychology Participant Pool and given course credit as compensation. Five participants never completed the task or had corrupted data due to issues with the testing facilities, thus the analyzed sample is N=23.

Materials.

Visual Stimuli.

204 novel colorful shapes on a black background (adapted from Aminoff, Gronau, & Bar,
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2006) (256px X 256px JPEG), which we termed as being “abstract art-like images”, were used in
this experiment. 192 of these images were used as an experimental stimulus set and 12 images
were used as practice block stimuli and not used in subsequent analysis. The experimental
stimuli consisted of two stimulus categories; the orientation of one half of the images was
predominantly vertical, and the other half comprised predominantly horizontally-oriented shapes.
In testing instructions, these categorizations were referred to as ‘more tall’ and ‘more long’
respectively. The ‘tall’ and ‘long’ differentiation specifically pertained to the experimental task
instructions and was randomly selected since these categories should have no inherent affective
qualities or impose differential cognitive demands across stimulus categories. Classification had
no relevance to the experimental questions at hand, or to whether images would be inhibited or
not. See Appendix A for example stimuli.

Modifications were made to the stimulus set to create a “cue” during Go/No-go trials.
The “cue” indicated if responses were to be made (“Go”) or to be inhibited (“No-go”). Here, the
same novel colorful shape images had a colour overlay that was either ‘Yellow’ or ‘Blue’. The
overlay presentation covered the entire item presented but did not obstruct or distort the image
visually. The cue was developed by creating a separate jpeg of each stimulus which contained an
overlay in Adobe Photoshop CS5®. “Yellow” overlays had RGB values of R:253, G:250, B:2 at
40% opaque and “Blue” overlays had RGB values of R:42, G:117, B:254 at 40% opaque.

Stimulus presentation and behavioural-response collection were controlled via EPRIME
2.0 and presented on an Intel Core2Duo computer with a 50.8 cm LCD monitor (resolution: 1680
x 1050 pixels). Each abstract-pattern measured 10.4° x 10.4° at a viewing distance of 57 cm and
was centrally presented on a white background.
Experimental Paradigm.

The entire testing session lasted approximately 1.5 hours. The paradigm used in this experiment was modified from several previously employed response-inhibition tasks. These modifications accounted for several methodological and interpretational considerations that would make the task amenable to fEMG measures. These modifications for the incorporation of fEMG are discussed here, though no fEMG was recorded at this stage. The paradigm consists of three tasks, performed consecutively (see Appendix 2. for task/trial sequence).

Firstly, a perceptual-feature sorting task was designed to obtain baseline psychophysiological responses to each item prior to any cognitive control. This task also served several other aims. At a most basic level, it determined whether a participant could discern each stimulus as a “horizontal” or “vertical” item. It also manipulated the level of representation the participant would have of the item in memory.

The sorting task fEMG measures should have no differences in affective-response between the stimuli being assigned to either condition (“Go” or “No-go”) in subsequent tasks. The sorting task also provides opportunity to assess how the fEMG waveform should look when no-inter trial changes in cognitive demands occur. Due to the differential visual presentation qualities of the sorting task from that which occurs in the Go/No-go task we are able to compare electrophysiological responses obtained simply due to the onset of a visual stimulus to the psychophysiological responses that occur when increased cognitive and behavioural processes are required in the Go/No-go task. Having a baseline task could demonstrate that the muscle activations obtained at the time of inhibition were affect-based and did not pertain to several other possible processes including motor responses when pressing the keys, eye movements,
attentional orientations at stimulus onset, or effort-related affective responses that may occur when an individual must make a response/discern between classes. Thus, not only the general intensity and direction of affective response that is evident during the sorting task should be informative, but also the general time course in which changes in propensity occur. The general time course of muscle engagement may be linked to the time of visual, cognitive, and behavioural responses and this time course can then be contrasted with the time course of muscle engagements that occur when additional task components are introduced for response-inhibition (e.g., stimulus onset, inhibition cue onset, average RT for response, etc.).

We repeated the task so that each stimulus was responded to three times. Stimulus repetition is a well-established method of raising the activation level of cortical representations of items and therefore facilitates processing as well as overt responses. Repetition should have heightened the representation of the stimulus, increasing its familiarity and saliency. This method has in previous experiments led to increased devaluation of inhibited items (Frischen, et al. 2012). Increases in devaluation with repeated prior exposures are believed to result because higher activation levels require higher cognitive control to inhibit further processing. Thus, the more familiar the item will be, the more inhibition which will need to be employed.

Repetition also provides us the experimental ability to assess whether repeated exposure to the stimulus results in a mere exposure effect. Harmon-Jones and Allen (2001) have found that mere exposure effects, an increased positivity towards repeatedly exposed stimuli, can be observed in fEMG responses to visual stimuli.

The second task performed was the Go/No-go procedure. This Go/No-go procedure was adapted from previous tasks (Driscoll, et al., in prep; Frischen et al., 2012; Martiny-Huengar, et
al., 2014). and requires the linking of response inhibition to a specific stimulus which is under ongoing processing (e.g., the determination of a stimulus-classification and preparation of a response). By having individuals prepare a motor response linked to specific stimulus qualities, however indicating the prioritization of this stimulus (whether to inhibit or not) through a separate stimulus-unrelated cue, the task ensures the affective response is linked to the specific item and not to stimulus classifications or evaluative codes which may have affective connotations that could be used to form biases across stimulus classes and thus inform subsequent evaluations (Dittrich & Klauer, 2012; Eder & Rothermund, 2008). This version of the Go/No-go procedure also allows for longer time-windows during inhibition periods, facilitating fEMG measurement.

The Go/No-go task in Experiment 3 will provide measures of affective reaction when response inhibition is applied (“No-go” trials) or not (“Go trials”). The Go/No-go task is repeated three times so that fEMG could be recorded during response windows of fEMG data for stimuli with no history of inhibition, a single prior episode of inhibition, and a history of repeated inhibition. Having these additional fEMG recordings meant we could record the affective consequences of the first episode of inhibition on the stimulus and in a subsequent encounter that wasn’t during an explicit evaluation. Thus, the second two repetitions of Go/No-go procedure will be used in Experiment 3 as measures of fEMG response for the stimuli with several different inhibition-episode status levels. fEMG response will be recorded in a “prior-to-inhibition” fEMG response window (before cue onset), a “peak-inhibition” fEMG response window (when the cue occurs) and a “later-inhibition” fEMG response window (the rest of stimulus presentation (post-cue) in a trial). If inhibition is an affect-related process which encodes devaluation at the time it happens, then fEMG measures could reflect change in stimulus-value by increased negative-
responses toward inhibited items during all fEMG response windows after the first episode of inhibition. This would indicate increased aversion, increased negative affect, or decreased positivity of an inhibited stimulus prior to any awareness of expected affective changes or the evaluation pending in the next task.

The final experimental task is a subjective evaluation procedure in which participants rate the relative “cheerfulness” of stimuli. This task allows an assessment of the effects of prior inhibition on stimulus affect using the explicit ratings typically used. In the evaluation task, it is expected that fEMG measures that will be employed in Experiment 3 will correspond with subsequent ratings for how cheerful the inhibited and non-inhibited stimuli are perceived to be.

**Design and Procedure.**

**Baseline: Perceptual-Feature Sorting Task**

The experiment employs a novel perceptual-feature sorting task at the beginning of the experiment. The experiment was designed this way under the assumption that while some abstract art like images based on the general attractiveness of each item may elicit more positive or more negative affective responses, no differences should exist between the items that will be assigned to “Go” or “No-go” classifications in later tasks or analysis. These differences may stem from a general predisposition to find appealing certain colours, geometric forms, or orientations of the stimuli. Inter-individual differences may also exist; thus, some items may inherently be more appealing due to personal preferences. However, these possibilities should be controlled by randomization of stimuli to later “Go” or “No-go” assignment.

The sorting task would allow us to ensure that Go and No-go item affective responses were equivalent prior to inhibition by providing fEMG measures of initial affective response to
stimuli outside of the response-inhibition task. Any possible differences in affective responses to vertical or horizontal items, the classification used for making responses in the sorting and Go/No-go task, should also be controlled for in subsequent analysis between “Go” and “No-go” conditions since these are equally assigned to “Go” and “No-go” stimulus class. However, regardless of unlikely pre-existing differences, the baseline task allows for a general reference to which “Go” and “No-go” affective responses and subsequent evaluations can be compared (if desired, though not employed in this analysis) and be used for ensuring equality between stimuli at the beginning of the experiment.

The task presents each stimulus (abstract-art like image) individually for 1650 ms. In this time the participant is to press one of two keys, a “tall” key or a “long” key, with the index finger of either hand (counterbalanced) to report whether the stimulus presented was oriented vertically or horizontally. Stimuli are presented in randomized blocks, balanced by equal numbers of stimuli that will be subsequently assigned a “Go” or “No-go” status.

**Procedure.**

Participants were told that during the experiment we would involve them in several tasks because we were interested in the human brain’s ability to discern simple features and make sophisticated assessments of common items. Once consent was obtained, further instructions to the first task’s procedure were provided. Participants believed they were involved in a computer task that distinguishes how quickly and accurately they could discern simple perceptual features of items. Each participant was in a closed room with only one testing computer. They were told to decide if the item was primarily vertical, and therefore “tall”, or primarily horizontal, and therefore “long”, and report their decision with the respective key. They were told to make
responses on all trials. If they were unsure of how to respond, they were to use their best judgment. The participant was instructed to rest their hands at the base of the keyboard with the respective finger over the respective key so that they were prepared to make responses with minimal additional movements. They were also told that accuracy had primacy over speed but to make their responses as soon as they were prepared to do so.

The task proceeded in three repetitions of eight- twelve stimuli blocks. Stimuli remained on screen for 1650 ms. Each stimulus was separated by a fixation cross lasting 1000 ms. Each block was separated by a self-paced break screen. Stimuli are presented and responded to three times each, once per set of blocks, in randomized order.

**Go/No-Go Response Inhibition Task.**

The same experimental stimuli were employed as that used in the sorting task. 12 additional stimuli were assigned to practice stimuli (not previously included but same in kind to the sorting task stimuli). The stimuli were assigned to two randomly assigned groups of “Go” (Respond) and “No-go” (Inhibit) stimuli. For each stimulus, a “Blue” and “Yellow” overlay item existed and this was used as a cue to the response inhibition required.

The experiment employs a widely-used method of inducing response inhibition, the Go/No-go procedure. The Go/No-go paradigm assumes inhibitory processes are phasic reactive mechanisms triggered by the external stimulus that is to be refrained from (Criaud & Boulinguez, 2013). The version of this task used has been adapted from previously employed tasks which have demonstrated devaluation of inhibited stimuli to be amenable to fEMG recording, as described previously.
During the Go/No-go task participants prepare a response to the experimental set of stimuli based on the predominant orientation of the respective items presented, as they did in the sorting task. However, while they are to prepare this response they wait until they are additionally cued the “Go” or “No-go” status of the stimulus. They are subsequently cued to carry through with such response based on the appearance of an overlay colour presentation (“Go” stimulus). They inhibit responses from items that are not characterized by this presentation colour (“No-go” stimulus) and rather become overlaid with an alternative colour. Thus, cognitive control must be employed during stimuli presentation and motoric responses must be moderated in relation to the ongoing information processing of task demands. Ultimately this procedure’s ongoing need for cognitive control and response inhibition results in a set of stimuli that are inhibited and a set that are not inhibited which can be used for comparative means.

Procedure.

Participants were told that they are going to continue tasks that evaluate how the human brain can perceive simple features (e.g. colour) and make sophisticated assessments (e.g. hair colour) about common items. The participants were told that they were to make speeded perceptual responses to a stimulus but only on trials when cued and that these responses would be assessed for accuracy (false-alarms and misses) and efficiency (speed). Therefore, they are to respond to items that have a specific overlay-colour appear (“Blue” or “Yellow”, counterbalanced across participants) as quickly and accurately as is possible once the overlay appeared.

The Go/No-go task begins with a practice block that lasted approximately 2 minutes. The practice block consists of 12 trials presented in the same fashion as the experimental loops. Each
practice trial stimulus was concordant to that of the experimental trials; however, these stimuli were not re-presented in any further task presentations and are not used in subsequent analysis.

During the practice block stimuli presentation was as stated below however feedback was provided and task effectiveness was ensured by the experimenter before continuing to the final task. The practice block could be repeated as many times as necessary to have above 80% accuracy on the task. Once 80% accuracy was achieved the participant was instructed that they would begin the actual task. Instructions indicated that the actual task was performed the same way, however, the experimenter no longer remained in the room during this period.

The experimental component of the Go/No-go task lasted approximately 30 minutes and included 3 repetitions of 8 experimental trial blocks. Each repetition used the same stimuli in alternate randomized orders. Each participant had an individual randomly assigned Go/No-go trial list in which half the vertical stimuli and half the horizontal stimuli were assigned to the “Go” or “No-go” conditions at chance. Stimuli remained consistently such assignment (a Go or No-go stimulus) throughout the entirety of the experiment. Each block contained 12 stimuli that were either to be responded to/have responses inhibited with a 50/50 likelihood.

On each Go/No-go trial participants were required to prepare responses about the orientation of different items. They carried through with their prepared motor response (key press) on 50% (6 experimental items) of these trials and inhibited responses on the other 50% (6 experimental items). Whether to carry through with responses or withhold from responding was indicated by a colour-overlay that is placed over the entirety of the image presentation which is one of two alternative colours; one colour indicating that the participant is to inhibit response (“Blue” or “Yellow”, counterbalanced) and another indicating to respond (“Blue” or “Yellow”, counterbalanced). Participants were specifically instructed towards the response colour only
(carry through with your response when the presentation turns “….” colour); no instruction was made regarding inhibiting response. Thus, items that are presented which do not have the instructed colour as their overlay-color were to be inhibited, or have a response withheld, but this is not the main objective of the task from the understanding of the participant.

Thus, the inhibition task had a responded to (“Go”) set of items and a non-responded or inhibited (“No-go”) set of items. However, the exact items included in each response-condition differed by participant by which set of items were randomly assigned to either set. The overlay was counterbalanced across participants, with alternative “Go” and “No-go” colours presented. The keys used to make responses were also counterbalanced.

Each item was presented for 600 ms at which time the participant was to simply prepare their response. Thus, they prepared whether to respond with the “tall” (v or m on keyboard) or “long” (v or m on keyboard) key to whether the abstract art-like pattern predominantly was oriented vertically or horizontally (exact key counterbalanced by participants). After this preparation period, the presentation overlay which cued response status was added to the image. The overlay presentation covered the entire item presented but did not obstruct or distort the image visually. The cue remained for 100 ms before returning to the original image presentation (no overlay) which remained for an additional 1000 ms (See Appendix Figure 2 for an example of stimulus sequence). A key response was recorded during this presentation for up to 1100 ms post onset of the cue (overlay colour). Each trial was followed by a 1000 ms fixation cross before the next item was presented.

At the completion of the first experimental set of 8 blocks x 12 trials - a second repetition of the same progression immediately began without awareness of the participant. Presentation was randomized in order and not consistent across repetitions, but each item remained
consistently as a responded (“Go”)/withheld from (“No-go”) item across blocks. Errors are recorded as non-response or missing data if a key is not pressed 1100 ms period after the cue for “Go” trials, or if the incorrect key was pressed (‘tall’ or ‘long’). Errors are recorded as uncompleted inhibition if responses were made for “No-Go” items during the 1100 ms period. After the Go/No-go task a subjective evaluation task was introduced.

**Post-Inhibition Subjective Evaluation.**

During experimental blocks of subjective evaluation trials participants made ratings of the abstract-art like images based on their relative “cheerfulness”. These subjective evaluations replicate the primary method of measuring affective response to stimuli used in previous research. This will occur in the final portion of the experiment, at this time the participant was informed that they would now perform a final task related to their ability to make complex assessments of visual stimuli.

**Procedure.**

Participants now made ratings about the stimuli’s “cheerfulness”. Thus, they assessed the stimuli based on a scale of one (not at all cheerful) to 4 (very cheerful). They were told to respond with their initial impressions and encouraged to use the entire scale of available responses. Each block of the subjective evaluation consisted of 12 trials of the same stimuli used in the response inhibition tasks. The task began with a single block of 12 practice trials which could be repeated as necessary of the same 12 practice stimuli used during the Go/No-go task. Practice trials are not included in subsequent analysis.

The experimental trials included 8 blocks of 12 stimuli interspersed with a break that was presented between each block. Each block consisted of equal “Go” and “No-go” items (50/50) in
a randomized order. Stimuli were presented on the screen for 1650 ms and separated by a 1000 ms fixation screen. Total task time lasted approximately 8 minutes.

Participants made affective judgments on a scale of 1-4 about their perception of the items cheerfulness; 1-indicating not at all cheerful and 4-indicating very cheerful. Stimuli presentation included one item per trial. Each item was an item used in the previous Go/No-go task; previously being it had been either a responded (“Go”) or inhibited item (“No-go”). The item was presented in the center of the screen, in the same position and size as was used during the Go/No-go task. Below the item was a scale from 1 to 4 with the corresponding range written below the 1 and 4 endpoints for participant reference (one=not at all cheerful and four=very cheerful). Stimuli presentation order was randomized, with 50/50 “Go” and “No-go” items per block.

Participants responded to the four-point scale using the keyboard. The keys across the top of the keyboard 1-4 correspond to the rating scale 1-4. Participant responses were measured for 1650 ms post stimulus onset. Errors were recorded as non-response or missing data if a key is not pressed before the 1650 ms period has ended. Each trial was then followed by interstimuli interval presentation of a central fixation cross for 1000 ms.

**Questionnaires and Debriefing**

In conclusion of the experiment, the participant was fully debriefed about the task, measures, as well as expected hypothesis. Participants were also given a series of questionnaires to record demographic information.
Measures.

**Demographic Questionnaire.**

The demographic questionnaire collects information on gender, age, handedness, marital status, race/ethnicity, religiosity, political views, SES, and GPA.

**Sorting Reaction Times and Accuracy.**

The response time and accuracy of the Sorting task was recorded and averaged across block and across participant. If a participant did not perform the sorting task as per the task instructions this would constitute as criteria for participant removal as it indicated likely impairments in attention or a lack of attending to task demands. While some participants’ sorting accuracy did fall below 2 SD of the mean (mean = 95% accuracy), their accuracy overall remained reasonable (above 75%). Therefore, only in conjunction with their performance on the other tasks were participants deemed to be retained or excluded; thus, no participant was excluded based on this criteria alone.

**Go/No-Go Reaction Times and Accuracy.**

The response time of the Go/No-go task was recorded and averaged across participant. Accuracy has been shown in previous research to be a critical factor in assurance that the appropriate response inhibition occurred. Poor No-go performance can be reflective of impairments in attention and the inability to exert inhibition (e.g., Aron & Poldrack, 2005). Errors included false alarms (responding when should have withheld response) and misses (not responding when should have) as well as errors of commission between the alternative keys denoting orientation (indicating was “tall” when was “long” and vice versa). Participants with accuracy below 2 SD of the mean (M = 95% accurate) accuracy (SD = +/- 5%) were removed from the data set. However, no participant met this removal criterion in Experiment 2.
Subjective Ratings.

Subjective ratings of the participant’s affective appraisal of the stimuli were collected on a four-point scale from 1-4; 1- being not at all cheerful and 4- being very cheerful. Errors were recorded as non-response or missing data if a key were not pressed before the 1650 ms period had ended. A non-response or missing data trial and all trials in which errors occurred in the Go/No-Go task that correspond to the specific-stimuli evaluated will be removed from analysis. The experimenter used visual inspection of participant responses post-task to determine whether participants followed task instructions. Participants failing to follow experimental instructions (e.g., failing to use entire rating scale, repeatedly pressing same rating key, etc.) were excluded from analysis as it is unlikely they were engaging in actual appraisals of the stimuli or had been experiencing attentional lapses that overcame their ability to perform the task. However, no participant met this removal criterion in Experiment 2. These exclusions were a necessary consideration however because these attentional lapses would make it impossible to ensure the measures of affective responses obtained in fEMG data during Experiment 3 were toward the specific stimuli and reflective of their processing of evaluations.

3.3 Results.

Response Inhibition and Affective Evaluation.

Only ratings of images associated with a correct Sorting Task and Go/No-Go response were included in our analyses. Once trials that were incorrectly responded to were removed, the remaining data were analyzed with a paired samples t-test to compare subjective rating of “Go” (responded) and “No-go” (Inhibited) items. Based on previous findings, we expected that abstract art-like images presented as “No-go” stimuli would be rated as less cheerful than images presented as “Go” stimuli.
Five participants were removed from analysis due to testing facility technical issues. No data was procured for these participants due to these issues during data collection. No participants were removed due to criteria pertaining to Go/No-go accuracy or participant engagement in following task instructions. Thus, the resulting N=23 are included in analysis. Participants rated “No-go” images as less cheerful than “Go” images \( t(22) = 1.90, p=0.04 \), one tailed; see Figure 5. The pattern of results was consistent with devaluation of inhibited images. Therefore, incorporating fEMG carried forward in Experiment 3.

![Cheerfulness](image)

**Figure 5.** Mean of “Go” and “No-go” subjective ratings for stimulus “cheerfulness” rated on a scale 1-4, 1 = “Not at all cheerful”, 4 = “Very cheerful” (Experiment 2). (Error Bars = SE) \( n = 23 \).
3.4 Experiment 3.

In Experiment 3, we evaluated the two competing accounts of inhibition-related devaluation by employing fEMG as an indirect measure of affect in the same behavioural paradigm used in Experiment 2. Simultaneously, the feasibility of fEMG measures for addressing these research questions was tested. The investigation of fEMG feasibility was performed using two alternative fEMG data collection methods. Two methods of fEMG were used because each method had alternative equipment and software. Which method for data collection and analysis would be more effective for our purposes was unknown at the outset of the project. Since issues were acknowledged within Experiment 1 for fEMG data collection, it was hoped that these issues would be ameliorated in Experiment 3 by updating this equipment’s methods and by using another equipment/method.

It was possible that both sets of equipment would not be equal for measuring emotion-specific muscle activations in our task. Beyond being recorded by alternative equipment, the two methods also differentiated in how trials were time-stamped during recordings. In one method, we recorded data only during trials in ‘sweeps’ of data that began just prior to a trial-onset. In the second method, we recorded continuous data during the entire experiment and ‘tagged’ when trials occurred. Which of these two methods of data collection procure more reliable data and are more effective during analysis is tested in this experiment.

Consequences from inhibition were investigated by concurrently measuring fEMG using both methods in separate samples while participants partook in the same paradigm used in Experiment 2. fEMG signals were expected to show engagement of specific muscles corresponding to affective consequences of inhibition at the time inhibition occurred. fEMG signals were also expected to show changes in the engagement of specific facial muscles
corresponding to changes in stimulus ratings (e.g., less liking should be accompanied by less ‘smiling-muscle’ engagement and more ‘frowning-muscle’ engagement). Thus, fEMG was recorded for two critical regions demonstrated in previous research to exhibit patterns of change related to increased positive or negative affect to visual stimuli. For positive response, fEMG activation patterns of the M. Zygomaticus Major were measured, previously shown to indicate positive affect and to fluctuate in positive emotional responses to stimuli. (e.g., Scherer & Ellgring, 2007; Winkielman & Cacioppo, 2001). For negative responses, fEMG activation patterns of the M. Corrugator Supercilli, a muscle engagement which indicates negative affect and mental effort (Waterink & van Boxtel, 1994), and demonstrated to show engagement during negative emotional responses to stimuli (Cacioppo et al., 1986; Fridlund & Cacioppo, 1986) was measured.

It’s predicted that the use of fEMG data will show emotion-related psychophysiological responses during critical periods of stimuli presentation and participant response; providing measures of what types of emotional responses occur during inhibition-related devaluation. It’s further predicted that these patterns of physiological change would correspond to the evident devalued affective evaluation in behavioural measures. Lastly, since the emotion-related consequences of employing inhibition for an object would become discernable during critical time periods of stimuli presentation, these muscle engagements would provide evidence towards the time that negative affect associated with inhibition occurs, dissociating which account better explains how inhibition-related devaluation is produced. If the data collection methods used in this experiment can provide reliable measures of emotion-related muscle activation, then fEMG should test the competing hypothesis through evidence of when emotional reactions occur.
3.5 Methods

Participants.

101 participants (24% male) participated in Experiment 3. These participants were split between two fEMG method samples. 50 individuals between the ages of 18 and 35 (M=19.48) participated in the fEMG Intronix sample. 51 individuals (27% male) between the ages of 18 and 35 (M=19.66) participated in the fEMG Biopac sample. Participants were recruited through the undergraduate Psychology Participant Pool and given course credit as compensation.

Materials.

Visual Stimuli.

See Experiment 2.

Equipment.

Two sets of fEMG recording equipment were used in this experiment. Each of these types of equipment, their respective methods for collecting data, and the modifications for linking the behavioural task presentation not already addressed in the description of the paradigm in Experiment 2 are described in detail below.

Equipment for fEMG-Intronix.

Activations of the M. Zygomaticus Major and the M. Corrugator supercilii were recorded on the left side of the face using bipolar placements of 10 mm disposable Ag/AgCl surface-electrodes (n=41) and then later replaced with Ag/AgCl surface-electrodes which were 4mm for the M. Corrugator Supercilli and 8 mm for the M. Zygomaticus Major (as per the recommendations of Fridlund and Cacioppo (1986)) (n=10). A 10 mm disposable Ag/AgCl surface-grounding electrode was placed on the forehead. The EMG raw signal was measured
with a V-Amp amplifier (Intronix Technologies Corporation), amplified by a factor of 2,000 with AC differential amplified (bandpass 0.2 and 500 Hz) digitalized by a 16-bit analogue-to-digital converter (Cambridge Electronic Design Limited 2008), and stored with a sampling frequency of 1000 Hz. Raw data were then digitally filtered with a 30 Hz low cutoff FIR filter, a 500 Hz high cutoff FIR filter, and a 60 Hz notch FIR filter, then rectified and transformed with the software program Signal 2.16.

Low pass filtering, similar to smoothing methods commonly employed for EMG recordings, was then performed at 2Hz in Matlab®. Baseline correction of the data was then performed by subtracting the mean fEMG activity from the 300 ms interval preceding the onset of the stimulus. Trials with fEMG activity exceeding 2 SD of variance from the mean of the condition were removed from further analysis. fEMG was screened using visual inspection for movement artifacts on a high-resolution computer. The signals were then integrated in task/stimuli specific epochs of the average recorded filtered-rectified activity. Mean fEMG engagement waveforms, per participant, for respective conditions, were obtained by collapsing across the trials which remained after outlier analysis and removal of trials containing behavioural errors.

Data was collected in triggered ‘sweeps’. The sweeps were periods of recorded data that spanned the duration of critical periods during task progression. Sweeps were communicated to turn on by Eprime at 300 milliseconds prior to stimulus onset. Sweeps were assigned to the respective condition of “Go” or “No-go” that the stimulus shown in that trial would belong to during the Go/No-go task. Thus, all stimuli which were “Go” items were stored as one sweep condition, and all “No-go” items were stored as another sweep condition. Sweeps were also
ordered so that one-to-one correspondence of each trial was possible, facilitating an item analysis as well as removal of sweeps for trials that had errors.

The limitations of this method of recording fEMG are that continuous data is not available outside of the period of the specific sweep (trial), thus no post-hoc analysis of any other period can be performed. Additionally, some sweeps did not properly become assigned to their respective conditions and remained “unassigned” making the data available but far more demanding to integrate into the data set. Due to the limited number of trials that this “unassignment” occurred, these data have not been processed. As well, each sweep across the entire physiological data file had to be of the same duration, limiting the flexibility that could be obtained for amount of data collected and stored across alternative trial types. Lastly, this specific triggering method in E-Prime did not allow for contingent ‘tagging’ of the trials which would have facilitated the data processing steps. For instance, if an error was made on the Go/No-go task such as where the participant failed to respond on a trial that was a “Go” item, it would have been ideal to have had the computer program omit this trial from the sweep data ‘tagged’ to the “Go” condition. These trials had to be subsequently removed by hand by the experimenter.

**Equipment for fEMG Biopac.**

Activations of the M. Zygomaticus Major and the M. Corrugator supercilii were recorded on the left side of the face using bipolar placements of 8 mm shielded Ag/AgCl surface-electrodes (as per the recommendations of Fridlund and Cacioppo (1986)). An 8 mm disposable Ag/AgCl surface-grounding electrode was placed on the forehead. The EMG raw signal was measured with a BIOPAC MP150 system equipped with EMG100C-MRI amplifiers and stored
with a sampling frequency of 2000 Hz in Acknowledge 4.0 or 5.0. Data were amplified and bandpass filtered with a 30 Hz low cutoff FIR filter, a 500 Hz high cutoff FIR filter, and a 60 Hz notch FIR filter.

Continuous data was recorded from the beginning of the experiment until the end of the experiment. E-Prime 2.0 communicated time-stamping to Acknowledge 4.0 or 5.0 of the behavioural task’s critical time points.

Raw data were rectified and low pass filtered at 2Hz in Matlab®. Trials were defined as a 1650 ms period following the onset of the stimulus, which was time-stamp recorded by EPrime 2.0 onto the continuous collection of fEMG signal. Baseline correction of the data was then performed by subtracting the mean fEMG activity from the 300 ms interval preceding the onset of the stimulus. Trials with fEMG activity exceeding 2 SD of variance from the mean of the condition were removed from further analysis. Trials in which a behavioural error occurred were also removed from the data set. Mean fEMG engagement waveforms per participant for respective conditions were then obtained by collapsing across the remaining trials of each condition after outlier analysis and removal of trials containing behavioural errors. The signals were then integrated in task/stimuli specific epochs of the average recorded filtered and rectified activity.

This method of physiological data recording had the ability to overcome several issues evident with fEMG-Intonix data collection methods.

Firstly, the equipment’s electrode leads were much lighter and specifically designed for collecting fEMG. This meant the equipment was much more comfortable for the participant and
that less issues with electrodes coming loose throughout the experiment were likely to occur. The electrodes themselves were also specifically designed for fEMG; were an appropriate size for collecting physiological data from the small muscles of the face—which our initial disposable electrodes used in fEMG-Intronix may not have been ideal for, and the electrodes were also shielded—potentially reducing electrical noise.

Lastly, the software communication is more flexible across Eprime to this system and allows for more data analysis efficacy. The data was recorded continuously and therefore post hoc questions can be assessed if they arise. Eprime ‘triggers’ to Acknowledge using inline script, unlike how it communicated to Signal with item properties. The inline script can be coded to be more conducive to flexible ‘tagging’ of the events. Flexible tagging was not performed in this experiment, but it was later understood how beneficial it would have been. Eprime can send alternative triggers to identify error trials or to ‘tag’ when responses were made using the fEMG-Biopac equipment and software. While not employed in this experiment, this flexible ‘triggering’ could be an immense advantage to the methods available with fEMG-Intronix. Since contingent tagging was not used in this experiment, these trials had to be subsequently removed by hand by the experimenter.

**Design and Procedure.**

Design and procedure of Experiment 2 was replicated with the exceptions noted for fEMG data collection. The same experimental paradigm was used, but this time fEMG recordings were collected. The experiment now began with fEMG equipment being affixed. The experimenter also did a brief assurance test by having participants move facial muscles being
recorded to ensure that the recordings were as expected. The participant was told to ignore the equipment while performing the tasks since the equipment was recording passive activity.

**Measures.**

See Experiment 2. All measures and procedures were replicated except in regards to fEMG data described below.

**Facial Electromyography**

fEMG measures were defined for alternative time-windows across each of the experiment’s tasks:

The sorting task served as an initial baseline in which the stimulus presentations should show equivalent recordings across stimulus categories (“Go”/“No-go”) and a baseline affective response to specific stimuli (inherent likeability of the specific item to the specific individual).

The Go/No-go trial recordings are inhibition/response periods as well as periods in which inhibition/response may have begun to impact stimulus liking. These time-windows are defined as follows: No inhibition history: an initial affective response during the period which the item is presented and the participant is preparing a motoric response but no “Go” or “No-go” cue has yet to be presented; Peak inhibition: as a inhibition/non-inhibition period within the time-point which the participant has been cued and begins processing whether they are to either carryout the response or inhibit it; Later inhibition: when the participant is inhibiting or responding on the trial; and Inhibition history presentations: in second and third repetitions, affective responses reflective of previous inhibition/response-related affective reactions may elicit altered emotional responses. In relation to stimulus presentation this timing is defined as follows. On each trial of the Go/No-go task the item was presented for 600 ms before a cue (the colour overlay), this time-
window is baseline (before inhibition/response history) on the first repetition and a history of inhibition/response measure that is dissociated from evaluation processing during the second and third repetitions of trials.

The cue came on after this period for 100 ms, from its onset and for a brief period following it could be expected that peak inhibitory processing was occurring. This period being considered “Peak Inhibition” makes sense considering our average RT data in the Go/No-go task. Participant responses on “Go” trials occurred at 451 ms on average. Thus, inhibition must have occurred prior to this response time for “No-go” trials. Previous neurophysiological evidence has also demonstrated similar time windows for inhibitory processes leading to models that posit inhibition peaks between 150-300 ms (i.e., Schall, Palmeri, & Logan 2017).

Gentsch et al. (2013) found concordance between ERP results and fEMG results as early as 200 ms using affective stimuli in a gambling task, thus demonstrating that fEMG response periods temporally align closely to the time of neurological indicators of cognition and affect. Other fEMG paradigms also report temporal specificity and quick fEMG emotion-specific responses. For instance, Oberman et al. (2009) found within a facial mimicry paradigm that electrophysiological responsiveness was apparent in emotion specific directions by the 200 ms post stimulus onset period. Kunecke et al. (2014) found muscle activations also significantly differed as early as the 300 ms post stimulus presentation period when visual stimuli of affective content were presented. Doallo et al. (2012), using FMRI, demonstrated coactivated inhibitory-related and affect-related neural activity during a Go/No-go task. Co-activation indicates that affective responses should be expected at the time of inhibition-related neural activation. Thus, the period for 200-300 ms post cue-onset is defined as a peak-inhibition/response period. Since
no other research has employed this measure in response inhibition investigations, here both a
200 ms and a 300 ms post-cue peak period are analyzed since we could not definitively assess
which duration would be more appropriate. Subsequent time in the trial (the image remained for
an additional 1000 ms post-cue) is defined as a later-inhibition period.

Lastly, during affective subjective ratings, the fEMG scores are defined as the time-
window representative of emotional responses during explicit evaluations of stimuli’s affective
properties.

All fEMG recordings were compared to a baseline period of muscle engagement which
preceded the stimulus onset by 300 ms. The fEMG data analyzed are the difference in activity
compared to this baseline period before any stimulus processing was elicited.

Exclusion criteria for fEMG trials was determined based on variance within each task, for
each condition. Thus, for each task a mean and a variance of the mean of fEMG recordings were
determined for stimuli that were “Go” and “No-go” stimuli during the response inhibition task.
Trials with an fEMG activity with variance above 2 SD of the condition during the stimuli
presentation of each task, for each condition, were excluded.

Trials in which a behavioural error occurred were also excluded from analysis (7%
Sorting Trials and 3% Go/No-go trials). This precluded any interference of electrophysiological
activity related to error processing or lapses of attention from psychophysiological analysis of
inhibition. Error trials were eliminated from fEMG data to reduce the influence that conflict or
error related processing could have had on the emotional responses recorded. Items associated
with errors are known to be amenable to affective consequences of such error (e.g., Botvinick,
2007; Chetverikov, 2014; Chetverikov et al., 2015; Fritz & Driesbach, 2013). This ensured that trials which were analyzed could be interpreted to result from inhibition processes. Especially since the dACC, one of the neural regions associated with inhibition also serves a role in monitoring for these conflicts and errors, it is important to control for these alternative sources of emotional response. When errors occurred in the Go/No-go task the stimuli of these trials were excluded from the Go/No-go fEMG averages and from the Evaluation task’s fEMG averages. Trials in which no response was made during subjective evaluations were removed from fEMG analysis as there is no way to ensure the subject was engaging in an evaluation of the stimulus.

Before statistical analysis, fEMG data were collapsed over trials by response inhibition task condition (responded (“Go”) or inhibition (“No-go”)). Statistical analysis was performed by-task. In the fEMG-Biopac sample it was also possible to perform this analysis by the level of presentations (presentation in repetition 1, repetition 2, repetition 3) / inhibition episodes (presentation in repetition 1, repetition 2, repetition 3) for the Sorting Baseline task and Response Inhibition (Go/No-go) procedure, respectively.

3.6 Results

Response Inhibition and Affective Evaluation.

Only ratings of images associated with a correct Sorting Task and Go/No-Go response were included in our analyses. The remaining data were then analyzed in IBM SPSS Statistics 24® with an Omnibus within-subject ANOVA (Inhibition: Go, No-go), with equipment group as a between subject factor. Based on previous findings, we expected that abstract art-like images presented as “No-go” stimuli would be rated as less cheerful than images presented as “Go”
stimuli. We were interested in whether items would be subsequently rated less cheerful when inhibited than non-inhibited, thus an item based analysis was performed with a paired t-test.

Two participants were removed from analysis due to testing facility technical issues. Data files were corrupted and/or abruptly terminated during testing, therefore no data was procured for these participants to analyze. Six participants were removed due to criteria pertaining to Go/No-go accuracy. 12 participants were removed due to participant engagement in following task instructions. A high proportion of these excluded participants were from the fEMG Intronix sample (N=8) and participant disengagement could be attributed to facility issues occurring at the time which made the testing room very warm; participants complained of discomfort and fatigue. Thus, the resulting N=81 (fEMG Intronix N=40 and fEMG Biopac N= 41) are included in analysis.

Participants rated “No-go” images as less cheerful than “Go” images $F(1, 79) = 8.56, p = .004 \eta^2 = .10$; the effect did not depend on the type of equipment, between group interactions were non-significant $F(1, 79) = 0.49, p = .49 \eta^2 = .01$; see Figure 6].
Figure 6. Mean of “Go” and “No-go” subjective ratings for stimulus “cheerfulness” within-subject. Rated on a scale 1-4, 1 = “Not at all cheerful”, 4 = “Very cheerful” (Experiment 3). (Error Bars = SE) (n = 81).

Devaluation was also evident in an item analysis when analyzed by when the items were assigned to the “Go” versus the “No-go” condition. When items were assigned to the “Go” condition they were rated more cheerful than when assigned to the “No-go” condition \([t(192) = 2.97, p = .003; \text{ see Figure 7}].\) Thus, results confirmed devaluation of images after inhibition of response in our modified task.
Figure 7. Mean of “Go” and “No-go” subjective ratings for stimulus “cheerfulness” for visual stimuli, when respectively assigned to either condition. Rated on a scale 1-4, 1 = “Not at all cheerful”, 4 = “Very cheerful” (Experiment 3). (Error Bars = SE) (n = 81).

Response Time During Affective Evaluation.

Response time (RT) data was analyzed during the subsequent evaluations to evaluate any behavioural differences on responses between “Go” and “No-go” conditions. Mean response time of evaluations for “Go” items was 860 ms for fEMG-Biopac and 898 ms for fEMG Intronix participants. Mean response times of “No-go” items were 864 ms for fEMG-Biopac and 881 ms for fEMG Intronix. RT between “Go” and “No-go” items was assessed with an Omnibus within subject ANOVA, with equipment as a between subject factor. No significant differences between conditions was found $F(1, 79) = .29, p = 0.59 \eta^2 = .00$, between group interactions were non-significant $F(1, 79) = 1.46, p = 0.23 \eta^2 = .02$, thus equipment used had no effect upon results.
The psychophysiological time course of Response Inhibition and Affective Evaluation as Measured by fEMG.

In addition to the participants removed for behavioural analysis, several additional participants were not included in the physiological analysis.

For the Zygomaticus analysis, from the Intronix sample, 1 participant was removed from the Go/No-go data and 3 participants were removed from the Subjective Evaluation data. This data was removed because of post analysis determination that data recording was abnormal in waveform and variance to the sample. This was likely due to electrodes coming loose over the course of the testing period, an issue which was common with the “stick on” electrodes used with this equipment. Thus, the resulting fEMG Intronix sample included in analysis is: N= 36 for Corrugator and Zygomaticus data at Sort, N= 36 for Corrugator data, N= 35 at Go/No-go for Zygomaticus data, and N=32 at Evaluation for Zygomaticus data.

From the Biopac Sample 3 participants were removed from the psychophysiological analysis for both the Zygomaticus and Corrugator. 2 additional participants were excluded for just the Corrugator analysis due to data collection issues that occurred or because of post analysis determination that data recording was not representative for the rest of the sample. Unusual data recording likely resulted because of electrodes coming loose during testing and therefore fEMG data collection was incorrectly performed. It was evident in these participant’s data that fEMG signals were not reflective of emotional responses, but rather consisted of recorded “electrical noise”. Thus, the resulting fEMG Biopac N= 37 for Corrugator data and fEMG Biopac N=38 for Zygomaticus data are included in analysis.
**Baseline psychophysiology - fEMG of muscle response at Sort.**

fEMG change in response scores were calculated between the level of response at point of analysis compared to the level of response at the 300 ms prior to trial onset (baseline). We hypothesized that Corrugator activation would be equivalent between stimuli that would later be assigned to “Go” or “No-go” conditions. We hypothesized that Zygomaticus activation, the positive emotion-related muscle responses, would also be equivalent between stimuli.

**Corrugator**

fEMG data collected during the sorting period was analyzed for the entire duration of the trial for differences in Corrugator response level between “Go” and “No-go” conditions using an Omnibus Repeated Measure ANOVA (Inhibition: Go, No-go) with equipment as a between subject factor. Recordings of negative emotion-related muscle responses of “No-go” stimuli showed no apparent differences from than those of “Go” stimuli \( F(1, 72) = 1.96, p = 0.17, \eta^2 = 0.03 \), no between group differences were evident \( F(1, 72) = 2.90, p = 0.09, \eta^2 = 0.04 \), see Figure 8.
Using Facial Electromyography to Test Competing Accounts of the Affective Consequences of Response Inhibition

**Figure 8.** “Go” and “No-go” Corrugator electrophysiological activation during sorting baseline task (Experiment 3). \( n = 74 \).

We were interested in whether a mere exposure effect may be evident with sort repetitions. Corrugator activation decreases across repetitions would indicate an increased positivity to repeated stimuli. This analysis exclusively includes Biopac data as this fEMG method facilitated parsing data by repetitions.

First, we assessed whether across repetitions there were differences in activation towards “Go” and “No-go” items (or remained equivalent). Activation did remain equivalent in all repetitions; during repetition 1 \([t(38) = -1.11 \ p = .27]\); during repetition 2 \([t(38) = .95 \ p = .35]\); and during repetition 3 \([t(38) = 1.80 \ p = .08]\). Thus, no differences in stimuli that were later assigned to “Go” or “No-go” stimuli occurred in any repetition. We then assessed whether Corrugator activation decreased across repetition, an indication of increasingly positive affective...
response that could have occurred if mere exposure increased stimulus liking. We did not see a mere-exposure effect. No differences occurred for “Go” stimuli from repetition 1 to repetition 2\(t(38) = -1.31 \ p = 0.20\); or repetition 2 to 3\(t(38) = -.70 \ p = .49\). No differences occurred for “No-go” stimuli either, from repetition 1 to repetition 2\(t(38) = .80 \ p = .43\); or repetition 2 to 3 \(t(38) = -.16 \ p = 0.88\).

**Zygomaticus**

fEMG data collected during the sorting period was analyzed for the entire duration of the trial for differences in Zygomaticus response level between “Go” and “No-go” conditions using an Omnibus Repeated Measure Anova (Inhibition: Go, No-go) with equipment as a between subject factor. Recordings of positive emotion-related muscle responses of “No-go” stimuli showed no apparent differences from than those of “Go” stimuli \(F(1, 72) = .88, \ p =0.35, \ eta^2 = .01\) and there was no between group differences \(F(1, 72) = .74, \ p =0.39, \ eta^2 = .01\), see Figure 9.

We were interested in examining changes across repetitions of the sorting task to evaluate a possible mere exposure effect. These, changes should have been equivalent across all stimuli if they occurred. Once again, the analysis is exclusively inclusive of Biopac fEMG data. Firstly, we assessed that across repetitions “Go” and “No-go” Corrugator activation remained equivalent. During repetition 1 \(t(38) = .22 \ p = .83\); during repetition 2 \(t(38) = .48 \ p = .64\); and during repetition 3 \(t(38) = .65 \ p = .52\) activation remained equivalent. Thus, no differences in stimuli that were later assigned to “Go” or “No-go” stimuli occurred in any repetition. We then assessed whether Zygomaticus activation increased across repetition, an indication of increasingly positive affective response that could have occurred if mere exposure increased stimulus liking. We did not see a mere-exposure effect. No differences occurred for “Go” stimuli from repetition
1 to repetition 2 \[ t(38) = -1.34 \ p = .19 \]; or repetition 2 to 3 \[ t(38) = .55 \ p = 0.59 \]. No differences occurred for “No-go” stimuli either, from repetition 1 to repetition 2 \[ t(38) = -1.19 \ p = .24 \]; or repetition 2 to 3 \[ t(38) = 1.83 \ p = 0.08 \].

**Figure 9.** “Go” and “No-go” Zygomaticus electrophysiological activation during sorting baseline task (Experiment 3). \( n = 74 \).

*Response-inhibition psychophysiology - fEMG of the muscle response at Go/No-go.*

fEMG change in response scores were calculated between the level of response at time-window of analysis compared to the level of response at the 300 ms prior to trial onset (trial baseline). We predicted that Corrugator activation, the negative emotion-related muscle responses, would be higher for items in the “No-go” condition. We predicted that Zygomaticus
activation, the positive emotion-related muscle responses, would be lower for items in the “No-go” condition, especially during peak-inhibition. We also expected that the disparity in muscle activations indicative of affect differences between responded and withheld from images would increase as subsequent inhibition episodes accumulated.

We also expected that there may be some discernable difference in how items are responded to prior to employment of inhibition in the pre-cue period in the second and third loops of the task. This “pre-cue” period we have defined as analogous to a subsequent encounter without any elicitation of evaluations. Thus, it would be a time window indicative of the item’s inhibition history and whether previous/increased history of inhibition lead to changes in subsequent emotional responses. This may be discernable by decreases in muscle responses associated with positive affect, or increases in muscle activation associated with negative affect for inhibited items.

Data for each muscle will be described for all three repetitions combined first, then differences across these repetitions will be described.

**Corrugator.**

fEMG data collected during the cue-period was analyzed for the first 200 ms of peak-inhibition period and the first 300 ms of peak-inhibition period for differences in Corrugator response level between “Go” and “No-go” conditions using an Omnibus Repeated Measure Anova (Inhibition: Go, No-go) with equipment as a between subject factor. Recordings of negative emotion-related muscle responses of prior “No-go” stimuli were significantly higher than those of prior “Go” stimuli; this was the case for the “200 ms” period after the cue-onset \( [F(1, 73) = 4.81, p = 0.03, \eta^2 = .06] \) and when the period was extended to a “300 ms” period \( [F(1, 73) = 5.94, p = 0.02, \eta^2 = .08, \text{see Figure 10}] \). The between group interaction was significant for
the early period \([F(1, 73) = 3.06, p = 0.09, \eta^2 = 0.04]\) but was non-significant for the later period \([F(1, 73) = 4.56, p = 0.04, \eta^2 = 0.06]\). This reflects quantitative differences in the equipment’s recordings; Biopac collected data demonstrated large increases in Corrugator activation for “No-go” stimuli but Intronix collected data showed only minor increases.

The differences between conditions for negative emotion-related muscle responses were not evident in the time-window prior to cue (image on screen and preparing to respond while wait for cue) \([F(1, 73) = 0.10, p = 0.32, \eta^2 = 0.01]\) (no between group interaction was evident \([F(1, 73) = 0.09, p = 0.76, \eta^2 = 0.001]\)). Differences were also not evident during the later-inhibition time window (while engaging in the motor-activity of making response or withholding response) \([F(1, 73) = 0.16, p = 0.67, \eta^2 = 0.002]\) (no between group interaction was evident \([F(1, 73) = 0.70, p = 0.41, \eta^2 = 0.01]\)).

We were interested in whether across repetitions any of these patterns would change, specifically whether a linear change may have occurred. A linear increase in negative muscle activation for “No-go” items would imply an increase, or cumulative effect, of inhibition episodes on negative affect during inhibition or towards an inhibited item. A linear decrease would imply a decrease of negative affect which may come about with increased fluency or a reduction of effort in performing inhibition. This in turn may reduce the negativity associated with performing inhibition or with the inhibited item. There may also be a general reduction or increase in the difference between Corrugator activation of “Go” and “No-go” trials. Thus, the previously performed analysis was performed for each Repetition of the Go/No-go task separately for comparison as well as waveform plotting to examine changes across loops. This analysis was only performed for the Biopac collected sample. Biopac data was only included because of utility in parsing data by repetition, something not available in the Intronix method.
**Figure 10.** “Go” and “No-go” Corrugator electrophysiological activation during Go/No-go task Peak Inhibition (Experiment 3). (n = 73).

Within Repetition 1 of the Go/No-go task is when the largest negative response towards “No-go” items occurred and is when there was also the greatest disparity evident between “Go” and “No-go” conditions. This negative emotion-related muscle response towards inhibited items decreased in subsequent repetitions (see Figure 11). The differences between “Go” and “No-go” images was significantly different at the peak-inhibition period of “300 ms” [t(36) = 1.99, p = .05]. No significant differences were found for the shorter time-window of “200 ms” post-cue onset [t(36) = 1.69, p = .10], or before cue [t(36) = .82, p = .42] or post cue [t(36) = -0.06, p = .95]. Significant differences were not found in subsequent repetitions. During Repetition 2; “200
ms” peak-inhibition period \([t(36) = 0.20, p = .85]\), “300 ms” peak-inhibition period \([t(36) = 0.55, p = .59]\), pre-cue period \([t(36) = .02, p = 0.98]\), and post-cue \([t(36) = 0.65, p = .52]\). During Repetition 3; “200 ms” peak-inhibition period \([t(36) = 0.13, p = .89]\), “300 ms” peak inhibition period \([t(36) = 0.59, p = 0.56]\), pre-cue period \([t(36) = -0.12, p = .91]\), and post-cue \([t(36) = -1.22, p = .23]\).

*Figure 11.* Time course of “Go” and “No-go” Corrugator electrophysiological activation during Go/No-go task, Repetition 1, Repetition 2, Repetition 3 (Experiment 3- fEMG Biopac). \((n = 39)\).

**Zygomaticus.**

fEMG data collected during the peak-inhibition period was analyzed for the first “200 ms cue” period and the first “300 ms cue” period for differences in Zygomaticus response level between “Go” and “No-go” conditions using an Omnibus Repeated Measure Anova (Inhibition: Go, No-go) with equipment as a between subject factor. Recordings of positive emotion-related muscle responses of prior “No-Go” stimuli were lower than those of prior “Go” stimuli. However, this difference was only marginal for the “200 ms” period \([F(1, 72) = 4.81, p = .06, \eta^2 = .06]\) and a between group interaction was evident \([F(1, 72) = 2.27, p = .03, \eta^2 = .03]\, see Figure 12). Again, the between group interaction reflects larger differences between conditions recorded.
using Biopac equipment. When the period was extended to a “300 ms” period the results were significant \([F(1, 72) = 6.11, p = .02, \eta^2 = .08]\) and the between group interaction was no longer evident \([F(1, 72) = 3.41, p = .07, \eta^2 = .05]\).

Differences between conditions were not evident in the pre-cue period (image on screen and preparing to respond while wait for cue) \([F(1, 72) = .46, p = .50, \eta^2 = .007]\) (no between group interaction was evident \([F(1, 72) = .44, p = .51, \eta^2 = .01]\)). During the post-cue period (while engaging in the motor-activity of making response or withholding response) no significant differences were evident \([F(1, 72) = .04, p = .84, \eta^2 = .001]\) (no between group interaction was evident \([F(1, 72) = 1.92, p = .17, \eta^2 = .03]\)).

Once again, we assessed whether changes across repetitions were evident; analysis using just the Biopac sample. A linear decrease in positive muscle activation for “No-go” items would imply an increase, or cumulative effect, of inhibition episodes on negative affect during inhibition or towards an inhibited item. A linear increase would imply a decrease of negative affect, or increased positivity, which may come about with increased fluency or a reduction of effort in performing inhibition. This may counter any negativity associated with performing inhibition or with the inhibited item. There may also be a general reduction or increase in the difference between zygomatic activation of “Go” and “No-go” trials in various repetitions. Thus, the previously performed analysis used to assess Zygomaticus activation was performed for each repetition of the Go/No-go task separately for comparison as well as waveform plotting to examine changes across repetitions.
Figure 12. “Go” and “No-go” Zygomaticus electrophysiological activation during Go/No-go task Peak Inhibition (Experiment 3). ($n = 72$).

Upon visual inspection of the recorded waveforms, it is within repetition 3 of the Go/No-go task that the largest negative-affect associated response towards “No-go” items occurred, indicated by the lowest Zygomaticus activation. There was also the greatest disparity evident between “Go” and “No-go” conditions in this repetition. This reduction in positive emotion-related muscle response towards inhibited items was far less evident in prior inhibition episodes at the cue-period (see Figure 8). In each repetition “No-go” items had lower Zygomaticus activation than “Go” items; but these differences did not reach significance for any of the time-periods for any repetition (see Figure 13).
For repetition 1, at the cue-period of “300 ms” \([t(37) = -1.48, p = .15]\), cue-period of “200 ms” post-cue onset \([t(37) = -1.38, p = .18]\), pre-cue \([t(37) = -0.09, p = .93]\), and post-cue \([t(37) = 1.46, p = .15]\). During repetition 2; “200 ms” cue-period \([t(37) = 0.12, p = .91]\), “300 ms” cue-period \([t(37) = 0.45, p = .65]\), pre-cue period \([t(37) = -0.23, p = .82]\), and post-cue \([t(36) = -0.42, p = .67]\). During repetition 3, at the cue-period of “300 ms” \([t(37) = -1.11, p = .27]\), cue-period of “200 ms” post-cue onset \([t(37) = -0.90, p = .38]\), pre-cue \([t(37) = -0.97, p = .34]\), and post-cue \([t(37) = -0.14, p = .89]\).

This suggests that inhibition’s effects on eliciting negative affect may be detected through differences in positive-emotion related muscle responses for inhibited items from responded items. We did not however see a strong indication of response differences across repetitions of the task.

Importantly, not obtaining significant results regarding positive affect-related muscle response changes across repetitions may also mean that a reduction in positivity towards
inhibited items in relation to exemplar stimuli or stimuli which have been responded to is not the main mechanism by which the devaluation develops for inhibited items. In conjunction with the results obtained for negative emotion associated muscle responses, in which higher Corrugator activation was evident during inhibition for “No-go” items, it appears that inhibition rather devalues inhibited stimuli through increased negative affect. This negative affect is most evident in the first repetition, indicating that inhibition’s effects on eliciting negative affect is strongest when predictions for inhibition requirement is low, possibly since this is when inhibition is most effort demanding or because of an aversion that occurs from probabilistic disconfirmation (i.e., affective-feedback-in-hypothesis-testing (Chetverikov, 2014), further considered in discussion).

**Subsequent encounter psychophysiology - fEMG of the muscle response at subjective evaluation.**

fEMG change in response scores were calculated between the level of response at point of analysis compared to the level of response at the 300 ms prior to trial onset (baseline). We predicted that Corrugator activation (negative emotion-related muscle responses) would be higher for items in the “No-go” condition. We predicted that Zygomaticus activation (positive emotion-related muscle responses) would be higher for items in the “Go” condition. fEMG data collected during the trial was analyzed for time-windows in the first 800 ms post-onset and the last 800 ms for differences in Corrugator and Zygomaticus response level between “Go” and “No-go” conditions using an Omnibus Repeated Measure Anova (Inhibition: Go, No-go) with equipment as a between subject factor.

**Corrugator**

Recordings of negative emotion-related muscle responses of prior “No-go” stimuli showed no apparent differences from than those of prior “Go” stimuli; this was the case for the
“early” period \([F(1, 72) = .002, p = .97, \eta^2 = .000]\) (no between group interaction was evident \([F(1, 72) = .35, p = .56, \eta^2 = .005]\)). This was also the case during the “late” evaluation period \([F(1, 72) = .64, p = .64, \eta^2 = .003]\) (no between group interaction was evident \([F(1, 72) = .48, p = .49, \eta^2 = .007]\)) of the trial (see Figure 14). These results disconfirm the prediction that negative affect toward inhibited items, recordable in the form of negative-emotion related muscle activation, is re-elicited at the time of subsequent encounter when making subjective evaluations.

\[
\text{Corrugator Activation at "Evaluation"}
\]

-0.02

\(0.06\)

\(0.02\)

\(-0.02\)

Figure 14. “Go” and “No-go” Corrugator electrophysiological activation during Subjective Evaluation in ‘Early’ and ‘Later’ periods of trial (Experiment 3). \((n = 74)\).

Zygomaticus

Recordings of positive emotion-related muscle responses of prior “No-Go” stimuli showed no apparent differences from those of “Go” stimuli; this was the case for the “early” period \([F(1, 69) = .45, p = .51, \eta^2 = .006]\) (no between group interaction was evident \([F(1, 69) =

\]
and when the period was extended to a “late” period \( F(1, 69) = .37, p = .55, \eta^2 = .005 \) (no between group interaction was evident \( F(1, 69) = .24, p = .63, \eta^2 = .003 \)). of the trial, see Figure 15. These results disconfirm the prediction that negative affect toward inhibited items, recordable in the form of reduced positive-emotion related muscle activation toward inhibited items, is re-elicited at the time of subsequent encounter when making subjective evaluations.

Figure 15. “Go” and “No-go” Zygomaticus electrophysiological activation during Subjective Evaluation in ‘Early’ and ‘Later’ periods of trial (Experiment 3). \( n = 71 \).

**Correlations of Corrugator and Zygomaticus Response and Subjective Evaluation**

We were interested in whether relationships were evident between level of muscle response and the corresponding subjective evaluations of item’s cheerfulness. We predicted that
the greater the disparity in muscle responses would correspond with higher levels of devaluation in subjective evaluation for “No-go” items. We also hypothesized that muscle responses indicative of being in states high in positivity (e.g., higher Zygomaticus activation) and low in negativity (e.g., lower in Corrugator activation) would correlate with higher subjective ratings of “Go” items and that opposite muscle responses would correlate with lower subjective ratings “No-go” items.

Thus, Pearson correlations were performed for the difference of “Go” and “No-go” negative/positive emotion-related muscle responses and the difference between “Go” and “No-go” subjective evaluation ratings.

Corrugator.

Higher differences in Corrugator activation towards “No-go” items than “Go” items at the time of inhibition correlated with higher differences in Corrugator activation towards “Go” items than “No-go” items at the time of subjective evaluation \([r(73) = -.367, p = .01]\).

Correlations were not evident between any other of the Go/No-go trial time-windows or the evaluation time windows or with any of these time windows and ratings. These correlations are summarized in the Appendix, Table 3.

Zygomaticus.

Correlation was evident between the difference in subjective evaluation of “Go” and “No-go” items and the level of Zygomaticus activation that was evident during the early evaluation period \([r(71) = .24, p = .05]\). Higher levels of disparity in the ratings of “Go” and “No-go” items (with a devaluation of inhibited items) corresponded with higher disparity in the muscle activation at this period (with a lower activation for “No-go” items). Zygomaticus activation during this early evaluation period also correlated with activation recorded at the peak
inhibition period of 300 ms \[r(70) = .23, p = .05\]. Higher activation of the muscle towards “Go” items during evaluation corresponded to larger decreases in the muscle’s activation toward “No-go” items during inhibition. No other time window showed correlations with another or with ratings. These correlations are summarized in the appendix, Table 4.

**Section 4: General Discussion**

This investigation has incorporated understandings about the neural underpinnings of selective attention along with assessment of psychophysiological response to evaluate how devaluations of inhibited items are formed during prioritization contexts. This study extended prior investigations of cognitive control and prioritization by moving beyond subjective affective impressions. During this investigation, I evaluated whether affect-related psychophysiological responses were evident at inhibition and additionally whether they were later elicited and impactful during subsequent encounters with items. The intentions were to evaluate the period in which emotional responses occurred, as a method for testing two competing accounts of previous results. Simultaneously, I assessed the feasibility of employing a novel experimental approach to investigating inhibition-related devaluation of visual stimuli which employed implicit measures of affect (fEMG).

This investigation used a modified version of a commonly employed response-inhibition task. In this paradigm, stimulus properties do not have any relationship to determination of prioritization level, and the participant is unaware of expected evaluation-impacts. During this task, I incorporated psychophysiological measures of emotion-related facial-muscle engagement (e.g., Electromyography) along with standard subjective measures (e.g., Self-report) of stimulus affect. These measures recorded affective response toward inhibited items in two different modalities (fEMG and subjective evaluation) for comparison. This converging evidence
approach has made it possible for the first time to assess the extent to which inhibition has a psychophysiological pattern of emotional response.

The ultimate intention of employing this novel experimental technique was to further our understanding about the mechanism by which inhibition causes negative affect by determining how a pattern of emotional-response could demarcate the type of affective components that occur toward stimuli, during and after inhibition’s employment. Facial Electromyography (fEMG) signals were expected to show changes in the engagement of specific facial muscles corresponding to changes in stimulus ratings (e.g., less liking should be accompanied by less ‘smiling-muscle’ engagement and more ‘frowning-muscle’ engagement) at critical periods which could dissociate between alternative explanations.

Using this psychophysiological perspective to explain the ramifications of prioritization has demonstrated new evidence about what type of emotional response occurs, as well as at what point relatively negative-affect towards inhibited stimuli derives. The evidence procured at the time of peak inhibition supports the Inhibition-Altered Value Account. By this account, reduced stimulus-value is formed and stored at the time of inhibition, and is a response to inhibition-coupled emotional signaling. However, while some of our results support the Inhibition-Altered Value Account, and no evidence supports the alternative account, results were not conclusive enough to completely preclude the Inhibition Trace Account or the possible existence of an additional third account yet to be proposed.

4.1 Findings

This inquiry was carried forth to resolve between two competing explanations, each with its own interpretation of how devaluation occurs, dissociable by when negative affect occurs. The time of emotional response allows interpretation about whether negative affective
consequences of inhibited items are due to re-elicited precepts of an inhibitory-status of an item at the time of evaluation or whether inhibition causes emotional responses that are being encoded as a stimulus-associated value representation at the time of inhibition. In the Inhibition-Altered Value Account, stimulus devaluation occurs at the time which inhibition is engaged. In the Inhibition Trace Account it derives later when an evaluation of the stimuli is elicited. These interpretations are thus dissociable based on when negative-affect was apparent at different time windows, especially during the time of inhibition.

Evidence demonstrated emotion-related muscle activation differences between inhibited and responded items occurring at the time of inhibition. Corrugator activation, the muscle associated with negative-affective responses, was significantly higher for “No-go” than “Go” stimuli at peak inhibition periods. In addition, Zygomaticus activation, the muscle associated with positive-affective responses, was significantly lower for “No-go” stimuli than “Go” stimuli. This evidence has provided a manner to evaluate whether emotional responses are occurring immediately at inhibition, or later in subjective evaluations. The data indicate that emotional responses are immediate. Evidence of emotional responses later, during subjective evaluations, was not found.

These findings suggest that inhibition has an immediate negative response that impacts stimulus “liking”. This is possibly due to negative emotional responses being encoded in memory as a reduced representation of value. While our results were unable to show negative emotional responses (in the form of EMG recorded muscle activation) at evaluation, the prior occurrence during inhibition does correspond with reduced reported “cheerfulness” of an inhibited visual stimulus. Why negative emotional responses were not evident during evaluation is not known, though this may be explained by some of the proposals put forth by Quigley and
Barrett (2014) that contend that processing strategies demanded by a task’s instruction can determine the subsequent use of previous experience to inform behaviour during current task objectives. Perhaps our evaluation task had differential expectations and demands from that of the Go/No-go task, and therefore subjective evaluations do not cause emotion-specific psychophysiological indices. It is possible to test this possible explanation with follow-up experiments. Using alternative manners of evoking negative affect can be associated with certain stimuli, for instance by employing a shock or startle treatment. Subsequently having participants make affective responses about the stimuli associated with this aversive stimulus, could determine if the fEMG indices of negative affect that occur at the time of the aversive stimulus should have been expected to be re-elicited at the time of evaluation.

We also assessed the affective responses across repetitions of the Go/No-go task because two outcomes for changes in affective responses across inhibition episode repetitions could have occurred with important theoretical implications. If the affective responses did not remain equivalent across trials, they either could have increased across inhibition episodes, or they could have decreased. Both outcomes would have had ramifications for interpreting how cognitive control tasks have implications for subsequent stimulus preferences.

Firstly, if we were to have seen an increase in level of affective response with stimulus repetitions we could have explained this result by proposing the item’s inhibition-related devalued precept is re-instated at each subsequent encounter. This reinstated precept undergoes processing when the item is re-inhibited in the next trial and a cumulative effect of inhibition’s affective consequences occurs. Thus, increasingly devalued precepts are subsequently encoded. This finding would have indicated that with each inhibition episode, devaluation increases. This is not what was found.
Here it was found that the largest affective response occurred during inhibition-cue on the first trial. The disparity between “Go” and “No-go” trial Corrugator activation reduced in a linear fashion with each loop. This aligns better with an opposing explanation, where an increased number of inhibition episodes decreases the affective response during the employment of inhibition. However, at this time the underlying mechanism of this effect is not understood. Several mechanisms related to effort (i.e., Inzlicht, et al. 2015), fluency (i.e., Cannon, Hayes, Tipper, 2010; Tipper, et al. 1985), and probability (i.e., Chetverikov & Kristjansson, 2015) may be involved. Increased inhibition episodes could result in increased ease or predictability in performing inhibition, thus ameliorating affective responding (Chetverikov & Kristjansson, 2015). Perhaps this reduction in emotional response occurs since aversion signals are no longer required as conflict decreases and a more cognitively-based precept of the stimulus and its contextual significance are available. Also, repetition may have learning-related implications that explain alterations in affective responses. These explanations remain to be investigated.

4.2 Methodological considerations of the employed paradigm

Every best effort was made to design an experimental paradigm that replicated previous findings and could feasibly incorporate fEMG. However, some skepticism exists about our modifications. It is possible this paradigm still had limitations.

Go/No-go trials were repeated three times because having several trials of each stimulus ensured a stable measure of affective response. However, it is possible that this decision had unfortunate ramifications for the subsequent devaluation reported in affective ratings. While the devaluation was significant in our experiment, the differences between ratings of “Go” and “No-go” items were lower than is often obtained following similar response inhibition tasks (e.g.,
Frischen et al., 2012 across 4 response inhibition tasks found main effect of response to have effect sizes of $\eta_p^2 = .4$, $\eta_p^2 = .28$, $\eta_p^2 = .18$, $\eta_p^2 = .05$. Chetverikov and Kristjansson (2015) had similar findings, showing that increases in search history reduced distractor devaluation. Their interpretation was that this aligns with affective-feedback-in-hypothesis-testing (Chetverikov, 2014). Here it is believed that the perceptual system generates hypotheses based on how a stimulus was perceived and attended to in previous history. Positive affect ensues when a hypothesis is determined correct, and negative affect is generated when a hypothesis fails; creating a reward/punishment system based on our predictive abilities. These rewards and punishments are delineated based on the strength of feedback, or the degree to which a prediction was novel (less-predictable) and confirmed or disconfirmed. Thus, affect reinforces the accumulation of accurate knowledge about the world, but affect is strongest toward what is yet to be known.

In our task, it’s possible that as outcomes become increasingly predictable the affective consequences diminished, as it had in their task. They interpreted their results to be ramifications of influences on predictions produced by search history with an item, which thus altered the affective impacts on stimulus preferences. Our task may have also generated such an effect. As the participant increasingly encountered the stimuli, they were increasingly aware of whether the item would be responded to our not. Thus, inhibition may have no longer been effortful, as it aligned with prediction. Thus, outcomes of the predictions may have had increasingly diminished returns in affective consequences (reward/punishment). At this point we do not know if increasing the inhibition exposures, without manipulations maintaining low-predictability of the associated response to be cued, may have led to a neutralization of devaluation that reduced the size of the effect.
If this were the case, it only further exemplifies the robust effect inhibition has for the affective evaluation of stimuli, since devaluation remained evident for inhibited items regardless of this additional possible influence. However, future follow-up to resolve this possibility could be easily achieved by manipulating the current paradigm to include trials in which stimuli did not remain predictably “Go” or “No-go” items along with those items which did. Thus, a task which reduced predictability of an item’s respective assignment to either “Go” or “No-go” status could test different reasons the affective response diminished. Either the task became increasingly ‘easy’, and therefore less negativity concerning error or ease of processing was generated, or the task had increasing apparent probability-associations with lower reward/punishment. Such a task could evaluate how this stimulus repetition impacted both affective response measured in fEMG and subsequent evaluations. Potentially, this sort of follow up could indicate that stronger devaluation would be evident in a task without repetition. It is also possible that correlations between fEMG and subjective evaluation may have been muddled by these increased repetitions.

Another implication of our task design was that many participants reported boredom and fatigue during the experiment. This is problematic in a task in which attentional control is required. Thus, task modifications which somehow broke up task components would be ideal in future designs. Experimental procedures such as those used in Mitchnik et al. (submitted) which had Go/No-go and Evaluation trials interspersed, but evaluations are of other non-experimental items could be useful in preserving task engagement while keeping evaluations of the Go/No-go images unbeknownst until the end of the experiment.
4.3 Alternative explanations of fEMG results

The results of this study indicate that emotion-related muscle responses (that could be correspondent with an aversion response) are evident at the time inhibition is employed. Since the results indicate a large aversion or negative response in early inhibition trials, it’s interpreted that negative emotional reactions at the time of inhibition are likely the main mechanism by which inhibition causes negative affective consequences for inhibited items. This aligns with previous results which have shown that devaluation is not a general reduction towards affective neutrality but rather an increased negativity for both positive and negative items (Frischen et al., 2011). Other results have also shown that inhibition causes not only decreased approach for appealing items but also increased avoidance of items which are aversive (Driscoll et al., 2017).

Overall, it appears that fEMG has been a useful implementation in our investigation. Having indications of the affective components that occur during inhibition, and their timing, has ultimately strengthened our understanding of selective attention’s consequences for stimulus value. However, these measures did not strongly correlate with subjective evaluations of the stimuli, therefore concluding that emotional responses are the underlying source of muscle activation remains tentative to further investigation.

A component of this investigation was to assess the feasibility of fEMG to study inhibition’s affective consequences. I have interpreted the muscle responses to be related to emotional response, since this has commonly been the case in previous research and the observed effect aligns with the theoretical constructs of interest, however some alternative explanations are possible. It is possible that other movements caused these muscle engagement differences. For instance, attention (Cohen, et al 1992), effort (Waterwink & van Boxtel, 1994), or surprise (Leite et al., 2012) may elicit movement in the Corrugator.
Was the Corrugator simply activated by eye movements during stimulus presentation and task responses? Eye movements that may have happened to do with luminosity of the images should have been controlled for by counterbalancing the “Go” and No-go” cue colour. Eye movements to attend to stimuli should not have been a factor since the cue was part of the image and therefore no movement of the eyes should have been required. Did movement while responding cause artifacts that appeared as muscle activations? If exertion of effort or the actual movement of making a response produced Corrugator activation, we should have seen higher Corrugator activation for “Go” trials. It is possible that when making a response (which occurred in the later trial post-cue period (average “Go” trial RT=451 ms) it did in fact cause some Corrugator activation because in the later waveform we do see more “Go” activation than “No-go” activation (ns.) though these sorts of movements are considered unlikely confounds (e.g., Fridlund & Cacioppo, 1986). Thus, while other explanations exist, the emotion-related interpretation still seems sound. Hopefully, future research can further substantiate the emotional nature of these responses, precluding these alternative possibilities.

fEMG being used as an indirect measure of implicit emotional reactivity was believed to be even more sensitive than direct measures such as self-reports that require participants to explicitly reflect on and articulate their emotional impressions. It was expected fEMG would be particularly well-suited as a converging approach for detecting the often subtle effects of inhibition on emotion- and motivation-related responses. However, correlations in this experiment between muscle response at the time of inhibition and subjective ratings were not evident. Without convergence, it would be overstepping the level of evidence available to conclude definitively that muscle responses measured the same construct that was measured by subjective evaluations.
One possible explanation for not finding correlations between these measures is a differentiation between affective and analytic processing that may be occurring at the time inhibition is applied versus later when making subjective evaluations. Whittlesea and Price (2001) showed that when stimuli are of a “same-familial-class”, subjects may have to adopt an analytic approach in tasks such as recognition, thus diminishing any fluency-related enhancements of multiple exposures even if these fluency-related enhancements are evident in other implicit tasks-such as making preference judgments of stimuli. It is possible, considering the multiple presentations of each stimulus—which may have increased fluency (and thus feelings of familiarity), the long time-windows of stimulus presentation, and the long response times participants took while making subjective evaluations in this task (over 800 ms), that similar implicit versus analytic processing discrepancies occurred in our task. Participants may have been adopting an analytic approach during subjective evaluations which did not require reference to encoded affective-stimulus qualities. Perhaps reducing the stimulus presentation time that is allowed for an evaluation in future experiments-forcing implicit processing when evaluating cheerfulness- would elicit affective responses.

Another possible interpretation is that having no affective response, but negative evaluations, may mean that affect had an immediate impact which lasted long term in an encoded stimulus-associated value representation. By resolving whether negative evaluations derive from an encoded representation of the inhibitory status or rather by encoded interpretations of stimulus value, we can better describe and infer about the functional significance and longevity of these effects. It has been previously shown that while attention-related changes in subsequent response to stimuli are short-lasting and transient (i.e., Tipper & Cranston, 1985), emotion-related changes are long lasting and stable.
It is also possible that in the subjective evaluation tasks employed to study inhibition-related devaluation do not employ affective emotional responses to the stimulus at the time of the evaluation. It is possible that the “abstraction” required of the questions asked in subjective ratings (e.g., how cheerful?, how attractive?, how dreary?) does not accurately assess the implicit levels of emotional impact inhibition has on stimulus value. For instance, after a large meal I may no longer be “feeling” positive affect while eating my favorite type of cake; eating anything when too full is adverse and unappealing. However, if I was asked to rate how delicious this cake was, I would likely report a high rating of how much I liked this cake. Thus, I would rate a positive affective response towards consuming this cake, despite my lack of interest in consuming the cake currently. My previous experience with the cake allows me to know its value (that it has caused positive affect in the past), but it will not cause me positive affect now. Perhaps employing an indirect measure, such as key-press approach and avoidance tasks employed in other previous research (i.e., Driscoll et al., 2017; Ferrey et al., 2012), may correlate with the affective responses recorded at inhibition.

Thus, employing fEMG has not come without challenges. Some of these challenges occurred throughout determining the most effective manner of incorporating it into our experimental procedure and some have occurred later in interpretation of results. The inferential nature of the measure and the to be noted issues with obtaining data makes it challenging to discredit remaining ambiguity concerning alternative processes (e.g., eye movements, effort, boredom) which could have influenced our results. It is possible that another analysis, such as a trial-by-trial comparison, may clarify whether muscle responses associated with affect did correspond to subjective ratings. This approach has been informative for discerning complicated effects in prior research studying inhibition-related devaluation (e.g., De Vito & Fenske, 2017).
4.4 Conclusions about fEMG method feasibility

One of the objectives of this research was to test the feasibility of using fEMG in our investigation, and to contrast between two possible methods of employing fEMG. Several reasons pertaining to data collection may have accounted for issues in detecting differences evident between “Go” and “No-go” conditions. It is not clear if the lack of significant response differences at certain time windows resulted from a lack of emotional response occurring, or if our techniques were simply not effective. The results of Experiment 3 further confirmed the issues we were having in employing the Intronix equipment and obtaining uncontaminated data within Experiment 1, suggesting some fEMG methods have limitations for cognitive control investigations.

Issues with employing the Intronix equipment included: electrodes which were larger than recommendations (Fridlund & Cacioppo, 1986) and were not shielded, changes in electrode type across participants (see methods), electrodes which did not seem to adhere as well as required for such a long task, a triggering method which seemed to cause artifacts in our baseline period of recording, and “noise” evident in recorded data which may have made emotional responses undetectable.

Several issues after data were collected were also evident with the Intronix recording method. Firstly, it is evident in waveform inspection that an artifact occurred in the baseline period while the equipment turned on. It is still unknown how this artifact developed but it did result from the Eprime triggering method employed. The data collected in Experiment 1 using the same equipment but a triggering method from the Psychopy software program did not cause this artifact. Secondly, data were highly variable in this sample. Large discrepancies are evident between level of activations of each participant. These activation discrepancies may have related
to equipment changes. We used a variety of different types of electrodes across participants. This was done as we worked through testing issues with this equipment in attempts to ameliorate “noise”. This may have led to issues in comparing across participants. Thus, comparison of data within the sample is challenging. Thirdly, the data was very noisy and contained many artifacts prior to cleaning, possibly because the electrodes used were unshielded (an option unavailable with the Intronix equipment). Messy original data may have made isolating true affective responses, and the differences between conditions for these affective responses, impossible when they occurred at a minute-implicit level. Thus, while we could record these responses with emotionally-arousing stimuli in Experiment 1, the responses in Experiment 3 may have been less discernable.

While issues were observed in our testing, it should be mentioned that this equipment’s functioning was tested by the manufacturer before its use. Therefore, the equipment was functioning, but our application may have been inappropriate. Likely, the Intronix equipment was not as suitable for fEMG purposes as the Biopac equipment was. These issues during fEMG-Intronix data collection, aside from some issues with electrode adhesion, did not exist with the fEMG-Biopac sample. fEMG measures were clearly more cogent while using Biopac fEMG methods. My conclusions are that the results obtained do not disconfirm the feasibility of the Intronix fEMG method for this investigation, but rather suggest that Biopac fEMG methods had more efficacy.

4.5 Future research

Several next steps are prudent in developing this experimental approach if it is to be continued to be used for assessing inhibition-related devaluation. This inquiry was carried out using stimuli that did not have pre-existing or inherent affective properties as a first step in
delineating whether affective responses arose solely based upon task demands. The paradigm associates some items with inhibition and then assesses the impact of such association on subsequent psychophysiological indices of affective response. This approach evaluates the possibility of altered affective responses to neutral stimuli that are derived from inhibition alone and how these affect-related changes may impact perceived attributes of stimuli such as subjective value. Future research should assess how these affective responses may interrelate with preexisting stimulus qualities, such as stimuli which vary in their social-biological significance, motivational incentive, emotional elicitation, hedonic approach and avoidance, or affective appraisal, to further dissociate how inhibition elicits affect in relation to other pre-existing or coinciding affective elicitations of the ongoing task context.

Importantly, using stimuli which elicit positive and negative emotional responses could assess whether the muscle responses that were recorded at the time of inhibition are indeed due to emotional responses. If items have inherent negativity then an increased negativity should be seen at cue for inhibited items, but not “Go” items. If the item normally elicits a positive response, only when this item becomes assigned to the “No-go” condition should negative responses be evident, and positive responses may dissipate. Thus, we may be able to isolate the responses measured to an emotion-based interpretation by the pre-existing emotional status of stimuli in future research. At this point, the questions that can be answered by fEMG in paradigms employing emotional stimuli remain beyond the scope of the current research. Trial-by-trial analysis of the current data may allow for the use of each abstract art-like image’s inherent attractiveness to perform a similar type of analysis, however, whether the propensity of their pre-existing differences in positive or negative qualities would make such differences apparent is unknown.
Obtaining converging evidence that muscle responses were emotion-based may also be obtained by taking an increasingly “holistic” approach in future research. For instance, several previous studies examining inhibition-associated-devaluation have employed EEG (DeVito et al., 2017; Kiss et al., 2012). EEG combined with our measures of fEMG may procure results which demonstrate correlations between level of inhibition successfully employed and the level of emotion-related muscle responses evident at that time. This combination of measures may thus become predictive of subsequent devaluation of the withheld from item.

As well, several other measures of arousal and negative affect could be combined with fEMG to provide additional evidence of emotional response. Bradley and Lang (2007) have put forth that the defense system is better explained by a cascade of several physiological responses, all of which when measured in combination are more informative than when established alone. Employing multiple indirect measures, which could converge to a clear indication of emotional response, could be used in future studies. Possible measures that could be incorporated include the eye blink startle reflex, heart rate, or skin conductance. Precluding alternative eye movements from those pertaining to emotional response, such as blinking or orienting, could also be done by the addition of eye-tracking in future studies.

Additionally, measurement issues may be ameliorated in future research by employing additional controls such as obtaining baseline measures of inter-individual differences in muscle engagement or by better methods for isolating muscles for electrode placement. It is possible that in this data many of the issues we had with obtaining affect-related responding were due to experimental error or naiveté for appropriate fEMG data collection. Having a standardized task that ensures both electrode placement and that muscles demonstrate affect-related electrophysiological change, could better assess inclusion criteria in future research.
4.6 Concluding remarks

Further investigation is warranted to confirm and substantiate the recorded emotion-related muscle responses that occurred during response-inhibition in our task. Our current use of fEMG as an indirect measure of affective response was successful, but has limitations. fEMG incorporation into this investigation was immensely labour intensive, and only procured a moderate level of expected results. Thus, the utility of this measure over the previously employed experimental techniques, such as subjective evaluation, remains questionable. The largest concerns for interpretation of our results include not having evidence of muscle responses indicative of negative affect for inhibited stimuli at subjective evaluation, and not obtaining correlational data to later stimulus-ratings. These missing sources of converging evidence leaves open to interpretation too many additional possible sources of muscle activation.

Despite these limitations, the evidence currently available from our results indicate that inhibition has negative-affective consequences measureable by facial muscle engagements. These muscle responses occurred at the time of inhibition, supporting the Inhibition-Altered Value Account. These results suggest that negative-affect related muscle responses are no longer required at a later evaluation for an evident impact on stimulus evaluation to occur. Thus, previous history appears to inform evaluations through alternative processes than affect re-elicited at the time of subsequent encounters. Despite no emotion-related muscle responses evident at the time, stimulus-related negative affect for inhibited items was measured in the form of devalued subjective evaluations. Thus, previous affective responses may be enough to continue to see the results of the previous affective consequences. This also seems to support the Inhibition-Altered Value Account. However, it may also indicate that there may be a third account, yet to be proposed, which only partially aligns with the account’s explanation. Lastly,
the results further show these negative-affective consequences are especially evident if a high level of inhibitory control was required.

While some of the results align with the expectations of the Inhibition-Altered Value Account, these results do not preclude the Inhibition Trace Account and pose additional questions about why no emotional response was elicited during affective-ratings. The findings described here could have substantial implications for our understanding of this cognitive-affective process, but are still not well understood.

It’s expected that as we further understand this process, our understandings can contribute to therapeutic research. Responses toward reward-related stimuli can at times become maladaptive as their high motivational incentives can drive behaviour at levels of investment and exertion which pose costs to other needs (i.e., Hyman & Malenka, 2001). Visceral factors often have an excessive influence within self-destructive behaviours characterized by lack of control such as overeating, addiction, and sexual misconduct (Loewenstein, 1996). Increases in the intensity of visceral factors can often produce suboptimal patterns of behaviours, at their heights literally precluding the ability to engage in decision related deliberations (Loewenstein, 1996). Thus, examining the visceral responses that occur during exertion of cognitive control, as well as determining visceral impacts on value perception and responses during choice, may be influential in addressing possible management interventions for individuals undergoing treatment for compulsion related disorders. The current evidence seems to indicate that there are long-term consequences of inhibition associated affect. If this is so, inhibition could be used to help ameliorate inappropriate stimulus valuation and attention orientation with long term consequences.
Addressing the emotional implications of inhibition may also be beneficial in surmising manners for modifying decision-making amongst individuals with neurological disorders that are characterized by social and non-social deficits in behavioural valuation including autism, schizophrenia, and depression (Baron-Cohen & Belmonte, 2005; Deldin et al., 2000; Langdon et al., 2006; Pelphrey et al., 2002). Thus, these results may be beneficial to the development of inhibition-based interventions that reduce motivational incentive or hedonic value amongst those individuals with disorders associated with issues in maintaining self-control (Ferrey et al., 2012).
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USING FACIAL ELECTROMYOGRAPHY TO TEST COMPETING ACCOUNTS OF THE AFFECTIVE CONSEQUENCES OF RESPONSE INHIBITION


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Appendix Figure 1.

Passive viewing of emotion eliciting stimuli

Explicit facial expression elicitation

1000 ms
Positive stimulus viewing
1650 ms
Angry Face!

1000 ms
Facial Expression Response
Angry Face!
1650 ms

1000 ms
Happy Face!
1650 ms

1000 ms
Negative stimulus viewing
1650 ms

Happiness

Explicit facial expression elicitation

Positive stimulus viewing
1650 ms

Explicit facial expression elicitation

Negative stimulus viewing
1650 ms

Explicit facial expression elicitation

Anger
Appendix Figure 2.

A. Vertical Novel Shapes

B. Horizontal Novel Shapes
C. Examples of stimulus sequence

**Perceptual-feature sorting task: Vertical item**

1. +
2. 1000 ms
3. Press “Tall”!
4. 1650 ms
5. +
6. 1000 ms
7. +

**Perceptual-feature sorting task: Horizontal item**

1. +
2. 1000 ms
3. Press “Long”!
4. 1650 ms
5. +
6. 1000 ms
7. +

**Go/No-Go task: Go-Trial**

1. +
2. 1000 ms
3. Response Preparation
4. Long or Tall?
5. 600 ms
6. +
7. 1000 ms
8. Response Cued
9. Go on Yellow!!
10. 100 ms
11. +
12. 1000 ms
13. Response
14. Go!
15. 1000 ms

**Go/No-Go task: No-Go-Trial**

1. +
2. 1000 ms
3. Response Preparation
4. Long or Tall?
5. 600 ms
6. +
7. 1000 ms
8. Response Cued
9. No-Go on Blue!!
10. 100 ms
11. +
12. 1000 ms
13. Response
14. No-go!
15. 1000 ms

**Subjective Appraisal task**

1. +
2. 1000 ms
3. Subjective Appraisal
4. How Cheerful?
5. 1650 ms
6. Not at all Cheerful
7. Very Cheerful

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USING FACIAL ELECTROMYOGRAPHY TO TEST COMPETING ACCOUNTS OF THE AFFECTIVE CONSEQUENCES OF RESPONSE INHIBITION
Table 1.

International Affective Picture System Images (IAPS).

<table>
<thead>
<tr>
<th>STIMULUS TYPE</th>
<th>DESCRIPTION/NAME</th>
<th>IAPS #</th>
<th>MEAN VALENCE (1-9)</th>
<th>AFFECT</th>
<th>MUSCLE</th>
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</thead>
<tbody>
<tr>
<td>IAPS DIGUST</td>
<td>burned child</td>
<td>3053</td>
<td>1.31</td>
<td>Disgust</td>
<td>Corrugator</td>
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<tr>
<td>IAPS LIKING</td>
<td>kid</td>
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<td>IAPS ANGER</td>
<td>ganster with gun</td>
<td>6243</td>
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<td>Anger</td>
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<td>IAPS DIGUST</td>
<td>stiches on neck</td>
<td>3195</td>
<td>2.06</td>
<td>Disgust</td>
<td>Corrugator</td>
</tr>
<tr>
<td>IAPS LIKING</td>
<td>Father</td>
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<td>IAPS ANGER</td>
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<td>9800</td>
<td>2.04</td>
<td>Anger</td>
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<td>IAPS DIGUST</td>
<td>dead cows</td>
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<td>IAPS LIKING</td>
<td>money</td>
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<td>7.51</td>
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<tr>
<td>IAPS ANGER</td>
<td>tiger being killed</td>
<td>6415</td>
<td>2.21</td>
<td>Anger</td>
<td>Corrugator</td>
</tr>
</tbody>
</table>
Table 2.

Warsaw Set of Emotional Facial Expression Pictures (WSEFEP).

<table>
<thead>
<tr>
<th>STIMULUS</th>
<th>DESCRIPTION/NAME</th>
<th>WARSAW #</th>
<th>PUTITY</th>
<th>INTENSITY</th>
<th>AFFECT</th>
<th>MUSCLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>WARSAW FACE HAPPY</td>
<td>Female 1</td>
<td>AD_7950</td>
<td>0.77</td>
<td>0.72</td>
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<td>WARSAW FACE DISGUST</td>
<td>Female 1</td>
<td>AD_8268</td>
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<td>0.73</td>
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<td>Corrugator</td>
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<td>Neutral</td>
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<td>WARSAW FACE HAPPY</td>
<td>Female 2</td>
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<td>Positive</td>
<td>Zygomaticus</td>
</tr>
<tr>
<td>WARSAW FACE DISGUST</td>
<td>Female 2</td>
<td>KP_0351</td>
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<td>0.71</td>
<td>Disgust</td>
<td>Corrugator</td>
</tr>
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<td>Female 2</td>
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<td>0.83</td>
<td>0.71</td>
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Table 3

Correlation Table of Negative-Emotion Associated Muscle Response and Subjective Evaluation
Corrugator electrophysiological activity during critical time windows

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<th>Dif300ms</th>
<th>DifEarlyEval</th>
<th>DifLateEval</th>
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Notes. *p<.05. **p<.01. ***p<.001.
Table 4

Correlation Table of Positive-Emotion Associated Muscle Response and Subjective Evaluation
Zygomaticus electrophysiological activity during critical time windows

<table>
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Notes. *p<.05. **p<.01. ***p<.001.