INTOLERANCE OF UNCERTAINTY AND THE PHYSIOLOGICAL CORRELATES OF ANTICIPATION AND APPRAISAL OF AFFECTIVE STIMULI

A DISSERTATION IN
Psychology

Presented to the Faculty at the University of
Missouri – Kansas City In partial fulfillment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY

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2021

INTOLERANCE OF UNCERTAINTY AND THE PHYSIOLOGICAL CORRELATES OF ANTICIPATION AND APPRAISAL OF AFFECTIVE STIMULI

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ABSTRACT

Intolerance of uncertainty (IU) is an important transdiagnostic construct found across many psychiatric conditions. This construct is thought to reflect a general tendency to interpret uncertainty as overly aversive, and often results in individuals engaging in atypical cognitive, behavioral, and affective processes. While the effects of IU are well documented in clinical contexts, the ability to capture and assess these abnormalities through the use of physiological measures in laboratory settings remains limited. Better understanding the association between IU and physiological measures is important, as it may speak to the underlying mechanisms responsible for what is overtly observed in clinical settings. In order to better understand the effect IU on emotional processes, the current study relied on an S1-S2 image viewing paradigm were S1 cues were manipulated to either provide information about the S2 image valence, or to provide no information about the S2 image valence. Cue-related stimulus-preceding negativity (SPN) and image-related late positive potential (LPP) were captured and assessed as measures of emotional anticipation and emotional reactivity, respectively. Self-reported arousal and valence ratings following image presentation were also captured to provide additional support of the physiological data. Data were compared between High- and Low-IU individuals. Results reveal that High- compared to Low-IU individuals exhibited greater emotional anticipation, as reflected by SPN, for certain affective cue conditions, as well as the uncertain cue condition. Between-group analyses for LPP data failed to reveal an effect of IU-group, but did reveal important trends revealing greater emotional reactivity for uncertain relative to certain conditions, and negative relative positive content; further discussion of these contrasts are provided in this document. Lastly, self-reported valence rating demonstrate that the effect of uncertainty is specific to negative images, with greater negativity reported for uncertain-negative compared to certain-negative images, and no observed differences of positive image conditions. Self-reported arousal ratings largely demonstrate greater arousal for affective relative to neutral, negative relative to positive, and certain relative to uncertain conditions; further discussion of these contrasts are provided in the document. Implications of these findings in the context of existing literature, as well as limitations and future directions are discussed.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the College of Arts and Sciences, have examined this dissertation titled "Intolerance of Uncertainty and the Physiological Correlates of Anticipation and Appraisal of Affective Stimuli," presented by Andrew David Wiese, candidate for the Doctor of Philosophy degree, and certify that in their opinion it is worthy of acceptance.

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CONTENTS

LIST OF ABBREVIATIONS

Deep Brain Stimulation = DBS

Cognitive Behavioral Therapy = CBT

Electroencephalogram = EEG

Electrooculogram = EOG

Event Related Brain Potentials = ERPs

Obsessive Compulsive Disorder = OCD

Inter Stimulus Interval = ISI

Intolerance of Uncertainty = IU

Intolerance of Uncertainty Scale – short from = IUS-12

Generalized Anxiety Disorder = GAD

Late Positive Potential = LPP

Major Depressive Disorder = MDD

Stimulus Preceding Negativity = SPN

Yale-Brown Obsessive Compulsive Scale = Y-BOCS

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ACKNOWLEDGEMENTS

I would like to offer my appreciation and indefinite gratitude to my committee chair and mentor, Dr. Diane Filion. You have been an outstanding mentor and support over the years, and I am forever grateful for the opportunities you have afforded me during my time at UMKC. I would also like to extend my sincere appreciation to Dr. Seung-Suk Kang. It has been a privilege to work alongside you in your lab, and I look forward to ongoing collaborations. For Dr. Seung-Lark Lim, I would like to thank you for your support and openness to allowing me to use your research space and equipment, along with your helpful commentary on different research projects over the years. Dr. Erin Hambrick and Dr. Joah Williams, I am thankful for your commentary and clinical considerations for this project. Dr. Kathryn Kriegshauser, I am forever grateful for the clinical and research opportunities at KCCAT, and I am particularly thankful for your commentary on IU and its association with anxiety and obsessive-compulsive spectrum disorders.

I would like to extend special appreciation to my wife, Alexa Metzger, who has been there for me since I started this journey; I could not have done this without your love and support. To parents, David and Kathryn Wiese, thank you for your unwavering encouragement, love, and constant backing. My sisters, Sarah Wiese and Carolyn Osberger, I am forever grateful to have you both in my corner, whether it be for perspective or a quick phone call to avoid work – thank you both. I would additionally like to acknowledge my late sister, Amy Wiese, whose premature passing inspired me from an early age to be curious about human emotion and behavior. This project would not be possible without these contributions from my family.

To the countless individuals along the way, whether they be course instructors, my graduate student peers, undergraduates I have mentored or worked with, patients, research collaborators, practicum and internship supervisors, or anyone else during my time at UMKC, thank you for your unique contribution towards this project and my doctoral degree.

CHAPTER 1

REVIEW OF THE LITERATURE

Intolerance of uncertainty (IU) is an important construct thought to reflect how individuals interpret and respond to situations marked by uncertainty, with those with higher levels interpreting uncertainty as aversive (Dugas, Schwartz, & Francis, 2004; Freeston et al., 1994). IU is a transdiagnostic construct associated with a wide range of psychopathologies, including but not limited to mood; anxiety spectrum; obsessive-compulsive spectrum; eating; and autism spectrum disorders (Carleton et al., 2012; Kesby et al., 2017; Neil et al., 2016; Summers et al., 2016). With these well documented associations, IU plays an integral role in the development and maintenance of different psychiatric conditions, where individuals with elevated IU engage in atypical cognitive, behavioral, and affective processes when faced with uncertainty (Carleton, 2012). Research on IU has largely been conducted from a clinical-treatment perspective, where the aims of research are to advance understanding of how IU is related to pathology and how IU can be modulated through intervention (Gentes & Ruscio, 2011). While important, it should be noted that the current understanding of biological mechanisms and physiological indices associated with IU remain understudied, to date.

This is a notable limitation in the understanding of IU, and psychopathology as a whole, as current nosologies, including the Diagnostic and Statistical Manual of Mental Disorders and the International Classification of Diseases (DSM-5; American Psychiatric Association, 2013; ICD-10; World Health Organization, 1992) are over-reliant on overt symptoms rather than underlying biological factors that may be responsible for what is overtly observable (Cuthbert & Insel, 2013). Furthermore, both psychiatry and psychology lag behind traditional medicine in utilizing biological indices for both diagnostic and treatment purposes (Wiese & Boutros, 2019; Boutros et al., 2005). The identification of physiological measures associated with IU could be an important step towards the integration of laboratory tests that can detect psychopathology, which may be robust to bias and assessment error. Furthermore, the identification of these measures may provide insight into the underlying mechanisms responsible for exaggerated IU, which may facilitate interventions, both pharmaco- and psychotherapies, designed to address and treat for these biological abnormalities. Cognitive-behavioral interventions focused specifically on IU (CBT-IU) show promise in treating overall pathology, as well self-report IU (Robichaud, 2013), however the mechanisms associated with these changes remain unclear. Exposing these underlying biological processes associated with transdiagnostic symptoms, such as IU, remains an elusive goal, however basic laboratory research is needed so that future interventions can target these abnormalities, and even go so far as to identify these abnormalities for assessment purposes.

Despite the overreliance on non-experimental approaches, some researchers have used measures of human physiology in experimental paradigms to help advance understanding of how IU and other transdiagnostic symptoms influence observable symptoms, including affective, cognitive and behavioral symptoms. These measures tend to be more objective and robust to bias compared to other measures (e.g. self-report and behavioral observations) of emotion (Appelhans, & Luecken, 2006). Additionally, physiological indices can provide excellent temporal resolution, which allows researchers to better understand how symptoms of psychopathology influence emotion in real time.

This approach of measuring human physiology in laboratory settings has been instrumental for advancing understanding of other transdiagnostic constructs, such as *error-*

monitoring (Grant et al., 2015; Olvet & Hajcak, 2008). This construct has been measured using error-related negativity (ERN), an ERP component observed immediately following the commission of an error during reaction-time tasks (Gehring et al., 2018). A large body of evidence has documented exaggerated ERN across anxiety disorders, has found that ERN is a reliable predictor of future psychopathology in children, and there is even growing support to consider exaggerated ERN as an *endophenotype* of psychopathology (Hajcaket al., 2019; Meyer et al., 2015; Meyer et al., 2018; Riesel, 2019). While this robust literature provides evidence of ERN as a measure of psychopathology, other ERP components also show unique associations with constructs of pathology. Notably, P300 has been documented as measure of attentional deficits and as a potential biomarker of schizophrenia (Hamilton et al., 2019), while LPP has been documented as a proposed measure of cognitive impairment in individuals with HIV and neurodegenerative diseases (Meghdadi et al., 2021; Waninger et al., 2018).

With unique cognitive, behavioral, and affective processes associated with IU, it is reasonable to posit this construct, much like error monitoring, may be associated with unique biological processes reflected by ERP components (Carleton et al., 2007; Shapiro et al., 2020). Here, it is essential that the research paradigm used to draw associations between a construct of interest (e.g. IU) and measures of interest (e.g. ERPs), is generalizable to what is experienced outside of a laboratory setting. In terms of IU, experimental paradigms that facilitate uncertainty are consistent with this aim, as individuals with higher levels of IU exhibit atypical responses when faced with uncertainty during their day-to-day; ERPs appear as a promising measure to capture these responses in an experimental setting to provide further evidence of these abnormalities.

One research paradigm that has been influential in identifying ERPs reflective of the day-to-day abnormalities in those with elevated IU is the S1-S2 image viewing paradigm. In this design, participants are presented with a cue (‘S1’) alerting them of a subsequent stimulus they need to prepare for and attend to (‘S2’) (Böcker et al., 2001). Importantly, cues (S1) can be manipulated to provide varying degrees of information about the proceeding stimulus (S2) (e.g. Gole et al., 2012). With this design, researchers are able to examine anticipatory neural responses specific to cues that can provide varying degrees of information about the S2 stimuli, as well as reactive neural responses to different stimuli that proceed the cues.

A recent study, Johnen and Harrison (2020) relied on this S1-S2 image viewing paradigm and presented participants with unpleasant and neutral images which were preceded by cues indicating either a 50-percent (‘uncertain’ condition); 70-percent (‘fairly certain’ condition); or 100-percent (‘certain’ condition) chance that an unpleasant image would appear following the cue. The researchers examined cue-locked ERPs and found no effect of condition on P200 amplitude, while later ERPs of interest, namely early posterior negativity (EPN), late positive potential (LPP), and stimulus preceding negativity (SPN), exhibited larger amplitudes for the ‘certain’ condition cues relative to the other two less certain conditions. While this is suggestive that anticipatory processes are affected by the amount of information provided by cues, the authors appropriately note the absence of positively valenced images, as well as no consideration of IU as an individual difference impacting the results and note these limitations that should be addressed in subsequent research. Furthermore, Johnen and Harrison (2020) limited their investigation to ERPs prior to image onset, making it difficult to draw conclusions on how varying levels of information provided by cues influence affective processes following image presentation.

A similar method was used in a 2017 study examining ERPs in responses to images preceded by either informative or uninformative cues in individuals with obsessive-compulsive disorder (OCD) and healthy controls (Dieterich et al., 2017). There data provide evidence of image-related P200 facilitation and N200 attenuation for images preceded by uninformative cues only for the OCD sample, while both samples exhibited image-related LPP facilitation following uninformative relative to informative cue conditions, and aversive relative to neutral. These data suggest individuals with OCD, a pathology often marked by high levels of IU (Hezel et al., 2019; Tolin et al., 2003), exhibit different early emotional reactivity following image based on cue type, as reflected by these early components (Dieterich et al., 2017). The authors were also able to find evidence of upper α suppression for affective and uncertain cues relative to neutral cues for their OCD sample. The researchers were unable to examine cue-related ERPs due to a concurrent behavioral task they were asked to perform in response to cues. Additionally, they only included neutral and aversive images, which makes it difficult to generalize these findings outside of a laboratory context where individuals can be presented with positively valenced stimuli following periods of uncertainty.

In their 2012 study, Gole and colleagues relied on a S1-S2 image viewing design where participants were presented with informative or uninformative cues prior to unpleasant or neutral images during each trial. After performing a median-split based on self-reported IU scores, the researchers were able to examine ERPs of interest during anticipation (e.g. after cue presentation) and reactive (e.g. following image onset) phases of the study. During anticipation, P200 facilitation in High- compared to Low-IU individuals was observed, suggesting greater attentional capture to threating information. Unexpectedly during anticipation, they did not observe an SPN component prior to image onset. This is particularly noteworthy, as SPN, a measure of emotional anticipation prior to stimulus onset, and is regularly observed during anticipation in S1-S2 designs (e.g. Moser et al., 2008; Poli, et al., 2007). Following exposure to image, High-IU individuals exhibited LPP facilitation to unpleasant images that followed informative cues compared to unpleasant images that followed uninformative cues. They interpret findings to suggest High-IU individuals engage in avoidance following the presentation of uncertain cues, which is reflected by the attenuation of LPP, a reliable measure of emotional reactivity to visual stimuli. The potential avoidance is conceptually similar to what is observed in clinical settings, where individuals with psychopathologies marked by elevated levels of IU consistently report behavioral and cognitive avoidance of situations marked my uncertainty (McGuire et al., 2011).

Even though the S1-S2 paradigm has been influential, other research paradigms have been used to capture the affective and cognitive processes associated with elevated levels of IU. In a rigged card game task, where participants *could* receive an electric shock, participants exhibited great SPN amplitude during periods of uncertainty compared to certainty, however IU did not appear as a significant contributor to SPN facilitation (Tanovic et al., 2018). To examine the relationship between error monitoring and IU, Jackson and colleagues (2016) relied on a dichotomous decision-making task (i.e. flanker task) to elicit an ERN, and found *prospective IU* to be positively associated with ERN amplitude, while *inhibitory IU* was negatively associated with ERN amplitude. These sub-measures of IU refer to the cognitive and behavioral facets when faced with uncertainty, respectively (Mahoney,

& McEvoy, 2012). Lastly, prospective IU has also been positively associated with LPP amplitude during mental imagery tasks, as well (MacNamara, 2018). While these other methodological approaches are important to advance understanding of IU, the S1-S2 paradigm is a particularly robust tasks, as it can facilitate uncertainty and while ERPs associated with anticipation and reactivity are measured.

Taken together, these findings demonstrate that ERPs are promising measures that can capture the cognitive, behavioral, and affective processes associated with IU in in real-world contexts. While the different research paradigms noted above remain crucial for further understanding the neural processes associated with IU, it is clear that the S1-S2 paradigm has many benefits. This paradigm allows researchers to examine (1) how cues (S1) affect anticipatory processes, as reflected by ERPs, (2) how emotional and neutral stimuli (S2) can influence affective response, as reflect by ERPs (3) how the manipulation of cues (e.g. informative versus uninformative) can influence emotional responses to different types of stimuli, and (4) The how individual differences in IU influence the anticipatory and reactive responses to different stimuli.

The present study has been designed to assess the anticipatory and reactive processes associated with IU in certain and uncertain contexts reflected by SPN and LPP, two ERPs measures thought to reflect anticipation and emotional reactivity, respectively (Böcker et al., 2001; Hajcak & Foti, 2020). In order to achieve this, and S1-S2 image viewing paradigm was used where cues (S1) were manipulated, and participants were presented with affective and neutral images (S2). The hypotheses for the present study are as follows:

Hypothesis 1a. If individuals with higher levels of IU engage in atypical anticipatory processes when faced with uncertainty, then individuals with High- compared to Low-IU should exhibit SPN facilitation during uncertain conditions.

Hypothesis 1b. If individuals with higher levels of IU engage in atypical anticipatory processes prior to facing affective content, then High- compared to Low-IU individuals should exhibit SPN facilitation prior to viewing affective images preceded by certain cues.

Hypothesis 2a. If individuals with higher levels of IU experience heightened emotional reactivity when responding to uncertainty, then individuals with High- compared to Low-IU should exhibit LPP facilitation when viewing affective images preceded by uncertain cues.

Hypothesis 2b. If individuals with higher levels of IU experience heightened emotional reactivity when responding to affective content, then individuals with High- compared to Low-IU should exhibit LPP facilitation when viewing affective images preceded by certain cues.

Hypothesis 3a. If individuals with higher levels of IU experience heightened emotional reactivity when responding to uncertainty, then individuals with High- compared to Low-IU should report higher levels of self-reported arousal and directional valence (that is, reported positivity for positive content, and negativity for negative content) as reflected by SAM scale ratings after viewing affective images preceded by uncertain cues.

Hypothesis 3b. If individuals with higher levels of IU experience heightened emotional reactivity when responding to affective content, then individuals with High- compared to Low-IU should report higher levels of self-reported arousal and directional valence as reflected by SAM scale ratings after viewing affective images preceded by certain cues.

CHAPTER 2

METHODOLOGY

Participants

For the present study, a sample of undergraduate students (N = 31) was recruited from an urban, Midwestern university. Participants were identified and screened using the university's online research portal to ensure normal or normal-to-corrected vision and hearing, as well as no history of central nervous system disease. Additional inclusion criteria were included, as this study was part of larger project, however these criteria fall outside the scope of the present study and are not discussed here. After determining suitability for the study, participants completed a series of self-report measures. A total of 94 participants enrolled in the study, with 54 completing all the questionnaires, 32 of whom presented for the EEG portion of the study; one participant discontinued the EEG portion of the study part way through the tasks resulting in a final sample of 31 participants. All participants were awarded one research credit for completing the self-report measures, and $30 for the laboratory portion of the study, at a pro-rated amount of $10 per hour for those who were unable to finish the laboratory visit.

In the original dissertation proposal, an extreme groups approach to participant recruitment and sampling was proposed, where self-reported IU was to be used to differentiate High- and Low-IU individuals, resulting in two groups of 30 participants each. An a priori power analysis estimating the sample size needed to detect a medium effect revealed that a sample of 40 individuals divided into two groups would have been sufficient (Cohen, 1969). Cutoffs for these two groups were taken from prior large-scale research assessing mean IU scores in healthy community and university samples (Low-IU) and a clinical sample (High-IU) (Carleton et al., 2012). Participants were to be recruited in each group until target sample sizes for the groups were obtained. Unfortunately, by order of the university administration and the KC Metro Health Department, in-person data collection was suspended indefinitely following the onset of the COVID-19 pandemic which resulted in a notable deviation from the originally proposed recruitment method, sample size, and IU scores used to define High- and Low-IU groups. In hope that in-person data collection would resume, an additional 25 participants were recruited and completed self-report measures and agreed to allow the researchers to contact them once safe to resume in-person data collection; however, in-person data collection remains suspended, to date, due to the ongoing COVID-19 pandemic (see Appendix C for additional commentary on the COVID-19 pandemic and the impact on this project).

With a limited sample size, High- and Low-IU individuals were identified using a median split on self-self-reported IU (Mdn = 33). While creating discrete groups using a continuous variable has been criticized and results in reduced statistical power (i.e. McClelland et al., 2015), there are theoretical justifications for using this approach. More specifically, when predictor variables are captured through reliable assessment measures and the distributions of the dichotomous groups are unique from one another, dichotomizing continuous variables may be appropriate to uncover phenomena associated with high and low levels of the construct of interest (DeCoster et al., 2009). In this study, mean IU scores for High- and Low-IU individuals appear close-to or meeting the original cutoff score borrowed from Carleton and colleagues (2012). Additionally, a median-split has been used in prior experimental research with a similar sample size while also examining ERP components and IU (Gole et al., 2012). Finally, the median-split resulted in two groups with self-reported IU scores that were significantly different from one another $t(29) = 8.818$, $p < .001$. Even though the original sampling method could not be used because of the COVID-19 pandemic, important considerations were taken to best evaluate the existing dataset. Relevant demographic information for the High- and Low-IU groups are provided in Tables 1 and 2.

Table 1.
Demographic data for Low-IU group.

N = 15	Mean (SD)	Range	Mdn
IUS-Total	26.27 (3.93)	19 – 32	26
IUS-Prospective[1]	18.40 (3.24)	14 – 24	18
IUS-Inhibitory[1]	7.67 (2.09)	5 – 12	7
Age	20.60 (2.47)	18 – 25	20
Gender			
Male	4		
Female	11		
Race			
American Indian or Native Alaskan	0		
Asian	1		
Black or A. American	3		
Latino	2		
Hawaiian or other Pacific Islander	0		
White	9		

[1]The IUS-12 is comprised of two subscales that will be described and examined in a later section of this report.

Table 2.
Demographic data for High-IU group.

N = 16	M (SD)	Range	Mdn
IUS-Total	39.88 (4.60)	33 – 47	41
IUS-Prospective	24.88 (3.61)	20 – 32	25
IUS-Inhibitory	14.88 (2.63)	10 - 20	14.5
Age	23.25 (5.07)	18 - 37	21
Gender			
Male	3		
Female	13		
Race			
American Indian or Native Alaskan	0		
Asian	1		
Black or A. American	3		
Latino	1		
Hawaiian or other Pacific Islander	0		
White	11		

Materials and Equipment

For the S1-S2 image-viewing task, images of unpleasant, neutral, and pleasant valence were selected from the International Affective Picture System (IAPS; Lang et al., 2008). A total of 75 unpleasant, 50 neutral and 75 pleasant images were selected for this study, with pleasant and unpleasant images matched on arousal $t(148) = 1.131$, $p = .260$. Of the 200 images used, only 60 unpleasant, 40 neutral, and 60 unpleasant images were used for the S1-S2 image viewing task. The remaining 40 images were used for another task that is not reported here; the allocation of images into the current S1-S2 image viewing task and the additional task were randomized across participants resulting in equal probability for each image being used in the S1-S2 image viewing task. The selected images were separated into five conditions: certain-positive, certain-neutral, certain-negative, uncertain-positive and uncertain-negative. The certain conditions consisted of 40 randomly selected images that match their labeled valence categories (e.g. certain-unpleasant condition consist of 40 unpleasant images). The uncertain conditions consisted of the remaining 20 pleasant and 20 unpleasant images. A list of IAPS images used in the present study can be found in Appendix E.

A Self-Assessment Manakin (SAM; Bradley & Lang, 1994) ranging from 1-to-5 was used to record self-reported arousal (1 = excited; 5 = calm) and valence ratings (1 = positive valence ; 5 = negative valence) following the presentation of each image. The SAM arousal and valence scales are displayed in Figure 1.

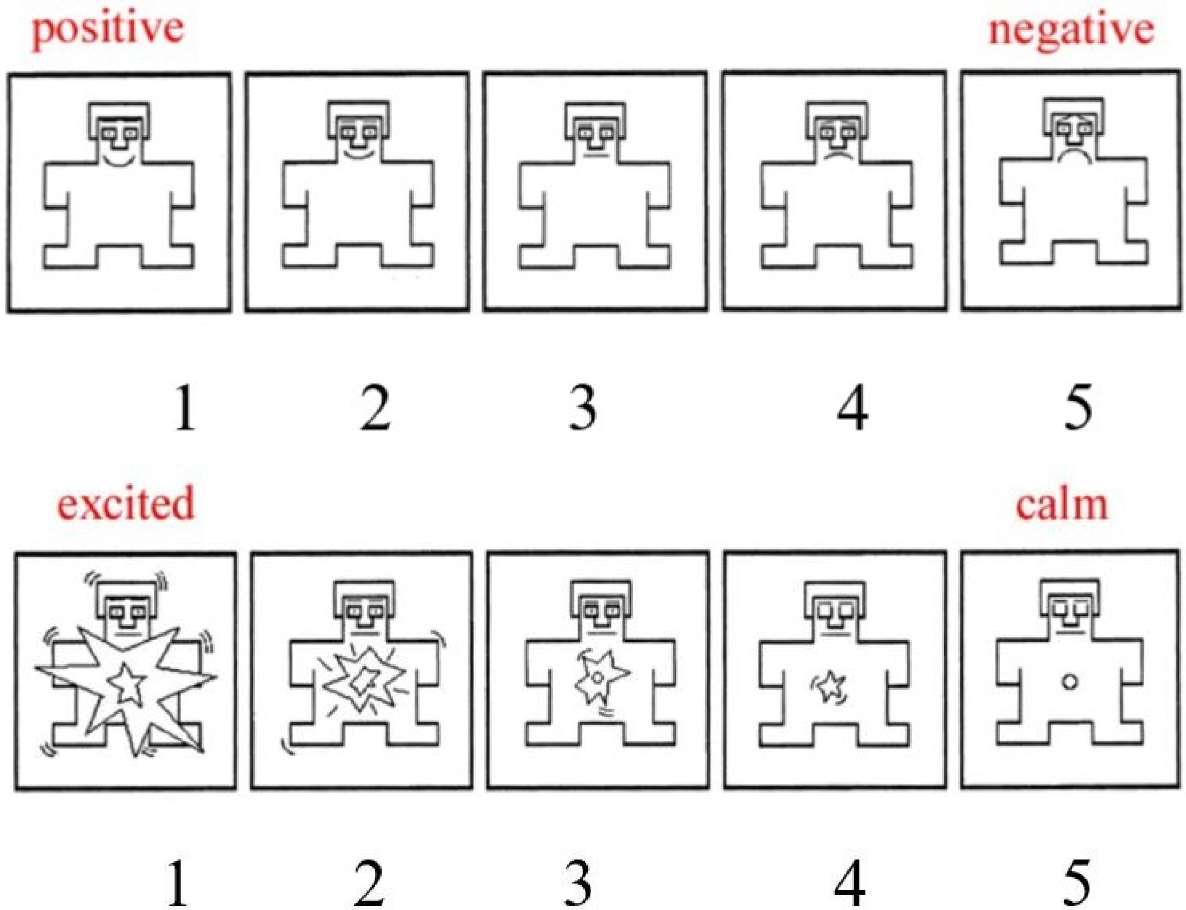

Figure 1. Self-assessment manakin (SAM) arousal and valence scales used to measure self-reported affect following the presentation of each image.

Experimental Task

The task used in the current study was an S1-S2 image viewing paradigm borrowed from previous IU and ERP image viewing studies (Gole et al., 2012; Grant et al., 2015; Schienle et al., 2010). In this paradigm, participants were provided with cues that either accurately identify the valence of an upcoming image (certain conditions), or cues that provide no information about the valence of an upcoming image (uncertain conditions).

At the start of each trial, participants were presented with one of the four cues, lasting 500ms in duration. Certain-unpleasant trials used a minus sign (-) cue, certain-positive trials used a plus sign (+) cue, certain-neutral images were used a circle (O) cue, and the uncertain image conditions, where cue provides no information about the upcoming image valence, used a question mark (?) cue. Pleasant and unpleasant image were represented equally following the presentation of the uncertain cue (probability = 50:50). Uncertain-unpleasant and uncertain-pleasant conditions were identical to one another, except for the valence of the image displayed after the cue. Because of this, these two conditions were collapsed into one group when analyzing cue-related ERPs. Images that followed each of the three certain cue conditions (+, O, -) always matched the cue's labeled valence (e.g. "+" weas always be proceeded by a positive image).

After 500ms of cue presentation, the cue was replaced by an inter-stimulus interval (ISI), lasting 3000ms. Participants were then be presented with an IAPS image for 2000ms. During IAPS image presentation, participants were encouraged to view the image the whole time it was displayed, and to try to avoid blinking or engaging in behavioral or cognitive avoidance strategies. Participants were then presented with the SAM scales, with the presentation order of the arousal and valence scales randomized across trials. In total, participants completed 160 trials, divided across four blocks, with each block consisting of 40 trials. The 40 trials in each block consisted of 10 trials from each of the three definitive conditions, and five trials from the two uncertain conditions. All images were randomly assigned to blocks and no images were repeated during the image viewing task. A single trial of the image task can be found in Figure 2.

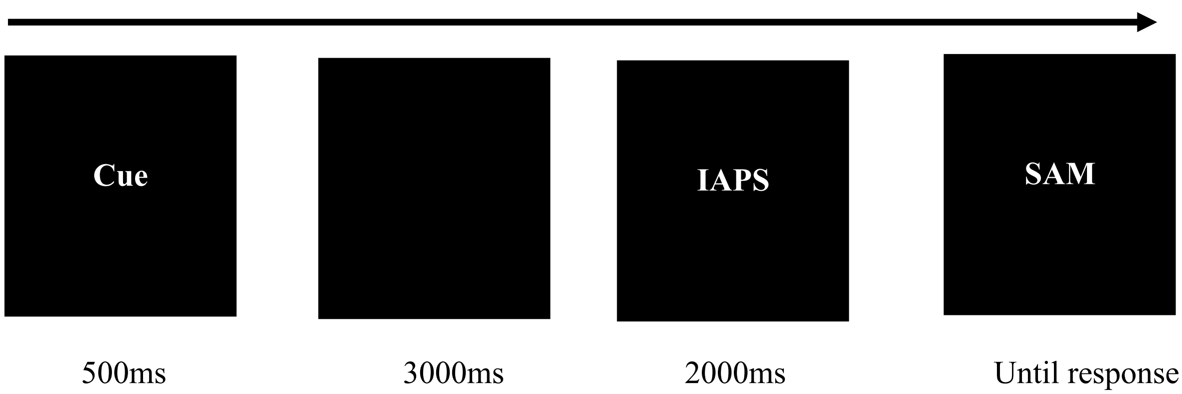

Figure 2. A schematic display of a single trial of the image viewing task. The placeholder "Cue" signifies the image viewing cue ("+", "-", "O", or "?") while IAPS signifies the image corresponding with the prior cue, and SAM refers to the SAM scales from Figure 1.

Self-Report Questionnaire Measures

For the present study, basic demographics were collected along with screening measures to ensure eligibility. Of primary interest, the Intolerance of Uncertainty Scale 12 (IUS-12; Carleton et al., 2007) was used to record self-reported IU, as well as the *prospective* and *inhibitory* subscales of the IUS-12. The 12-item measure is a modified version of the original IUS-27, which was first developed in French and subsequently translated to English (Buhr & Dugas, 2002; Freeston et al., 1994). The current IUS-12exhibits strong correlation to the original scale (r = .96) and has high internal consistency (α = .85). Furthermore, this measure is widely used across both clinical and research settings. Additional self-report measures were administered, however constructs they assess fall outside the scope of the current project. A complete list of these measures can be found in Appendix B, Table A-1. The IUS-12 can be found in Appendix D.

Procedures

The current study was part of a larger study of which Dr. Seung-Suk Kang was Principal Investigator. The full study was approved by the UMKC Institutional Review Board. All participants were recruited through the university's online research portal where studies are posted and made available for voluntary participation. Individuals who enrolled were informed that the present study consist of two parts, (1) a series of online psychological questionnaires lasting approximately 40-minutes, and (2) a laboratory visit consisting of a series of computerized tasks while physiological measures are recorded, for approximately three to four hours. After enrollment, participants were provided a link containing a consent for research, which was required prior to the any of the self-report measures.

Upon completing the consent document, participants were presented a series of screening questions including age, vision and hearing status, and additional exclusion criteria that were relevant to a portion of the research protocol outside of the scope of the present project. Individuals who met criteria were permitted to continue with the study questionnaires and were asked to complete the measures at their own pace. Those who completed all of the questionnaires and provided contact information were compensated with one research credit and contacted via email to enroll in part two of the study.

After working with the study coordinator, participants were invited to the laboratory for their scheduled visit. Upon arriving, participants were welcomed, seated in front of a computer, and fitted with an appropriately sized EEG cap and auxiliary sensors before completing a series of eight separate tasks, one of which participants completed twice (see Appendix B for additional details). Once these tasks were completed, participants then proceeded with the image viewing task. The laboratory visit concluded with two final tasks that are also outside of the scope of this project.

As previously noted, in-person data collection was suspended indefinitely on March 12th, 2020, when all in-person university services were suspended due to the ongoing COVID-19 pandemic. Participants were still permitted to complete self-report questionnaires online and informed that contact information would be retained, and that they may be contacted in the future to complete the laboratory portion of the study. All contact information and identifiers obtained were kept separate from self-report data. Additional details are provided in Appendix C.

EEG Recording and Offline Processing

Continuous electroencephalography (EEG) data were recorded from 64 reusable Ag/AgCl electrodes (actiCHamp, Brain Products GmbH, Gilching, Germany) at 512 Hz sampling rate. Electrodes were placed in accordance to the standard 10-20 system outlined by Picton and colleagues (2000). Auxiliary Ag/AgCl electrodes were placed on the right and left outer canthi muscles to record horizontal electrooculogram (HEOG) activity, as well as the right orbicularis occuli and right corrugator muscles to record vertical electrooculogram (VEOG) activity.

EEG data were pre-processed offline using a custom MATLAB pipeline (version 2017a, The MathWorks Inc., 2017; Kang et al., 2015). All EEG data were down-sampled to 256 Hz and subjected to a .1 Hz a high-pass filter; a 20 Hz low-pass filter was applied after data were pre-processed. Data were inspected for high and low frequency noise using an independent component analysis (ICA) procedure outlined by Kang and colleagues (2015). Ocular, cardiac, muscular and electrical signal noise ICs were identified, segmented, and subsequently removed from the recorded EEG data. All EEG data were then rereferenced to the average of all EEG channels before data were epoched. All ERP time- windows and electrode sites were informed by prior literature and confirmed based on visual inspection of ERP waveforms and topography maps.

During the anticipatory phase of the study, cue-related SPN was defined as the mean activity 1000ms prior to image onset at frontal sites (FP1, FP2, AF3, AF4, and Afz) using a 100ms baseline correction. The time window and electrodes of interest were identified based on visual inspection of topography maps (Figures 3, 4, & 5). Visual inspection of the cue-related SPN also revealed a pronounced negative deflection during this time window of interest for all participants and conditions (Figures 6). Finally, prior research has examined cue-related SPN at frontal sites immediately preceding image onset using a similar time window (MacNamara & Barley, 2018; Shafir & Sheppes, 2018; Tanovic & Joorman, 2019).

Following image presentation, the LPP component was examined during two time-windows of interest (400-700ms and 700-1000ms) as the mean amplitude of central-posterior and central-parietal sites (CPz, CP1, CP2, Pz, P1, P2, P3, and P4) These sites were selected based on prior literature (e.g. Foti & Hajcak, 2008; Hajcak et al., 2009), along with visual inspection of topography maps (Figures 7, 8, 9, & 10) and image-related ERP waveform at electrode sites of interest (Figures 11 & 12). LPP data were baseline corrected by subtracting the average activity 100ms prior to image onset.

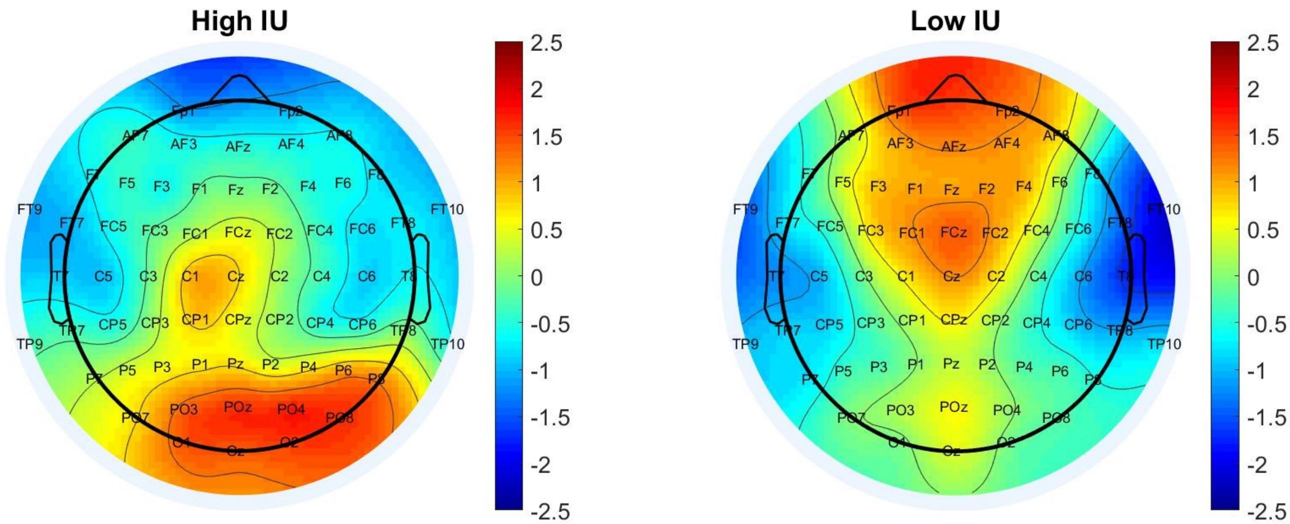

Figure 3. Topography of the average SPN response across all conditions for High- and Low-IU groups during the 1000ms interval immediately before image onset. Negativity for High-IU but not Low-IU individuals can be observed at the electrodes FP1, FP2, AF3, AF4, and Afz

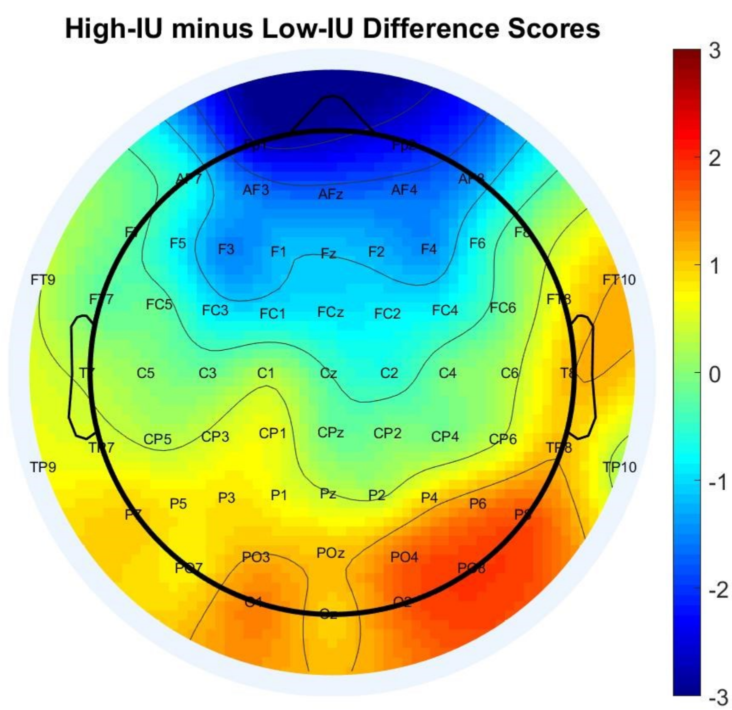

Figure 4. Topography of the SPN (FP1, FP2, AF3, AF4, and Afz) difference score between groups (High- minus Low-IU) during the 1000ms interval immediately before image onset.

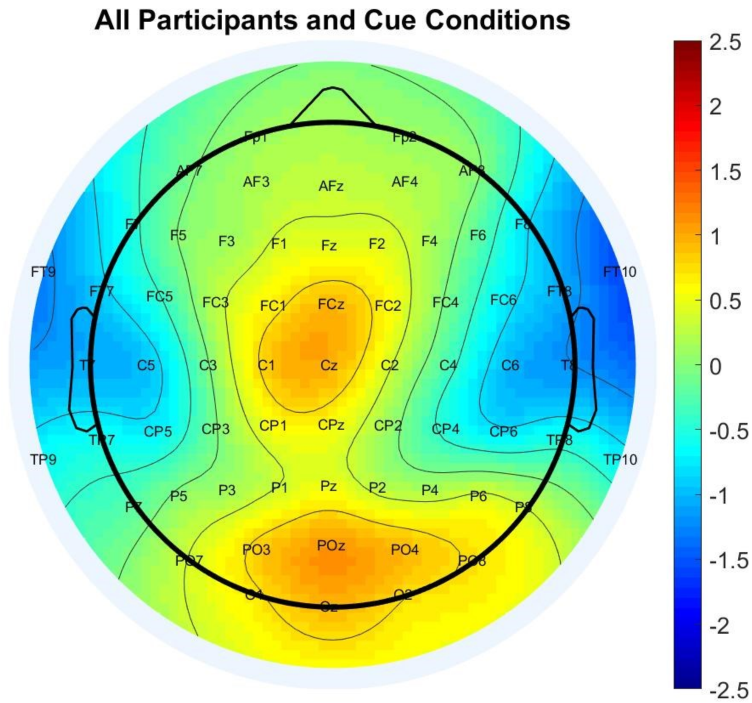

Figure 5. Topography of the average SPN ((FP1, FP2, AF3, AF4, and Afz) response across all conditions and participants during the 1000ms interval immediately before image onset.

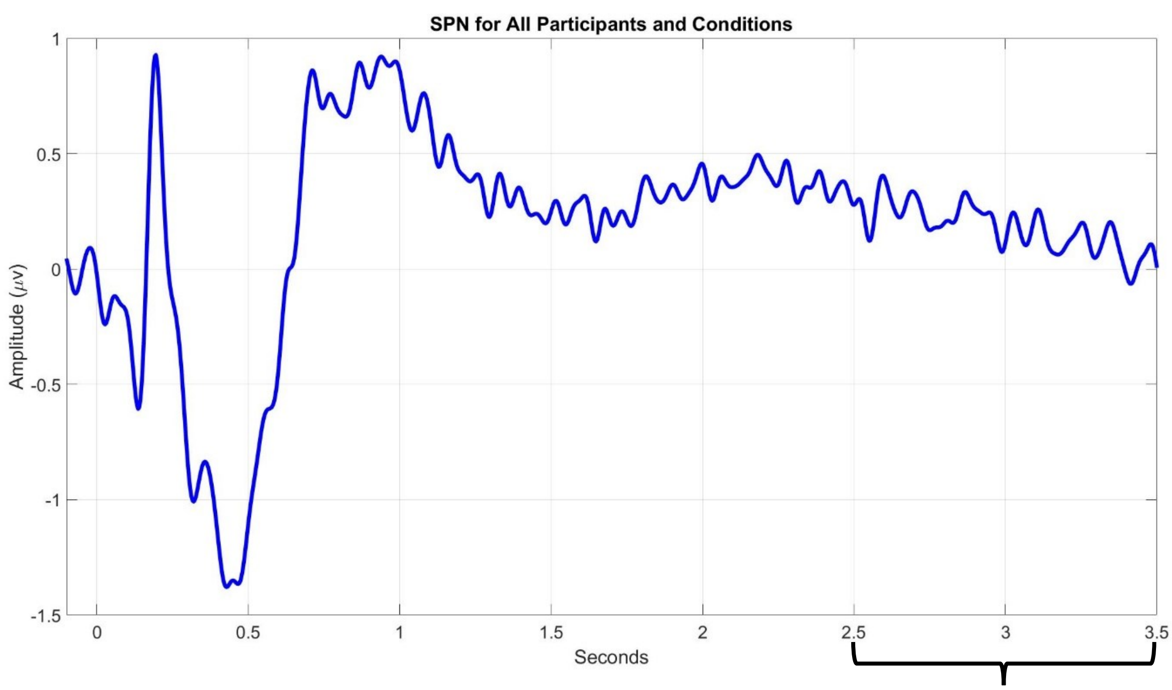

Figure 6. Cue locked event-related potential (ERP) averaged across all participants and conditions at frontal sites (FP1, FP2, AF3, AF4, and Afz). Bracketed region signifies the time window for the SPN component.

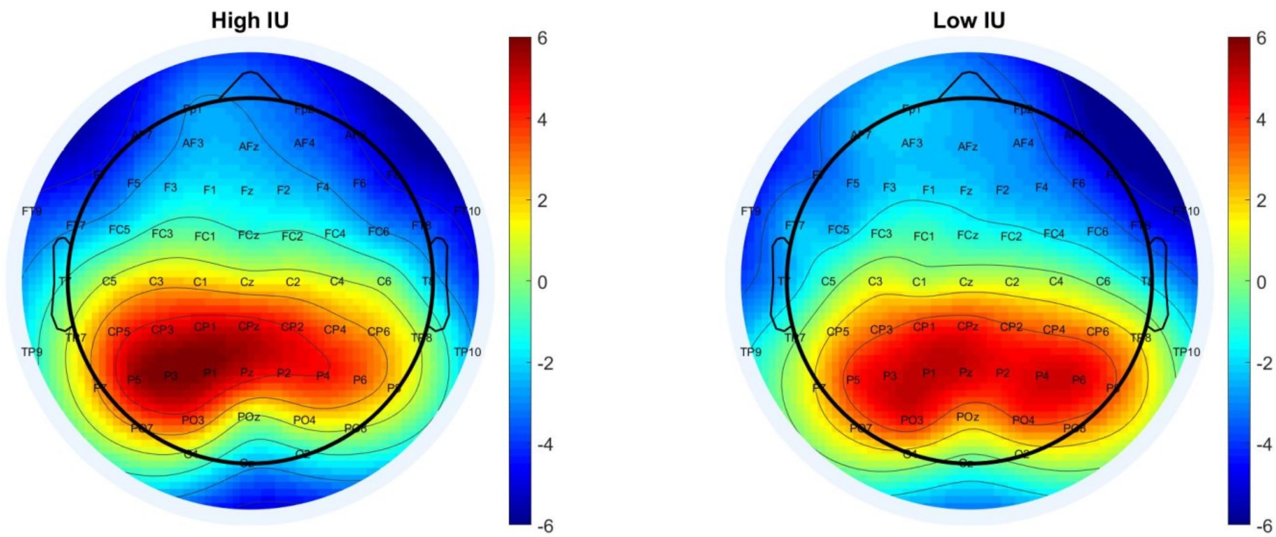

Figure 7. Topography of the average LPP (CPz, CP1, CP2, Pz, P1, P2, P3, and P4) response across all conditions for High- and Low-IU groups during the 400-700ms interval immediately following image onset.

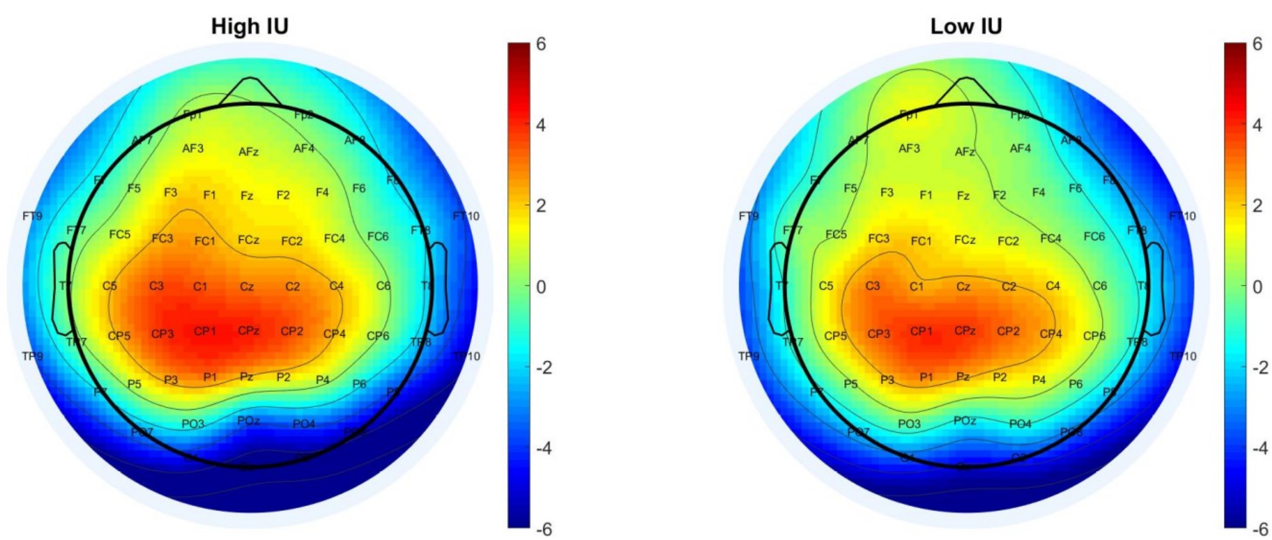

Figure 8. Topography of the average LPP (CPz, CP1, CP2, Pz, P1, P2, P3, and P4) response across all conditions for High- and Low-IU groups during the 700-1000ms interval immediately following image onset.

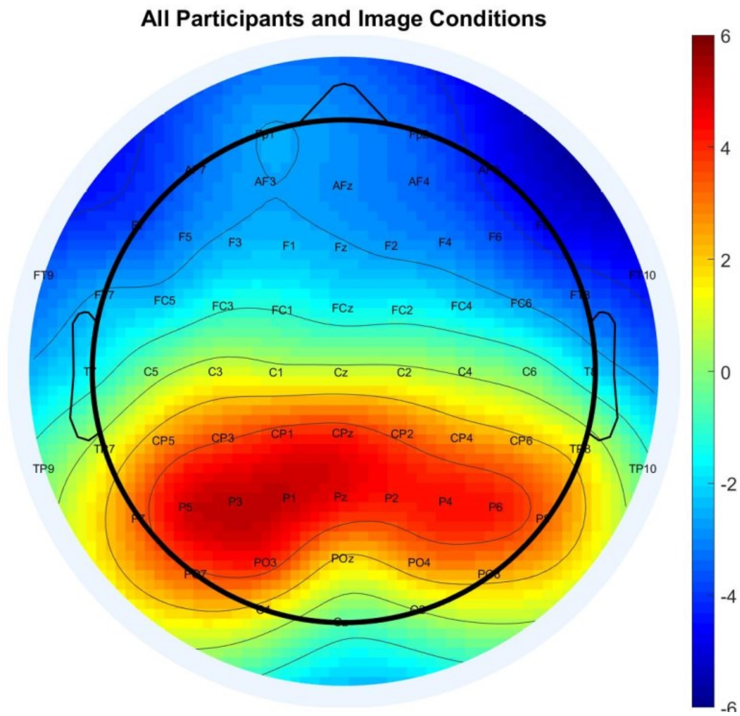

Figure 9. Topography of the average LPP (CPz, CP1, CP2, Pz, P1, P2, P3, and P4) response across all conditions and participants during the 400-700ms interval immediately following image onset.

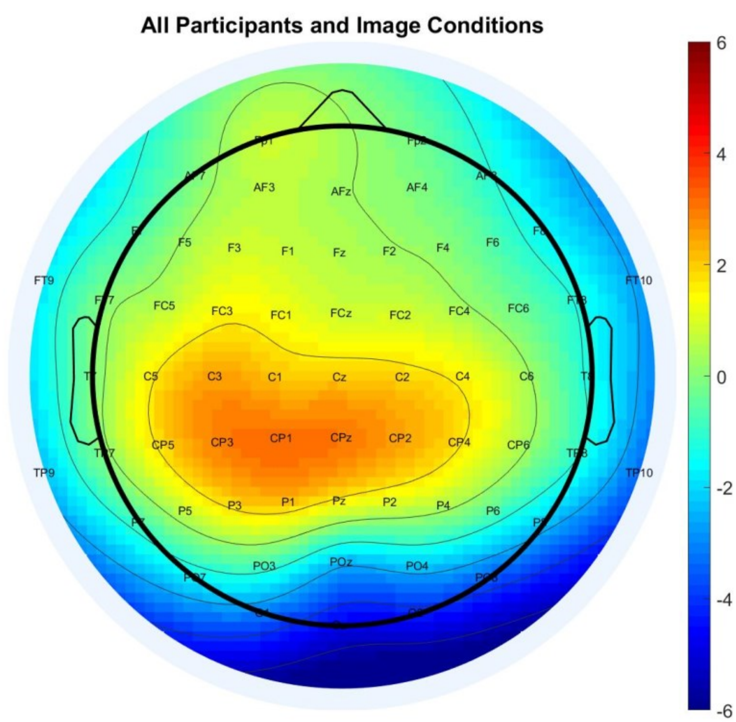

Figure 10. Topography of the average LPP (CPz, CP1, CP2, Pz, P1, P2, P3, and P4) response across all conditions and participants during the 700-1000ms interval immediately following image onset.

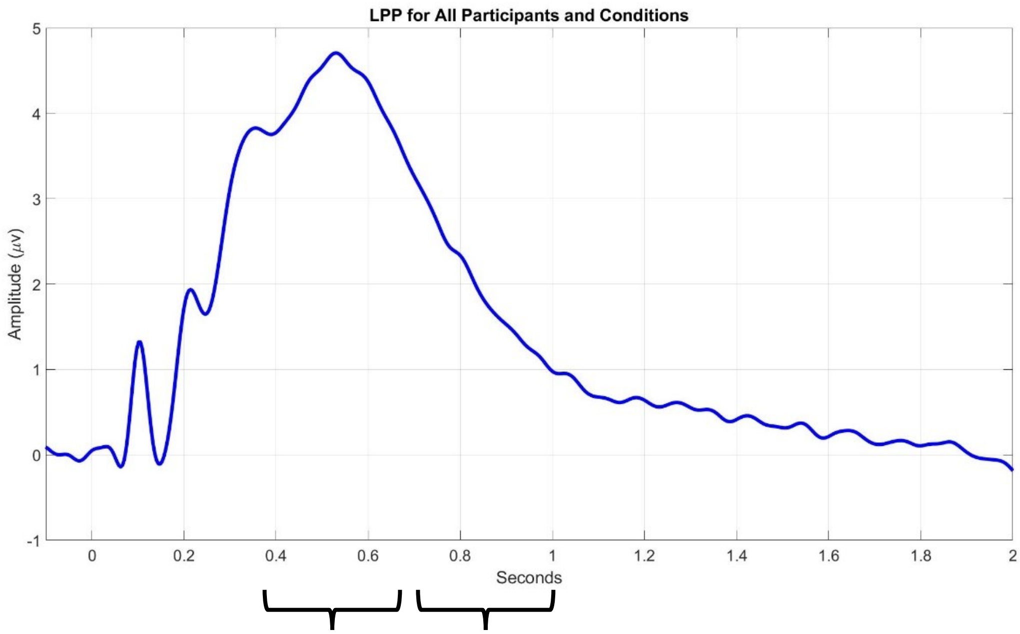

Figure 11. Image-locked event-related potential (ERP) averaged across all participants and conditions at central-posterior and central-parietal sites (CPz, CP1, CP2, Pz, P1, P2, P3, & P4). Bracketed regions signify the time windows for the LPP component.

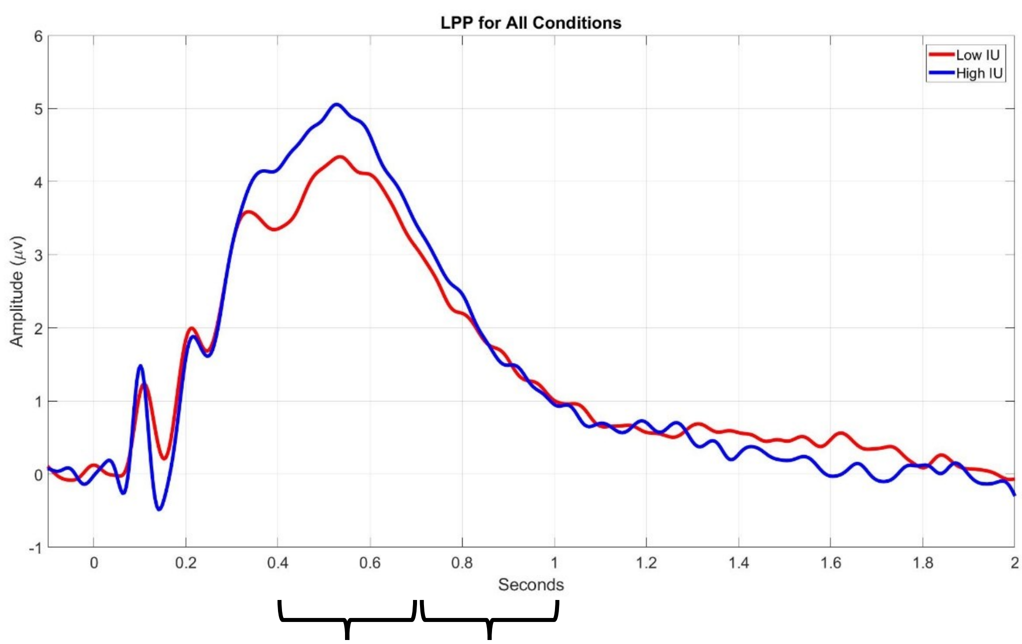

Figure 12. Image-locked event-related potential (ERP) averaged across conditions for High- and Low-IU groups at central-posterior and central-parietal sites (CPz, CP1, CP2, Pz, P1, P2, P3, & P4). Bracketed region signifies the time window for the LPP component.

CHAPTER 3

RESULTS

ERP Data

Hypotheses 1a & 1b. Hypotheses 1a and 1b predict that if individuals with higher levels of IU engage in atypical anticipatory processes, then they should exhibit SPN facilitation during all affective cue-conditions (certain-positive, certain-negative, and uncertain) relative to those with lower levels of IU. In order to test this, SPN data were subjected to a 4 X 2 (condition X group) repeated-measures ANOVA. No violations of Mauchly's test of sphericity were revealed $\chi^2(5) = 10.94$, $p > .05$. A significant effect of group emerged $F(1, 29) = 5.67$, $p = .024$, however no effect of condition $F(3, 87) = .377$, $p = .770$, or group X condition interaction emerged, $F(3, 87) = .665$., $p = .576$.

Post-hoc independent samples t-tests were used to delineate the observed group-effect. Significant difference between High- and Low-IU groups were observed for all affective cue conditions, and not neutral: certain-positive $t(29) = 2.68$, $p < .05$; certain-negative $t(29) = 2.11$, $p < .05$; uncertain $t(29) = 2.65$, $p < .05$; neutral $t(29) = 1.51$, p > .05. Mean SPN amplitudes for High- and Low-IU groups are displayed in Figure 13. Waveforms for combined conditions for the two groups are found in Figure 14, and individual affective conditions can be found in Figures 15, 16, and 17.

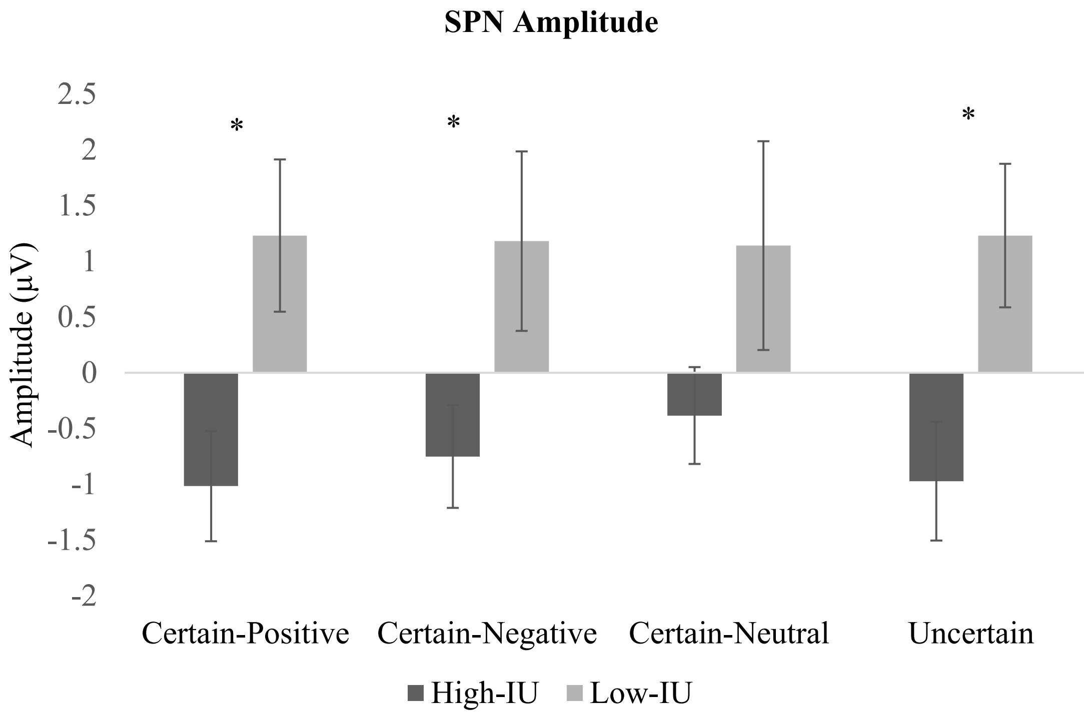

Figure 13. Mean SPN amplitude for High- and Low-IU groups for all cue conditions. Error bars represent standard error. * = $p < .05$.

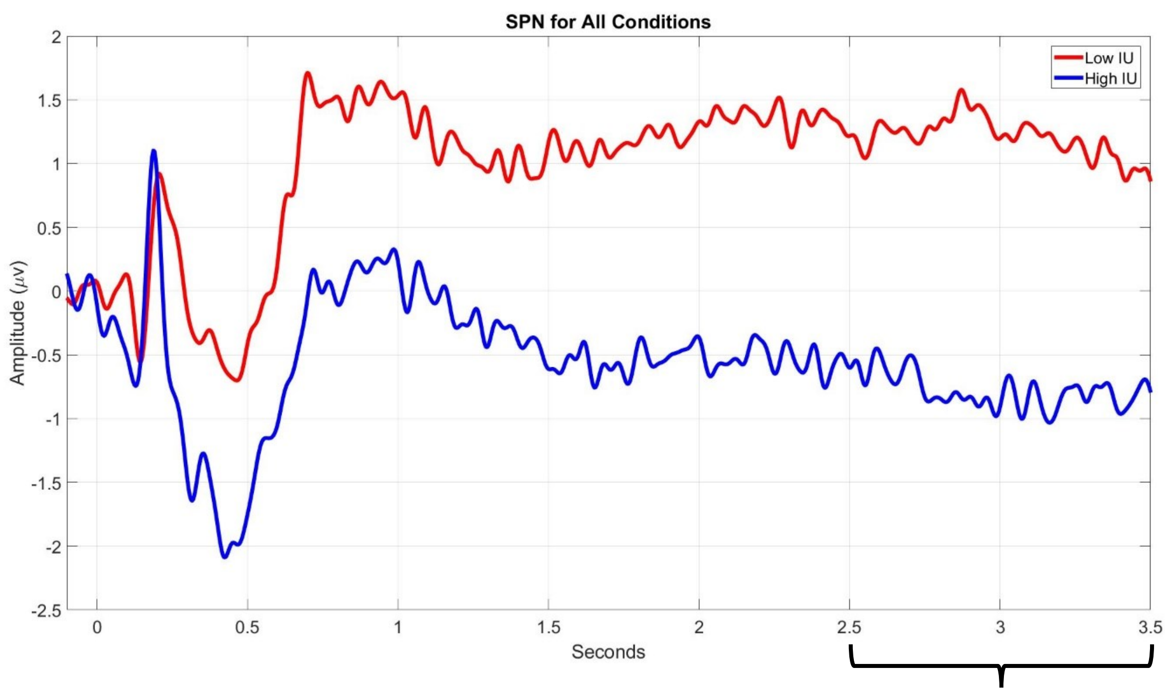

Figure 14. Cue-locked event-related potential (ERP) averaged across conditions for High- and Low-IU groups at frontal sites (FP1, FP2, AF3, AF4, and Afz). Bracketed region signifies the time window for the SPN component, with greater negativity observed for High- compared to Low-IU groups.

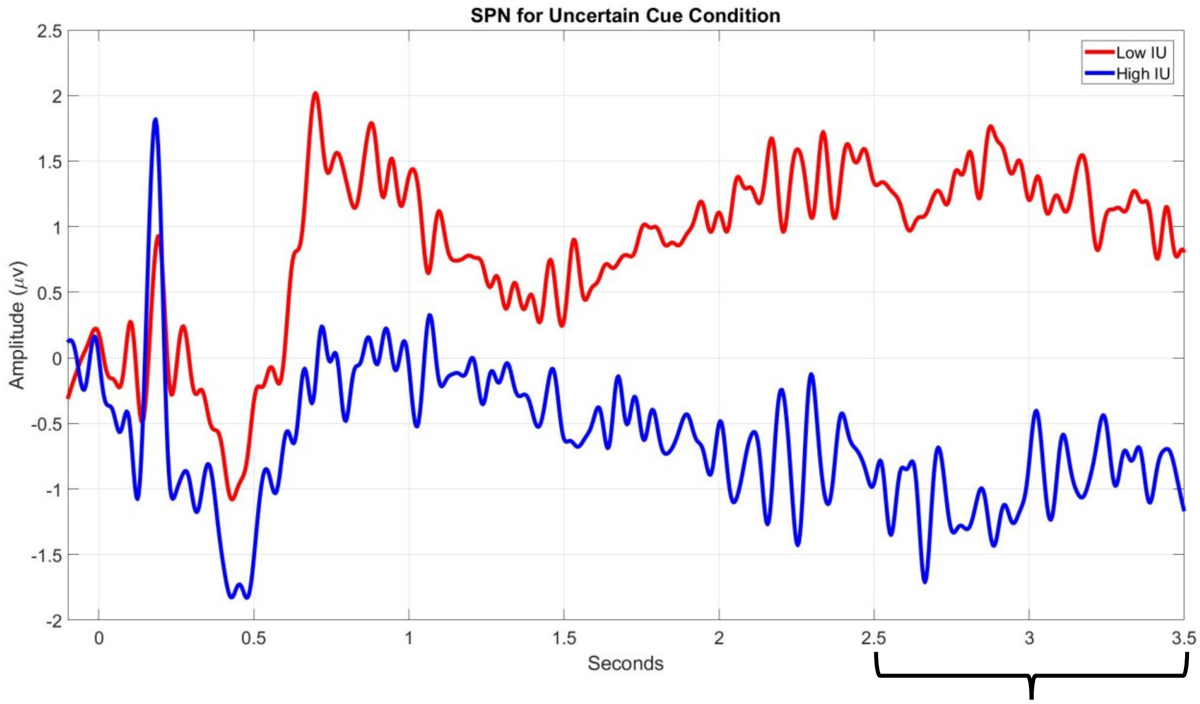

Figure 15. Cue-locked ERP during uncertain cueing condition for High- and Low-IU groups. Negative deflection from 2.5 – 3.5 seconds is thought to reflect SPN component, with greater observed negativity for High-IU group.

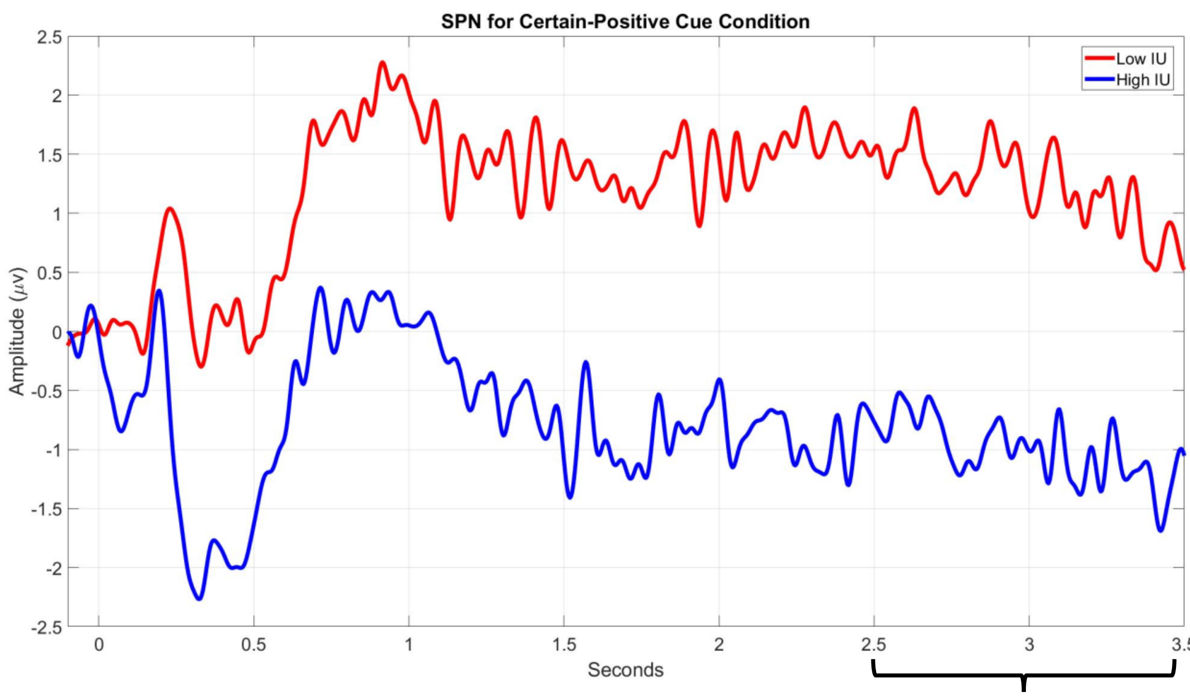

Figure 16. Cue-locked ERP during certain-positive cueing condition for High- and Low-IU groups. Negative deflection from 2.5 – 3.5 seconds is thought to reflect SPN component, with greater observed negativity for High-IU group.

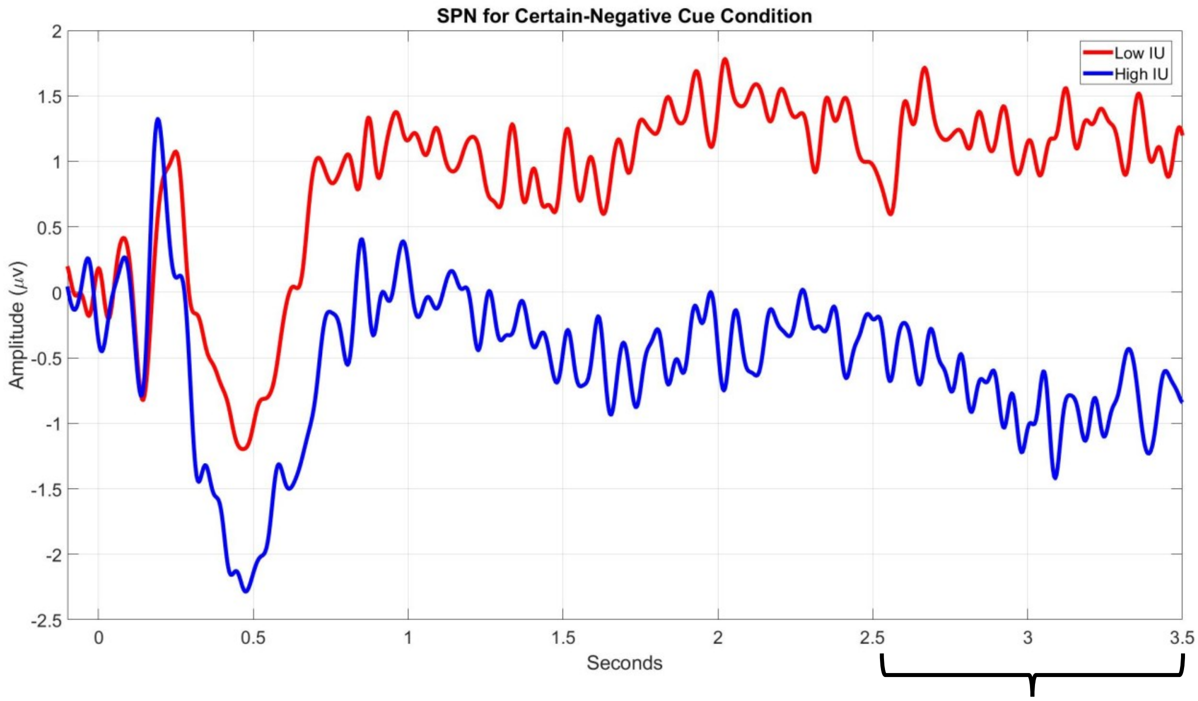

Figure 17. Cue-locked ERP during certain-negative cueing condition for High- and Low-IU groups. Negative deflection from 2.5 – 3.5 seconds is thought to reflect SPN component, with greater observed negativity for High-IU group.

To further assess the relationship between IU and anticipatory processes, as reflected by SPN, supplementary correlational analyses were conducted. Self-reported IU was associated with greater SPN negativity, prior to the onset for certain-positive images (r = -.374, p < .05), and uncertain images (r = -.427, p = .017). Trend-level significance emerged between self-reported IU and SPN amplitude during certain-negative trials (r = -.308, p = .092). In examining IU subscales, inhibitory IU was also significantly correlated with SPN amplitude prior to uncertain images (r = -.375, p = .038). These findings provide additional support for the results of the between-groups analyses. The data reveal SPN facilitation at higher levels of IU while anticipating affective stimuli, both certain and uncertain. Together, these findings suggest that High- compared to Low-IU individuals engage in heightened emotional anticipatory processes, which are in direct support of hypotheses 1a and 1b.

Hypotheses 2a & 2b. Hypotheses 2a and b predict that if individuals with higher levels of IU experience heightened emotional reactivity when faced with affective content, then they should exhibit LPP facilitation during all affective cue-conditions (certain-positive, certain-negative, and uncertain) relative to those with lower levels of IU. In order to test this, LPP data were subjected to a 5 X 2 (condition X group) repeated-measures ANOVA; this analysis approach was used for both early (400-700ms) and later (700-1000ms) LPP time windows. While examining early LPP, Mauchly's test of sphericity revealed a violation of sphericity, $\chi^2(9) = 25.7$, $p = .002$; degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .656$). A significant effect of condition was revealed $F(2.62, 76.09) = 9.74$, $p < .001$, however no effect of group $F(1, 35.02) = .628$, $p = .434$ or condition X group interaction emerged $F(2.62, 76.09) = .759$, $p = .554$. Results of the omnibus test are displayed in Figure 18. The LPP waveform showing main effect of condition is displayed in Figure 19.

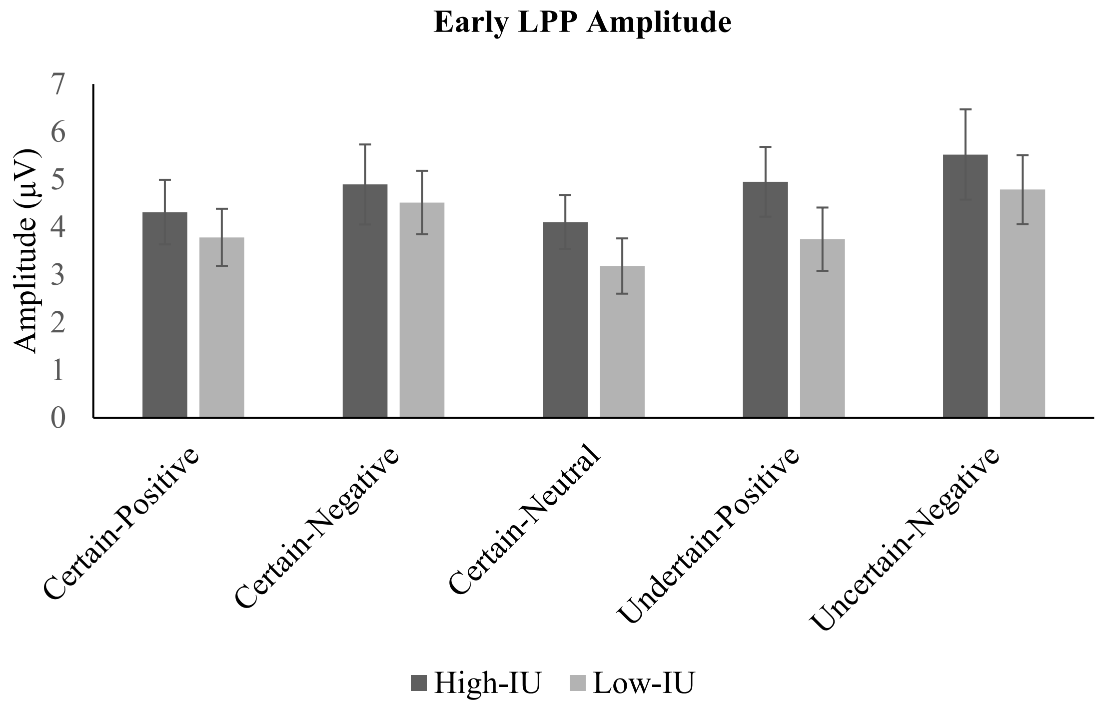

Figure 18. Mean early LPP amplitude, 400-700ms following image onset. Results reveal effect of condition, and no effect of group or group X condition interaction. Error bars represent standard error.

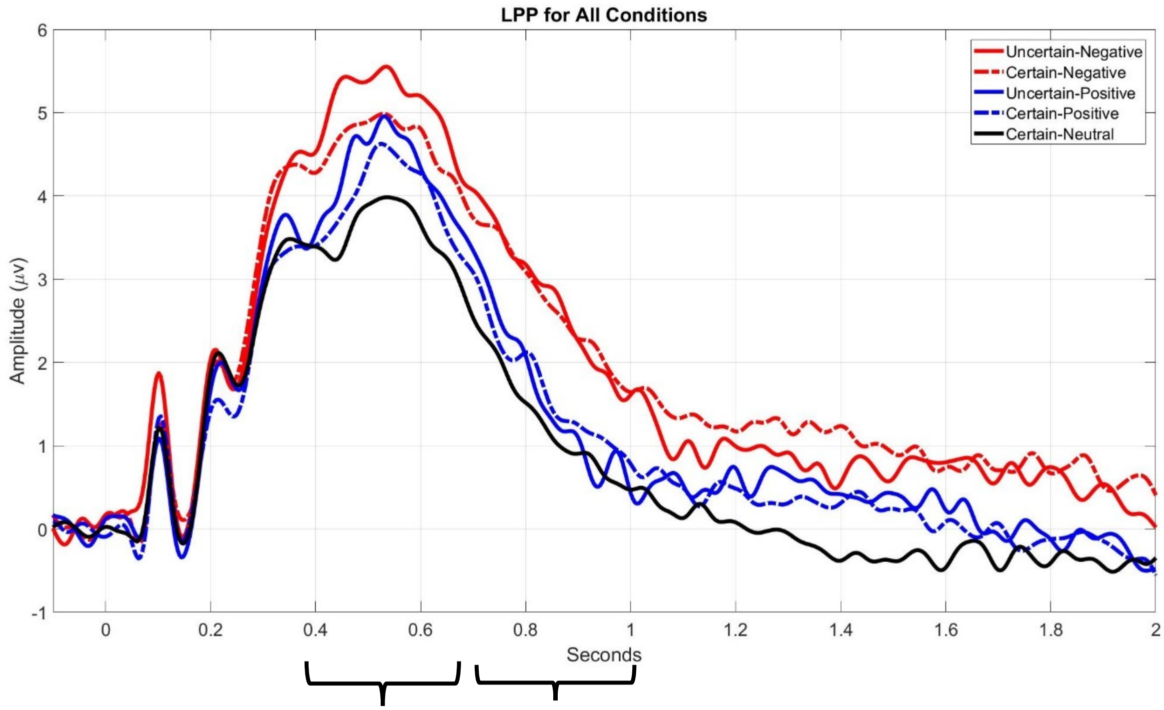

Figure 19. Cue locked event-related potential (ERP) for all of the image viewing conditions central-posterior and central-parietal sites (CPz, CP1, CP2, Pz, P1, P2, P3, & P4). Bracketed regions signify the time window for Early (400-700ms) and Late (700-1000ms) LPP.

Post-hoc t-tests were conducted to examine differences in LPP amplitude based on condition during the 400-700ms window. Largely consistent with prior literature (e.g. Foti, Hajcak, & Dien, 2009), greater positivity was observed for during the certain-negative condition (M = 4.71, SD = 2.95) compared to the certain-positive condition (M = 4.05, SD = 2.49), $t(30) = 3.47$, $p = .002$, as well as for certain-negative (M = 4.71, SD = 2.95) compared to certain-neutral image condition (M = 3.65, SD = 2.26) $t(30) = 3.77$, $p = .001$. Surprisingly, only trend-level significance appeared in differentiating LPP amplitude between the certain-positive condition (M = 4.05, SD = 2.49) and neutral image condition (M = 3.65, SD = 2.26) $t(30) = 11.81$, $p = .08$.

Planned contrasts were also used to examine the effect of uncertainty on LPP amplitude during image viewing. A trend-level difference emerged between uncertainty-negative (M = 5.16, SD = .59) and certain-negative conditions (M = 4.71, SD = 2.95), $t(30)$ = 1.95, p = .06. Greater positivity was observed for uncertain-negative (M = 5.16, SD = .59) compared to certain-positive (M = 4.05, SD = 2.49), $t(30)$ = 3.82, p = .001, as well as uncertain-negative (M = 5.16, SD = .59) and uncertain-positive (M = 4.36, SD = 2.78), $t(30)$ = .24, p = .022. No difference was observed between uncertain-positive (M = 4.36, SD = 2.78) and certain-negative (M = 4.71, SD = 2.95), $t(30)$ = 1.31, p = .20, or uncertain-positive (M = 4.36, SD = 2.78) and certain-positive (M = 4.05, SD = 2.49), $t(30)$ = 1.58, p = .124. These contrasts and general trend of conditions are displayed in Figure 20.

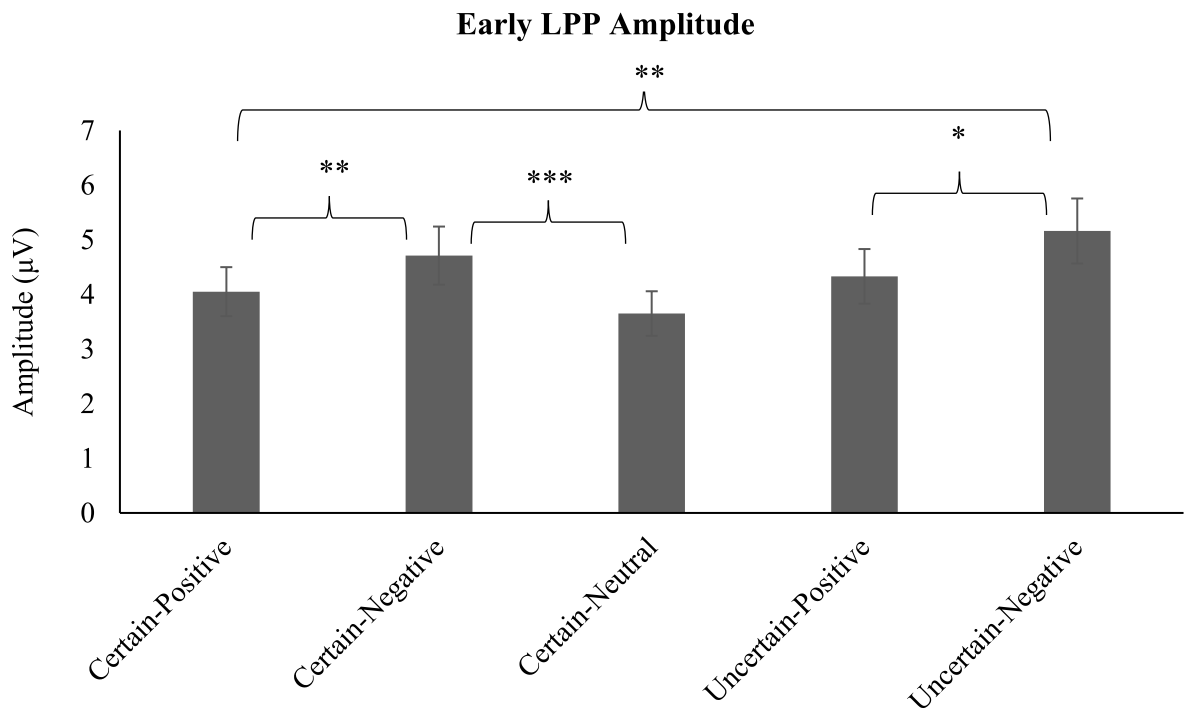

Figure 20. Mean early LPP, 400-700ms following image onset displaying effect of condition. Greater positivity is observed for affective relative to neutral, negative relative to positive image conditions, and uncertain relative to corresponding certain conditions. Trend level difference (p = .06) between uncertain-negative and certain-negative is not marked in this figure. Error bars reflect standard error. * = $p < .05$; ** = $p < .01$; *** = p = .001.

Simple correlations were conducted as a supplementary analysis to examine linear trends between self-reported IU and LPP activity. Interestingly, difference scores between uncertain and certain conditions appeared to exhibit unique linear relationships with self-reported IU scores. IU exhibited a positive association with LPP difference scores between uncertain-positive and certain-positive conditions ($r = .427$, $p = .017$), and this association was particularly strong when examining prospective IU ($r = .580$, $p = .001$). Prospective IU was also associated greater differences in LPP amplitude between combined-uncertain and combined-certain conditions ($r = .367$, $p = .042$). Overall, the findings related to early LPP only partially support hypotheses 2a and 2b, with the correlational analyses showing associations between IU and differential responses between positive image conditions. While not originally hypothesized, LPP findings do suggest enhanced emotional reactivity as a function of uncertainty.

A 5 X 2 (condition X group) repeated-measures ANOVA and post-hoc t-tests were used to examine sustained emotional reactivity following image onset during the later LPP time window (700-1000ms) of interest. Mauchly's Test of Sphericity revealed a violation of sphericity, $\chi^2(9) = 31.27$, $p < .001$; degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .604$). Much like the earlier LPP window of interest, a significant effect of condition was revealed $F(2.42, 70.11) = 11.62$, $p < .001$, and no effect of group $F(1,29) = .02$, $p = .888$) or condition X group interaction emerged $F(2.42, 70.11) = .205$, $p = .854$. Results of the omnibus test are displayed in Figure 21.

Post-hoc t-tests for the definitive image viewing conditions during the 700-1000ms window revealed similar contrasts to those during the earlier window of interest. A significant difference in LPP amplitude emerged between certain-negative ($M = 2.68$, $SD =$

2.35) and certain-positive (*M* = 1.65, *SD* = 1.92), *t*(30) = 4.87, *p* < .001, as well as certain-negative (*M* = 2.68, *SD* = 2.35) and neutral (*M* = 1.31, *SD* = 1.84), *t*(30) = 5.17, *p* < .001. The difference between certain-positive (*M* = 1.65, *SD* = 1.92) and neutral (*M* = 1.31, *SD* = 1.84) revealed a trend-level difference, *t*(30) = 1.86, *p* = .072.

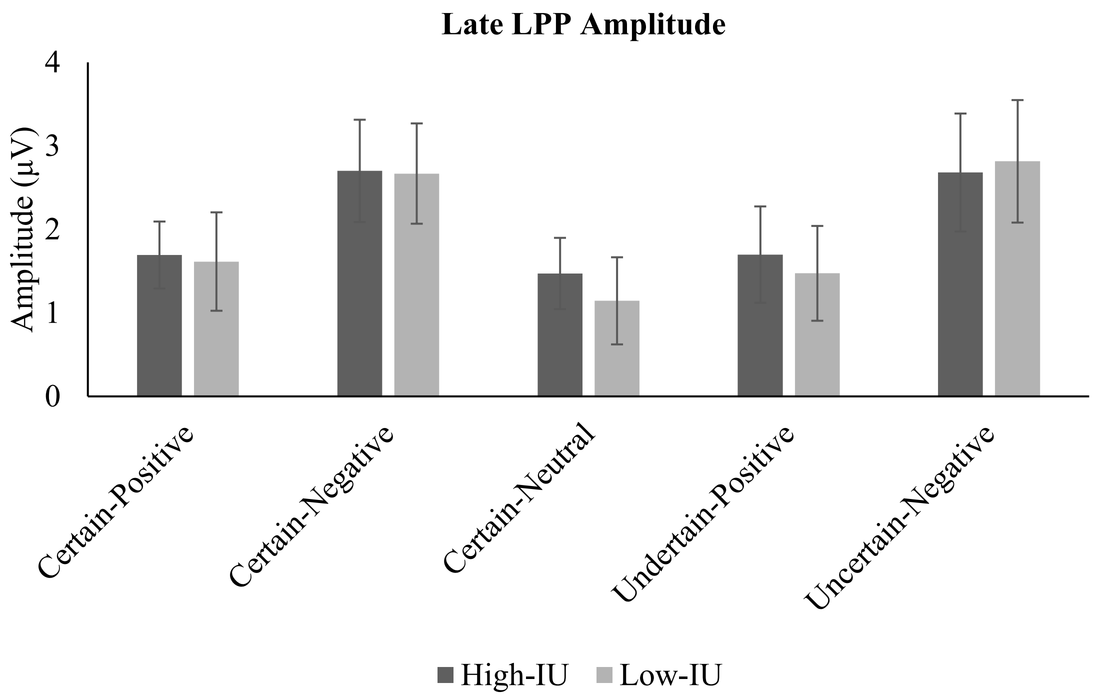

Figure 21. Mean late LPP amplitude, 700-1000ms following image onset. Results reveal main effect of condition, and no effect of group, or group X condition interaction. Error bars represent standard error.

Additional contrasts were conducted to examine the effect of uncertainty on sustained emotional reactivity during image viewing. The trend-level differences that were present during the earlier LPP window was no longer present between uncertain-negative (*M* = 2.74, *SD* = 2.78) and certain-negative (*M* = 2.68, *SD* = 2.35), *t*(30) = .247, *p* = .807. Furthermore, no difference was present between uncertain-positive (*M* = 1.58, *SD* = 2.22), and certain-positive (*M* = 1.65, *SD* = 1.92), *t* (30) = .33, *p* = .743. Differences did appear when contrasting uncertain-negative (*M* = 2.74, *SD* = 2.78) and certain-positive (*M* = 1.65, *SD* = 1.92), *t*(30 = 3.313, *p* = .002; certain-negative (*M* = 2.68, *SD* = 2.35) and uncertain-positive

(M = 1.58, SD = 2.22), $t(30) = 4.105$, $p < .001$; and uncertain-negative (M = 2.74, SD = 2.78) and uncertain-positive (M = 1.58, SD = 2.22), $t(30) = 3.246$, $p = .003$. These contrasts and general trend of conditions are displayed in Figure 22.

Simple correlations were conducted to examine linear trends between IU and difference in sustained LPP amplitude between certain and uncertain conditions. No significant correlations emerged, suggesting that, contrary to the hypotheses, IU may play a role in early emotional reactivity (i.e. 400-700ms) rather than during sustained emotional processing.

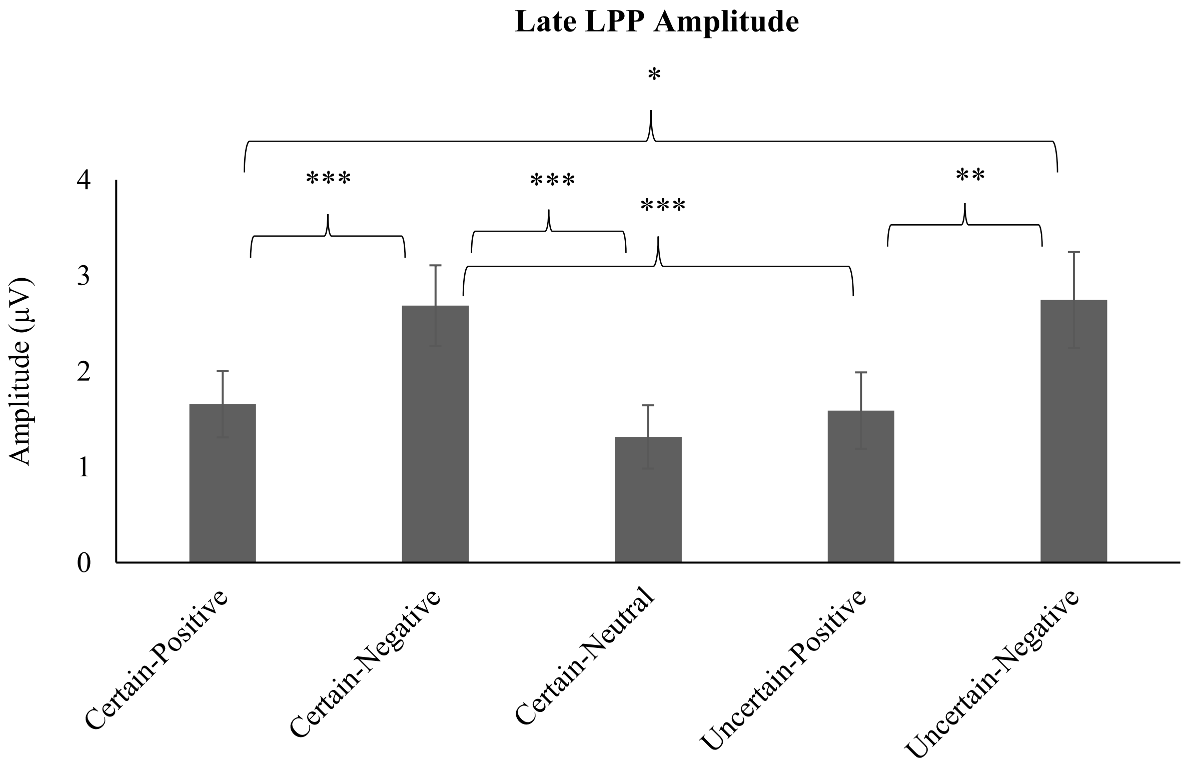

Figure 22. Mean late LPP, 700-1000ms following image onset displaying effect of condition. Greater positivity is observed for affective relative to neutral, negative relative to positive image conditions, and uncertain relative to corresponding certain conditions. Trend level difference ($p = .07$) between certain-positive and neutral is not marked in this figure. Error bars reflect standard error. * = $p < .05$; ** = $p < .01$; *** = $p = .001$.

Self-Report and SAM data

Hypotheses 3a & 3b. Hypotheses 3a and 3b predict that if individuals with higher levels of IU experience heightened emotional reactivity when responding to affective content, then they should report higher levels of arousal and directional valence after viewing affective images during certain and uncertain conditions. In order to test these hypotheses, 5 X 2 (condition X group) repeated-measures ANVOAs were used for both arousal and valence ratings. Post-hoc tests were also used to further delineate results.

For self-reported SAM arousal ratings, Mauchly's test revealed a violation of sphericity for arousal ($\chi^2(9) = 64.95$, $p < .001$); degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .53$). Results revelated a significant main effect of condition, $F(2.11, 61.23) = 121.48$, $p < .001$, no effect of group $F(1, 29) = .22$, $p > .05$, and no group X condition interaction $F(1.31, 37.93) = .365$, $p > .05$.

Post-hoc t-tests were used to delineate differences between in self-reported arousal ratings for the different image viewing conditions. Largely, results reveal significantly greater levels of self-reported arousal for affective conditions relative to neutral; negative relative to positive; and uncertain relative to certain, apart from the certain-positive and uncertain positive image contrast. For certain conditions, certain-negative images (M =2.5, SD = .51) were rated as more arousing than certain-positive (M = 2.87, SD = .73) $t(30) = -2.8$, $p < .01$; and certain-neutral (M = 4.33, SD = .49) $t(30) = -17.8$, $p < .001$; while certain-positive was rated as more arousing than certain-neutral, $t(30) = -15.4$, $p < .001$. In uncertain conditions, uncertain-negative (M = 2.38, SD = .58) was rating as more arousing than uncertain-positive (M = 2.89, SD = .68) $t(30) = -4.12$, $p < .001$. Within affective categories, uncertain-negative was rated as more arousing that certain-negative, $t(30) = -2.49$, $p < .05$; while uncertain-positive was rated equally as arousing as certain-positive, $t(30) = 1.5$, $p = .14$. Both uncertain-negative and uncertain positive were rated as more arousing than certain-neutral; $t(30) = -16.49$, $p < .001$ and $t(30) = -17.88$, $p < .001$. These contrasts are displayed in Figure 23.

Similar results were obtained for self-reported SAM valence ratings. Mauchly's test revealed violations of sphericity for both valence ($\chi^2(9) = 128.87$, $p < .001$; degrees of freedom were corrected using Greenhause-Geisser estimates of sphericity ($\varepsilon = .33$). Results revealed a significant main effects of condition, $F(1.31, 37.9.3) = 433.01$, $p < .001$, no effect of group, $F(1, 29) = .042$, $p = .84$, and no significant group X condition interaction, $F(1.31, 37.93) = .365$, $p > .05$.

To further explore differences in valence ratings, post-hoc t-tests revealed that uncertain-negative images ($M = 4.47$, $SD = .32$) were rated more negatively than certain-negative images ($M = 4.37$, $SD = .054$) $t(30) = 4.17$, $p < .001$; uncertain-positive images ($M = 2.05$, $SD = .073$) and certain-positive images ($M = 2.01$, $SD = .43$) showed no differences in self-reported valence, $t(30) = 1.16$, $p = .254$. The results are displayed in Figure 24.

Overall, the findings regarding self-reported SAM valence and arousal do not provide support for hypotheses 3a or 3b, as IU does not appear as a construct resulting in differential emotional experiences, as reflected by self-reported SAM ratings. The findings do, however, suggest that uncertainty relative to certainty, and negative content relative to positive and neutral results in a more intense emotional experience for individuals.

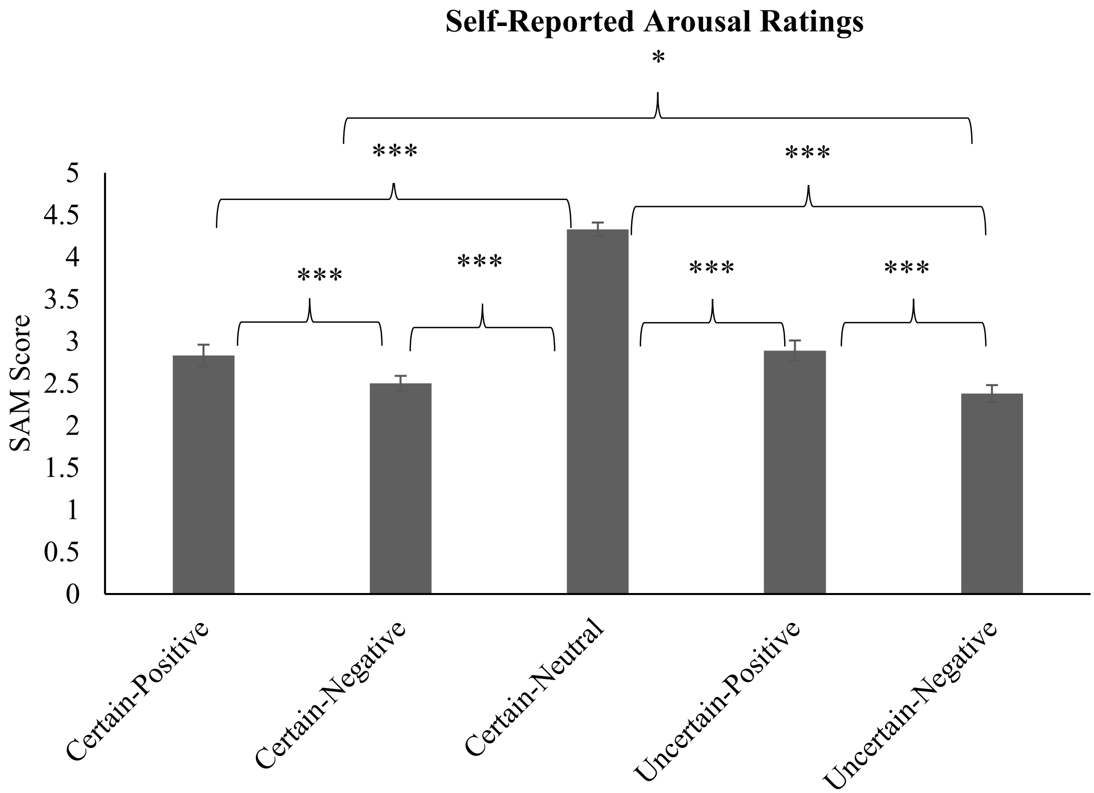

Figure 23. Self-reported arousal ratings for all image conditions. SAM score *1 =arousing; and 5 = unarousing.* Error bars reflect standard error. * = $p < .05$, ** = $p < .01$, *** = $p < .001$

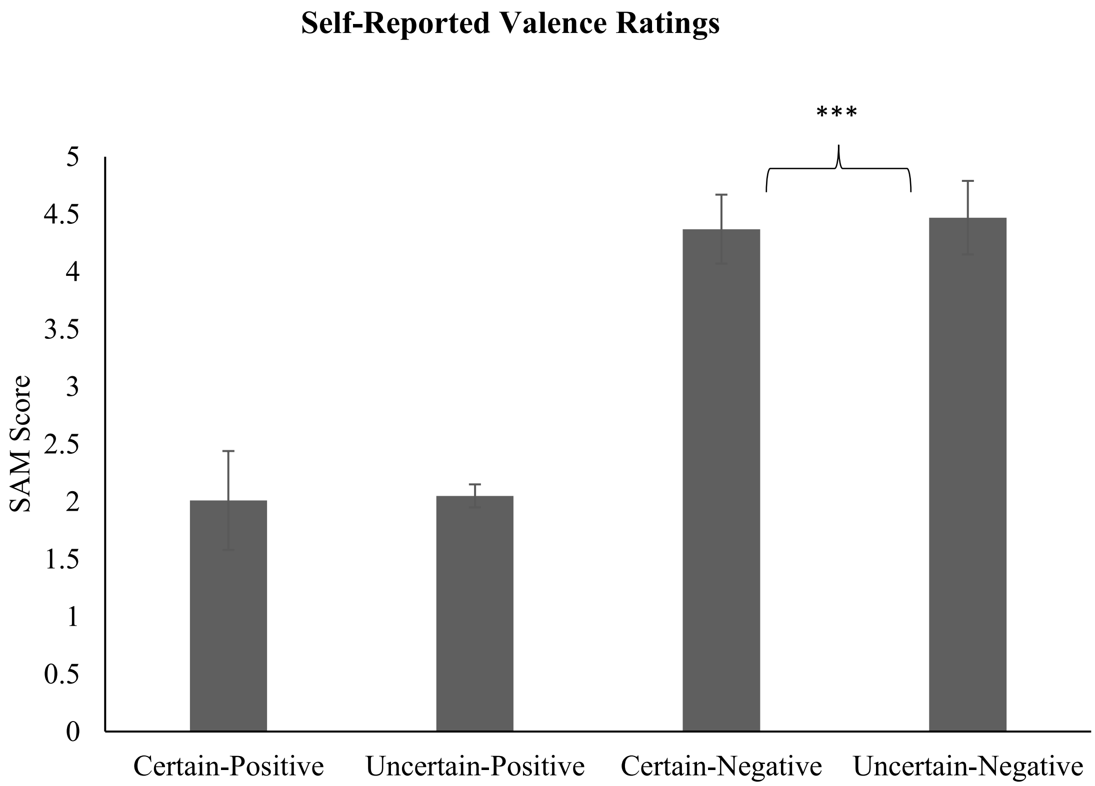

Figure 24. Self-reported valence ratings for all affective image conditions, where SAM score *1 = positive; 3 = neutral; and 5 = negative.* Error bars reflect standard error. *** = $p < .001$

CHAPTER 4

DISCUSSION

The primary aim of this study was to examine the emotional processes associated with anticipation of and reaction to different affective stimuli during periods of certainty and uncertainty in individuals with high and low levels of IU. Importantly, individuals with higher levels of IU are believed to interpret uncertainty as aversive and experienced heightened emotional reactivity when faced with uncertainty compared to individuals with lower levels of IU (Freeston et al., 1994; Ladouceur et al., 1998). To examine these anticipatory and reactive processes, an S1-S2 image viewing paradigm was used where S1 cues were manipulated to either accurately inform participants about the S2 image valence, or to provide no information about the S2 image valence. During this task, EEG was recorded so that two ERP components, SPN and LPP, could be examined. These ERP components are thought to reflect anticipatory processes for upcoming relevant information, and emotional reactivity to stimuli, respectively. In addition to these two ERP components, self-reported arousal and valence following image presentation were measured to further examine emotional reactivity in individuals with high and low levels of IU following both certain and uncertain conditions.

Overview of the Results

Hypotheses 1a & 1b. During anticipation, larger SPN amplitude was observed for the High-IU group compared to the Low-IU group, suggesting greater attentional allocation and preparation for upcoming stimuli (Brunia et al., 2012). Unexpectedly, cues did not impact SPN amplitude, as individuals with High-IU exhibited greater reactivity compered to Low-IU across all affective conditions; the knowledge of an upcoming stimulus appeared sufficient to result in different anticipatory processes in these two groups, as reflected by SPN. Correlational analyses provide additional support of this relationship between IU and heightened anticipation, as reflected by SPN. Significant linear relationships were observed between self-reported IU scores and SPN amplitude during the certain-positive and uncertain cue conditions, and trend-level significance for certain-negative cue condition. These correlations suggest that elevated IU is associated with exaggerated emotional anticipation prior to affective stimuli, that is, certain-positive and negative, and uncertain conditions. These findings regarding SPN amplitude and IU provide direct support of hypotheses 1a and 1b, demonstrating that IU is associated with atypical anticipatory processes for both certain and uncertain affective contexts.

Hypotheses 2a & 2b. To examine emotional reactivity following image presentation, LPP was examined during two separate time windows. Following image presentation, differences in LPP amplitude emerged during the 400-700ms window as a function of condition where uncertain-negative condition resulted in greater emotional reactivity compared to both certain-positive and uncertain-positive conditions, and certain-negative resulted in greater reactivity compared to certain-positive. Trend-level significance was observed when contrasting uncertain-negative to certain-negative, with greater positivity following uncertain-negative images. Importantly, these between-group analyses failed to identify significant differences when contrasting High- and Low-IU groups, which does not directly support hypotheses 1a or 2b.

This main effect of condition remained, along with most contrasts observed earlier when also examining the later LPP time window (700-1000ms), with the exception of no trend-level difference between uncertain-negative and certain-negative, and greater LPP amplitude for certain-negative compared to uncertain positive, which was not observed in the earlier LPP time window. Consistent with the earlier LPP time window, there was no effect of group. Much like the earlier LPP time window, these findings do not provide support for hypotheses 2a or 2b, but do provide support of well-documented findings of LPP is more sensitive to aversive compared to pleasant and neutral content (Hajcak & Foti, 2020). Furthermore, while the data presented here failed to reveal significant differences in LPP between uncertain-positive and certain-positive and trend-level significance in LPP between uncertain-negative and certain-negative which suggesting that emotional reactivity for affective stimuli is heightened when preceded by uncertainty.

The correlational analyses do provide partial support of hypotheses 2a and 2b. Here, a significant positive relationship was observed between self-reported IU and early LPP difference scores between uncertain-positive and certain-positive conditions. This finding suggests that at higher levels of IU, individuals have a heightened emotional reaction to pleasant stimuli preceded by uncertainty compared to certainty. Additionally, prospective IU, which is thought to measure the cognitive facets of IU, showed the same relationship to uncertain-positive and certain-positive LPP difference scores. This may suggest that the cognitive facet of IU is driving this association. While the findings only partially support hypotheses 1a and 2b, they do provide evidence that IU is associated with different emotional reactivity to positive stimuli based on the amount of information provided before stimulus presentation.

Hypotheses 3a & 3b. To examine self-reported emotional reactivity, arousal and valence ratings were recorded after each of image to assess the participant's emotional experience. The results do not support the hypotheses, however, they do provide important evidence regarding the role of uncertainty on self-reported arousal and valence. Firstly, these findings demonstrate that in negative image viewing conditions, uncertainty compared to certainty results in greater arousal ratings and greater negative-valence ratings; these effects were not observed in the context of positive images. Furthermore, affective image conditions were rated as more arousing than natural, and negative more arousing compared to positive. Collectively, these findings highlight a potential negativity bias which appears particularly strong in the context of uncertainty. IU did not appear as an important factor in how participants rated image arousal or valence.

Implications of the Current Findings in the Context of Existing Literature

Hypothesis 1a, 1b and the SPN. Importantly, findings regarding SPN facilitation for High- compared to Low-IU prior to affective images is novel. Prior attempts examining IU and SPN (e.g. Gole et al., 2012) have failed to elicit an SPN component during and S1-S2 image viewing paradigm where cues were manipulated to be informative or uninformative. A potential explanation for the presence of an SPN component in the present study is that a normed picture set, the IAPS (Lang et al., 2008), was used. Gole and colleagues (2012) relied on a combination of IAPS images and other unspecified images making it possible the picture set was insufficiently arousing. This is noteworthy, as prior literature suggests SPN is a measure of anticipatory emotional reactivity and is associated with motivation towards and relevance of upcoming stimuli (Brunia et al., 2012; Moser et al., 2009; Poli et al., 2007). If the stimuli are unarousing, they are unlikely to elicit strong anticipatory emotions resulting in minimal motivation to engage in anticipatory processes. Furthermore, recent S1-S2 image viewing studies where IU *was not* examined have been able to elicit an SPN component using IAPS images (Johnen & Harrison, 2019; Johnen & Harrison, 2020), which further highlights the concern regarding the stimuli used by Gole and colleagues (2012).

The correlational analyses provide evidence of heightened emotional anticipation prior to affective images regardless of image valence in individuals with higher levels of IU. It is plausible that in the current paradigm, the cues used had a generalizing effect on individuals and resulted in heightened anticipatory processes compared to individuals with lower levels of IU. Prior conditioning literature examining threat generalization in High- and Low-IU individuals has found that High-IU individuals are more likely to generalize cues and exhibit heightened skin conductance responses compared to Low-IU individuals (Bauer et al., 2020; Morris et al., 2016). While both groups exhibited a pronounced negative-going SPN component prior to image onset collapsing across all conditions (Figure 14), the more negative amplitude found in High-IU individuals suggests greater emotional anticipation associated with this generalizing effect of cues prior to image onset. In treatment settings, similar observations are often made. In the context of generalized anxiety disorder (GAD) and OCD, two pathologies marked by elevated IU, individual often exhibit difficulty discerning threat from safety, and ambiguity during anticipation is interpreted as dangerous (Grillon et al., 2017; Hirsch & Matthews, 2012; Kaczkurkin & Lissek, 2013). The present laboratory findings are in direct support of these clinical observations.

While scientifically interesting, these findings regarding IU and SPN may have clinical treatment implications. It is well established that IU changes as a function of intervention when using empirically supported treatments (e.g. Boswell et al., 2013), however there has been growing emphasis on developing clinical interventions specifically targeting IU. In a recent study, an IU enhanced CBT internet-based protocol was developed for adolescents with sub-clinical pathology who also endorsed elevated levels of both IU and worry (Wahlund et al., 2020). This intervention was designed specifically to address anticipatory concerns, which appear uniquely attributed to IU. This was achieved through the use of both imaginal and *in-vivo* exposure to situations marked by uncertainty. The intervention was largely efficacious, as participants demonstrated significant reductions in both self-reported IU and worry symptoms, and parents and participants reported general satisfaction with the intervention (Wahlund et al., 2020).

These findings in adolescents are supported by adult intervention research, as well. In GAD literature, there is evidence documenting that after CBT intervention, changes in IU mediate changes in *worry*, the hallmark symptom of GAD (Homyea et al., 2015). During the implementation of a transdiagnostic CBT intervention, similar results were observed, where changes in IU predicted response to treatment across different anxiety disorders (Talkovsky & Norton, 2016). From this, a logical step in this line of work is to firstly to replicate the current findings regarding SPN facilitation associated with IU, and *if* SPN appears as a reliable proxy for IU, future research should examine whether SPN can be modulated through intervention. While it is reasonable to state that CBT results in reduction of self-report IU, it remains unclear if these interventions influence neural markers, namely, SPN. This could provide support of SPN as a potential biomarker, or endophenotype, of psychopathology.

A similar approach has been used in examining ERN with growing support of this neural measures as an endophenotype of anxiety and obsessive-compulsive spectrum disorders (Hajcak et al., 2019; Riesel, 2019). This has largely been consistent with the RDoC approach of identifying underlying mechanisms and biological factors specific to pathology that are not captured in current disease nosologies (Insel & Cuthbert, 2015). A large body of literature has identified ERN as a predictor of future pathology, which may make ERN an appropriate target for intervention (Anokhin et al., 2015; Meyer et al., 2015; Meyer et al., 2018).

If neural measures, such as SPN and ERN, truly reflect psychopathology, then they appear as appropriate intervention targets to reduce current symptom presentation, or ward off future pathology (Riesel, 2019). Empirical findings exist showing that intervention can modulate ERN amplitude. Attention-bias modification (ABM), where individuals are taught to direct attention away from errors, has been associated with ERN attenuation (Nelson et al., 2017). Similar observations have been made following a brief expressive writing exercise, and compared to a control condition, those who engaged in the brief writing exercise exhibited ERN attenuation (Schroder et al., 2018). Lastly, there is evidence demonstrating that mindfulness-based interventions could be effective in modulating ERN amplitude in depressed patients, where ERN typically appears blunted (Barnhofer et al., 2017).

Not only have these interventions been shown to modulate psychopathology, but growing evidence suggests they may be effective in modulating ERN, a suspected biomarker of psychopathology. Currently, evidence suggest IU and pathologies marked by elevated IU respond to psychotherapeutic interventions. The data presented here also provide preliminary evidence that IU is associate with SPN facilitation, especially when anticipating affective stimuli. In addition to building support of this finding, a logical next step is to examine if SPN can be modulated as a function of intervention.

Regarding non-psychotherapeutic interventions, prior imaging research has documented associations between IU and striatal volume, a brain region implicated in both

GAD and OCD presentations (Kim et al., 2017). Deep brain stimulation (DBS) for OCD has been used to target the striatum, with clinical trial research demonstrating that DBS of this region is associated with OCD symptom reduction reflected by the Yale-Brown Obsessive Compulsive Scale (Y-BOCS; Goodman et al., 1989) (Barcia et al., 2019; van der Vlis et al., 2021).

In connection with SPN and IU, the striatum is a neural region associated with anticipatory processes, and activation can be modulated through cuing, and stimulus expectancy (Masaki et al., 2010; McClure et al., 2003; Ren et al., 2017). Imaging research examining anticipation of both monetary reward and delivery of nicotine has documented associations between striatum activation and insular cortex activation, with the insula thought to play a unique role in the development of the SPN component, as well as IU (Cho et al., 2013; DeSerisy et al., 2020; Hackley et al., 2020; Kotani et al., 2009; Tanovic et al., 2018). Tying this together, the region region being targeted through DBS exhibits relationships to the region thought to be at least partially responsible for both IU and SPN. This non-psychotherapeutic intervention could very well modulate SPN amplitude, as existing evidence already demonstrates it is effective for overall symptoms reduction in OCD patients.

With the striatum as a target for DBS in treatment-refractory OCD cases, it is not currently approved for GAD or pathologies associated with IU. DBS for OCD was approved United States in 2009 by the Food and Drug Administration (FDA) under the Humanitarian Device Exemption (HDE) to treat “severe to extreme” refractory OCD cases (Kahn et al., 2021). Even though this ruling has been made for OCD, it is possible that individuals with other treatment-refractory pathologies marked by elevated IU could be included in future

DBS interventions; major depressive disorder (MDD) is another pathology marked by elevated IU where this has been explored, although the results are less promising (Dougherty et al., 2015). Improving understanding of these biological mechanisms of pathology may allow for more targeted and specific intervention, whether it be through psychotherapeutics, or more invasive means, such as DBS or psychiatric medications.

Hypothesis 2a, 2b and the LPP. The current findings regard the effect of condition on LPP amplitude, as well as linear trends that emerge between LPP amplitude and self-report IU provide additional support of existing literature and contribute in unique and meaningful ways. Firstly, the observed differences between certain image viewing conditions in both early (400-700ms) and late (700-1000ms) LPP windows are consistent with prior literature, with greater LPP amplitude for negative, followed by positive and then neutral images (Foti et al., 2009; Hajcak & Foti, 2020; Huang, & Luo, 2006). The LPP component is thought of as a measure of emotional reactivity, or emotional relevance of the perceived stimulus, and this observed difference between negative and positive images is thought to reflect a negativity bias (Bradley, 2009; Huan & Luo, 2006). This heightened awareness of aversive stimuli functions as a biological safety mechanism designed to promote wellbeing and avoidance of risky behaviors (Norris, 2021). This negativity bias can be observed in children as young as four years old, and newer evidence that an exaggerated negativity bias as reflected by LPP may be a predictor of future internalizing disorders (McLean et al., 2020). Interestingly, this negativity bias as reflected by LPP is often less pronounced in older individuals, as they show preferential attention towards positivity and away from negativity (Fields et al., 2021). Here, shortened future time horizon (e.g. future longevity) for older adults is believed to result in preference towards positivity as a potential attempt to maximize limited time, whereas this time horizon is less salient for younger individuals (Carstensen et al.,1999; English & Castensen, 2017). As noted, the findings in the present study are largely consistent with prior research, as the sample of university students exhibit exaggerated LPP during certain-negative images relative to the other certain image viewing conditions.

Regarding the uncertain image conditions, LPP facilitation for uncertain compared to certain conditions during the earlier LPP is consistent with prior literature, although only trend-level significance was observed for negative images and no significance was observed for positive images (Dieterich et al., 2016; Dieterich et al., 2017). Even though statistical significance was not obtained, the overall trend in LPP amplitude is consistent with what previously been observed. In two studies, Dieterich and colleagues (2016; 2017) were able to capture LPP facilitation for uncertain-negative compared to certain-negative, as well as uncertain-neutral compared to certain-neutral image viewing conditions. More recently, a similar result was obtained in a study were cues provided inaccurate information about imperative stimulus valence, where inaccurate cues were associated with LPP facilitation related to accurate cues (Johnen & Harrison, 2019). Collectively, the data presented here are consistent with these findings suggesting that information presented prior to stimulus onset can impact emotional reactivity, as reflected by the LPP component. This is in direct contrast to Gole and colleagues (2012) who provide evidence of LPP facilitation for certain relative to uncertain image conditions.

A potential explanation for this LPP facilitation associated with uncertain conditions is that the heightened attentional allocation serves as a defensive mechanism to increase awareness of potential threat (Dieterich et al., 2016). In the context of psychiatric illness, this is observed in both anxiety and obsessive-compulsive spectrum disorders where internal and external stimuli marked by uncertainty are interpreted as *dangerous*, and exaggerated efforts are taken to gain certainty about the presence of aversive stimuli so they can be accounted for and addressed (Morein-Zamir et al., 2020). Anxious individual exhibit heightened distress when faced with uncertainty (especially with higher levels of self-reported IU), and because of this, learning how to manage and cope with uncertainty presents as an integral piece of treatment across psychiatric presentations (Boswell et al., 2013).

The supplementary correlational analyses in this study provide novel findings regarding the relationships between IU and LPP. The strong correlation observed between IU and the difference-score between uncertain-positive and certain-positive image conditions suggests those at higher levels of IU are more likely to exhibit heightened emotional reactivity when faced with uncertainty. Importantly, this relationship was not observed when examining difference scores for the negative image conditions. This finding is consistent with the current understanding of IU, as individuals with higher levels of IU react more strongly to unpredictable events, and uncertainty is equated with aversiveness (Carleton et al., 2007; Dugas et al., 2005). In the current study, it is reasonable to propose that uncertain-negative and certain-negative images were responded to in a similar way, as the uncertain cue may not have had any additional impact on emotional reactivity; both the "-" and "?" were viewed as cues alerting of future threat for individuals with higher levels of IU, while "+" served as a safety signal.

The association observed with positive image conditions provides evidence that uncertain cue was interpreted as aversive, while the certain-positive cue was interpreted as an indicator of future positive emotion, resulting in differentiation in responses as a function of IU. This is consistent with observed LPP differences between certain-negative and certain-positive images (Foti et al., 2009; Hajcak & Foti, 2020; Huang, & Luo, 2006). Here, however, the effect on LPP appears specific to individuals with higher levels of IU, and only when contrasting positive image conditions.

While these findings regarding LPP fit within the context of existing literature and do contribute in meaningful ways, there are limitations that should be accounted for in future research. Firstly, the distribution of participant sex is heavily skewed towards females. With this, future research using a larger sample may examine the influence sex on ERP components, as prior research demonstrates that male and female brains respond differently to affective content (Filkowski et al., 2017). Additionally, other constructs closely associated with IU were not examined as potential individual difference variables contributing to the results presented here. One construct that should be examined and controlled for in future research is *worry*, or the future-fixation and preparation for adverse outcomes (Barlow, 2002). Even though IU is theoretically distinct from worry, literature to date has found strong associations between these constructs (Boelen et al., 2010; de Bruin et al., 2007; Osmanağaoğlu et al., 2018). Worry was not controlled for in the current set of analyses for two specific reasons: (1) the current study was theory driven and the experimental paradigm was designed to create uncertainty in order to match the construct of interest, and (2) a limited sample size made controlling for worry difficult to justify (see Appendix C for additional commentary on sample size).

Future studies may take additional steps to facilitate uncertainty during an S1-S2 image viewing paradigm. Of note, uncertainty was only present in the context of affective images, and not with neutral images. Prior studies included uncertain-neutral conditions (e.g. Dieterich et al., 2016; Dieterich et al., 2017; Gole et al., 2012) and were able to observe an effect of uncertainty. This condition was not included in the present study out of concern of the number of trials participants were exposed to and time commitment, as the current study was part of a large study where additional tasks were completed (see Appendix B for additional details). In order to encourage participant engagement across all tasks, an uncertain-neutral condition was not included.

Lastly, future S1-S2 image viewing research should consider manipulating the probability of valenced images based on cues. Newer research (e.g. Johnen & Harrison, 2019; Johnen & Harrison., 2020) has used this approach, where cues alert participants about the probability of different outcomes. This approach may have greater external validity to the one used in the present study, where uncertain cues resulted in 50:50 probability of positive or negative images. Outside of a laboratory setting, affective outcomes are not binary, and the probability of positivity and negativity are not equal across all contexts. This should be examined further in future research.

Even with these limitations, the ERP data presented here provide novel findings that contribute significantly to increased understanding of the IU construct. More specifically, these data provide evidence SPN amplitude is impacted by individual differences in IU; that uncertainty relative to certainty shows trends of LPP facilitation for affective images; and that LPP exhibits unique responses in relation to cues alerting participants of affective stimuli.

Hypotheses 3a, 3b and SAM Arousal and Valence. Largely, the findings regarding self-reported arousal and valence provide evidence of higher emotional reactivity (i.e. arousal and directional valence) for affective compared to neutral, negative relative to positive content, and uncertain compared to certain, with this last point specific only to negative image conditions; uncertain-positive and certain-positive conditions resulted in identical arousal and valence ratings. These findings provide notable contributions within the context of existing S1-S2 image viewing literature. As previously noted, many prior studies relied only on using negative and neutral images, making it difficult to draw conclusions about the role of uncertainty compared to certainty for positive content (Dieterich et al., 2016; Dieterich et al., 2017; Goel at el., 2012; Johnen & Harrison, 2020). In studies that do include positively and negatively valenced images, researchers only examined self-reported valence rating (Johnen & Harrison, 2019). The findings of the current study complement and contribute to existing literature examining valence, while providing novel findings by reporting arousal ratings during the S1-S2 image viewing task.

The current findings regarding self-reported valence, where uncertain-negative conditions were rated as more negatively than certain-negative, and no differences were observed for positive image viewing conditions, are inconsistent with prior research. Johnen and Harrison (2019) demonstrated that conditions where cues accurately indicated upcoming image valence were found to result in greater directional valence compared to conditions where cues provided inaccurate information about upcoming image valence. In their study, it appears the expectation of a positively or negatively valenced image primed the individual to interpret the images more positive or negative once presented compared to when they are expecting an image of a certain valence category and saw one of the opposite category. This priming effect has also been observed in studies that used cueing conditions similar to those in the present study, with uncertain cues and certain cues preceding positive or negative images. Using an S1-S2 paradigm, participants reported greater positivity for certain-positive compared to uncertain-positive conditions, and greater negativity for certain-negative compared to uncertain-negative conditions (Lin et al., 2012; Lin et al., 2015).

The disparate findings between Johnen and Harrison (2019) and the present study may be attributed to differences in cueing condition manipulations. In the present study, the uncertain condition indicated that the upcoming stimulus could either be positive or negative, while in the Johnen and Harrison (2019) study, they created uncertainty by presenting an image that did not match the cue. While subtle, these differences in manipulating certainty may have important effects of how individuals respond to the images. To facilitate feelings of uncertainty, Johnen and Harrison (2019) primed individuals to see positive or negative images and then presented them with an image of the opposite valence category. With this approach, uncertainty is not introduced *until* the image is presented. In the current study, uncertainty was introduced by the cue itself, where participants were informed that they could be presented with a positive or negative image, and were required to wait until the image was presented. Here, it is possible that the point in which uncertainty is introduced impacts how affective content is interpreted.

Regarding the discrepancies between the current study and those of Lin et al. (2012; 2015), it should be noted that these studies relied on relatively small samples ($N = 18$; $N = 19$, respectively), and that positive and negative images were used twice for each participant, in both certain and uncertain conditions. To this later point, there is existing evidence documenting emotional habituation when participants are presented with affective content they have already encountered (Dudas et al., 2017; Wright et al., 2001). This must be considered when interpreting the results of Lin and colleagues (2012; 2015), as the repetitive presentation of the same stimuli could have had an unexpected effect on participants emotional experiences. In the present study, images were only used one time each. Additionally, the self-reported valence rating findings in the current study are concordant with the current LPP findings, where greater negative emotion was observed across *both* measures for uncertain-negative conditions relative to certain-negative content, and no difference observed between uncertain-positive and certain-positive during both early (400-700ms) and late (700-1000ms) time windows.

Regarding self-reported arousal ratings, the aforementioned literature did not capture self-reported arousal ratings. The findings in the present study is novel in the context of S1-S2 image viewing research where S1 cues are manipulated to induce uncertainty prior to image presentation. In conjunction with the self-reported valence findings, the present study provides evidence for enhanced bottom-up emotional reactivity for negative compared to positive stimuli, and that uncertainty plays a unique in modulating arousal and valence ratings for negative content alone. This is conceptually consistent with what has been documented in prior literature, where uncertainty is generally viewed as an unpleasant experience, and there is as strong desire to gain certainty (Hsee & Ruan, 2016; Tormala & Rucker, 2018). Additionally, it suggests that uncertainty may have an additive effect on the observed negativity bias.

While these findings are novel, it is essential that they be replicated in future research. This is particularly important, as the findings regarding valence are inconsistent with prior literature, although this may be attributed to methodological differences, and the findings regarding arousal appear novel. Lastly, while a statistically significance was observed in contrasting valence ratings for negative image conditions, the real-world implications of this finding may be called into question. Both empirically and anecdotally, it is known that uncertainty is aversive, and particularly aversive for some individuals in pathologies marked by elevated IU. With this, however, it is difficulty to draw conclusions of what the observed ".1" difference self-reported valence for uncertain- and certain-negative image conditions truly means outside of a laboratory context. As stated, these findings do need to be replicated to provide additional concordance between physiological measures of anticipation and emotion (e.g. SPN and LPP) and behavioral measures of emotion (e.g. SAM arousal and valence).

Conclusion. Intolerance of uncertainty is an important transdiagnostic construct associated to a wide range of pathologies. Clinical research has been able to demonstrate that this construct is associated with atypical affective, cognitive, and behavioral processes, and that it can be modulated through psychotherapeutic interventions. Lagging, however, is an understanding of how these processes are reflected through physiological measures. The present study was designed to draw connections between what is observed in clinical settings and laboratory settings to better understand the neural processes that may reflect these abnormalities. The findings in the present study provide further evidence of the role of IU during anticipation and reaction to stimuli during periods of certainty and uncertainty. These findings are further supported by the concordant behavioral data. Ultimately, the data presented here may have important clinical assessment and treatment implications that should inspire further investigation of IU, uncertainty, and physiological and behavioral measures of emotion and anticipation.

APPENDIX A

EXPANDED REVIEW OF THE LITERATURE

Certainty is conceptualized as confidence about what humans believe to be true and false about their environment (Fischhoff et al., 1977). Largely, certainty shapes behavior, as individuals often engage in behaviors they are certain will elicit favorable outcomes or prevent unfavorable outcomes from occurring (Skinner, 1953). The certainty that individuals hold for a given outcome can range from complete uncertainty, where the outcome is unknown or weakly held, to complete certainty, where an individual feels they have definitive knowledge of an outcome happening (Tormala & Rucker, 2018). When individuals are uncertain of what outcomes their behaviors will elicit, they often experience conflict, with some individuals better able to manage distress associated with uncertainty than others (Freeston et al., 1994).

The more information we have about our environment, the more steadfast we become in our beliefs and attitudes, and in most cases, certainty is based on prior experiences (Tormala, 2016). When we repeatedly experience the same outcome (B) following a particular behavior or context (A), we can feel more certain that A will result in B (Tormala & Rucker, 2018). While different individuals can hold the same belief, the certainty about their shared belief can vary based on the consistency of their experiences. For example, two people could hold favorable opinions about a local restaurant, but one person may be more certain in their opinion because they have eaten at and enjoyed the restaurant multiple times over the past year, while the other person may be less certain in their opinion because they have had mixed experiences at the restaurant. In this example, two individuals hold the same opinion, but one person is more certain in their opinion because of the same repeated experiences at the restaurant.

Certainty influences how we appraise and interpret our environment. It is fundamentally tied into our emotional experiences and appears as an important domain that influences both internal and external behaviors (Tiedens & Linton, 2001). When faced with uncertainty, we engage in overt and covert behaviors to increase our degree of certainty (Festinger, 1954; Pelham & Wachsmuth, 1995). For example, when someone is uncertain of their social standing in a group, they often engage in checking or reassurance seeking behaviors to help increase certainty. While it may be adaptive to increase certainty in some contexts, there are other settings where this becomes maladaptive. When individuals become hypervigilant and overly attuned to their social standing, they may engage in compulsive checking or reassurance-seeking behaviors in attempts to regulate their uncertain emotional state (Elhai et al., 2018; Heerey & Kring, 2007). Even though these behaviors may increase certainty and regulate unpleasant emotional experiences, they do not allow the individual to tolerate feeling uncertain, and when faced with another similar situations, they will find themselves over-reliant on checking and reassurance-seeking behaviors.

In addition to influencing both internal and external behaviors, certainty is an important construct for defining emotions. In their 1985 emotion appraisal model, Smith and Ellsworth identified 15 separate emotions, and examined how they differed from one another on six separate dimensions, which included: *pleasantness, controllability, attentional activity, anticipated effort, agency,* and *certainty*. The *certainty* domain of this model has received extensive attention in affective literature, and has allowed researchers to understand how emotions that appear similar to one another on traditional arousal-valence models (e.g., Feldman Barrett & Russell, 1998; Russell, 1980), are actually different form one another (So et al., 2015).

As example of this, both *anger* and *anxiety* appear as similar emotional experiences in traditional arousal-valance models of emotion, but can be differentiated from one another using the certainty domain. Both emotions are marked by negative valence and high arousal, but with the certainty domain from Smith and Ellsworth's model (1985), it becomes clear how these emotions can be differentiated. When individuals experience anger, they are often certain to *whom* or *what* they are directing their highly aroused and negatively valenced emotion towards. This certainty that is characteristic of anger is absent in anxiety, an emotion where individuals are generally less certain of where their highly aroused and negatively valenced emotion is being directed.

Smith and Ellsworth (1985) were also able to differentiate positively valenced emotions from one another by using certainty as a dimension. The emotion of *surprise*, much like *happiness* and *pride*, is positively valenced and highly aroused, However, it is associated with greater levels of uncertainty than the other two aforementioned emotions (Smith and Ellsworth, 1985). Collectively, certainty appears to have great influence on behaviors and environmental appraisal, and can even be used to define our affective states.

Since certainty and uncertainty are fundamental to the human experience, understanding how individuals respond to uncertainty is an important area, with extensive literature suggesting that aversive responses to uncertainty are a hallmark symptom of a number of psychopathologies, including anxiety, depressive and obsessive-compulsive disorders (Carleton et al., 2012). Negative appraisal to uncertainty has been studied as an individual difference variable, commonly referred to as *intolerance of uncertainty* (IU).

Individuals who are intolerant of uncertainty hold cognitive biases towards uncertain situations, and tend to interpret uncertainty as aversive and inherently unpleasant (Dugas et al., 2005). In contrast, individuals who are low in IU do not find situations marked by uncertainty to be overly unpleasant (Butzer & Kuiper, 2006; Freeston et al., 1994).

This construct has received increasing attention over the past 25 years, with both basic and applied researchers attempting to advance the field's understanding of IU. To date, researchers have largely focused on understanding how IU is associated with psychopathology, how it can be modulated through psychological intervention, and how it can be measured with self-report questionnaires. Burgeoning research has also attempted to elucidate how individual differences in IU affect emotional reactivity in real time, as measured by physiological responses. Despite notable advancements in all of these lines of research, there are limitations in our understanding of how and which physiological indices are sensitive to IU, and how IU may affect human emotions in real time. Furthermore, the underlying biological mechanisms that result in elevated levels of IU remain elusive. The remaining sections of this review outline what is currently known regarding IU, current limitations that exist in the field related to the use of human physiology as a measure of emotion in IU literature, and a proposed methodological approach that could be used to address these limitations and advance the field's understanding of how human physiology is related to IU.

Intolerance of Uncertainty and Psychopathology

A wide range of psychiatric illnesses have been associated with IU, although, IU was originally conceptualized as a symptom of generalized anxiety disorder (GAD), and not a symptom other illness (Freeston et al., 1994). Individuals with GAD exhibit marked impairment in day-to-day functioning due to future-oriented, excessive and uncontrollable worry about everyday events (American Psychiatric Association, 2013). In their 1998 paper, Dugas and colleagues examined the relationship between GAD and IU, finding that they could discriminate between individuals with and without GAD based on self-reported IU scores better than other related constructs. Researchers further examined the relationship between IU and GAD, showing that healthy controls with moderate levels of worry also self-reported lower IU scores compared to a sample of individuals with GAD (Ladouceur et al., 1998). Furthermore, Dugas and colleagues (2007) have been able to demonstrate that self-reported IU scores can accurately predict GAD symptom severity among individuals with moderate and severe GAD even when controlling for age, gender and depressive symptoms. The relationship between GAD and IU has been consistently replicated and it is widely assumed that IU is a symptom of GAD (Bomyea et al., 2015).

Since IU appears to be strongly related to GAD and GAD symptom severity, intervention research has sought to understand how changes in IU may be related to symptom improvement. Research has documented that cognitive behavioral therapy (CBT) is effective in reducing both IU and other GAD symptoms, suggesting that IU can effectively be changed through intervention. Notably, an early case study found a reduction in IU scores preceded improvement in overall functioning, suggesting that IU could be an important mediating variable in symptom severity and impairment (Dugas & Ladouceur, 2000). In 2015, Bomyea and colleagues replicated this finding by asking individuals with GAD to complete a 10-12 week CBT intervention for GAD, with bi-weekly assessments of worry and IU symptoms. Their findings following treatment indicated that changes in IU mediated changes in worry, with changes in IU accounting for 59% of the reduction in worry. IU appears as a unique variable that needs to be addressed in treatment in order to decrease GAD symptom severity, but may also have important implications for other patient presentations (Bomyea et al., 2015).

In recent years, extensive evidence has also demonstrated that compared to healthy controls, higher levels of IU are found across pathologies, including individuals with obsessive-compulsive disorder (OCD; Gentes & Ruscio, 2011; Gillett et al., 2018; Tolin et al., 2003), social anxiety disorder (SAD; Boelen, & Reijntjes, 2009; Carleton et al., 2010; Counsell et al., 2017), panic disorder (PD; Carleton et al., 2014), major depressive disorder (MDD; Dugas et al., 2004; Miranda et al., 2008; Yook et al., 2010), eating disorders (Kesby et al., 2017) and autism spectrum disorder (ASD; Boulter, Freeston et al., 2014; Neil et al., 2016; Wigham et al., 2015).

Since IU appears across many different pathologies, researchers have begun to conceptualize it as a *transdiagnostic* symptom, or a symptom that is common across diagnostic categories (Krueger & Eaton, 2015). Evidence suggests that higher levels of IU do not lead to one particular diagnosis, but rather put an individual at greater risk for meeting criteria for internalizing disorders (Carleton et al., 2012).

The Growing Importance of Transdiagnostic Variables

Since the advent of the *Diagnostic and Statistical Manual of Mental Disorders, 3rd edition* (DSM-III; American Psychiatric Association, 1980), researchers and practitioners have conceptualized psychopathologies as distinct and different from one another, with identifiable and observable affective, behavioral and cognitive processes that are unique to each psychopathology (Nolen-Hoeksema & Watkins, 2011). More recently, however, there has been growing interest in understanding the characteristics and processes that have causal relationships across diagnoses (Barlow et al., 2004; Dadds & Frick, 2019). Examining characteristics that predispose individuals to a variety of psychopathologies has been referred to as a transdiagnostic approach, with these individual differences across commonly referred to as transdiagnostic symptoms or variables. This approach to understanding psychopathology is novel, as existing noslogies, including both DSM-5 and ICD-10, conceptualize diagnoses as discrete and unique presentations (Krueger & Eaton, 2015). In practice, however, there is notable overlap across diagnoses and shared characteristics that suggest pathologies have commonality. It has been suggested that a transdiagnostic approach to understanding pathology is helpful, as it: (1) identifies the continua of human thoughts, feelings, and behaviors to understand how pathology develops, (2) elucidates why certain diagnoses share diagnostic criteria and are often co-morbid, and (3) helps simplify our treatments by creating interventions that address common across related pathologies (Nolen-Hoeksema and Watkins 2011). This is drastically different from earlier approaches of understanding psychopathology, where each pathology was thought of as unique in its diagnosis, etiology and treatment.

To date, a number of transdiagnostic variables have been identified, particularly across anxiety and depressive disorders. McLaughlin and Nolen-Hoeksema (2011) provided empirical evidence of the transdiagnostic nature of *rumination*, or repetitive fixation on negative symptoms or experiences that perpetuates anxiety and depressive disorders. The authors sampled and tested over 1,500 adolescents and 1,300 adults at multiple time points, and demonstrated that rumination significantly mediated the relationship between anxiety and depressive disorders in both samples. The researchers stated that rumination may be an important variable that results in the development of anxiety and depressive disorders, and that by treating maladaptive rumination, clinicians may be able to address co-morbid anxiety and depressive disorders (McLaughlin & Nolen-Hoeksema, 2011). This result has since been replicated, with research documenting that baseline measures of rumination significantly mediated the relationship between anxiety and depressive disorders and changes in rumination mediated the longitudinal relationship between anxiety and depressive disorders (Drost et al., 2014). Similar observations have been made in research with children, with childhood rumination associated with the presence of different internalizing disorders (Snyder et al., 2019). Within the last year, machine learning researchers have also been able to create predictive models to better understand anxiety, depressive, trauma, and obsessive-compulsive spectrum disorders, with self-reported measures of rumination appearing as a key predictor of symptom severity across these presentations (Júnior et al., 2020). Collectively, these findings provide growing evidence of rumination as one of many important transdiagnostic variables.

Anxiety sensitivity (AS), a dispositional trait where somatic and cognitive symptoms are interpreted as aversive, has also been conceptualized as transdiagnostic (Boswell et al., 2013). Historically, this symptom was commonly thought of as unique to panic disorder, however evidence does suggest this construct is found across anxiety and obsessive-compulsive spectrum disorders (Boswell et al., 2013) AS can be modulated through interoceptive exposure (IE) regardless of the specific pathology with which the individual has been diagnosed (Wald, 2008; Craske et al., 2010). Additionally, substantial decreases in AS scores have been found to be associated with sustained changes in symptom severity at 6 months post-treatment (Boswell et al., 2013).

These transdiagnostic factors are helpful for providers, as they provide specific treatment targets where intervention techniques can be used across diagnostic categories to address shared symptoms. Both anxiety and depressive disorders are associated with elevated *trait-worry* (Akbari & Khanipour, 2018). In treatment contexts, this allows providers to teach both anxious and depressed patients skills such as cognitive restructuring, with benefit. Additionally, research suggests early peer victimization predisposes youth to a wide range a pathology, and in order to account for this, there has been growing emphasis on early interventions for at risk youth (Forbes et al., 2020). Understanding these shared symptoms across presentations is a relatively novel approach of understanding psychopathology, but may allow for better and more targeted interventions.

Development of IU as a Transdiagnostic Variable and Treatment Implications

In a 2006 theoretical review of potential transdiagnostic variables, Starcevic and Berle identified IU as a viable candidate to examine from a transdiagnostic approach. In recent years, there has been an explosion of literature examining how IU affects individuals and blurs diagnostic boundaries as outlined in the current DSM-5. Mahoney and McEvoy (2012) conducted a study where they sampled individuals diagnosed with GAD, panic disorder, agoraphobia, OCD and/or depression, and compared their self-reported IU scores to those of undergraduates from a previously published study, finding that the clinical sample had significantly higher IU scores. Furthermore, they found that self-reported IU scores were largely equivalent across diagnoses and that there was a positive association between self-reported IU and the number of pathologies for which someone met criteria (Mahoney & McEvoy, 2012). In the same year, this same research group provided further evidence that IU truly is transdiagnostic by demonstrating that IU helps mediate the relationship between neuroticism and symptoms of GAD, OCD, social phobia, panic disorder with agoraphobia, and depression (McEvoy and Mahoney, 2012). Collectively, these studies suggest that IU is associated with a wide range of pathologies, and helps to explain the relationship between other symptoms and pathologies.

From these studies, there is evidence to suggest that IU is shared across diagnostic categories, but without normative data with suggested cut-points to define elevations, it is difficult to draw clinical conclusions from self-reported IU scores. Fortunately, Carleton and colleagues (2012) conducted a study where they recruited large clinical (i.e. anxiety, depressive and obsessive compulsive disorders), community, and university samples, and had participants complete a self-report measure of IU. Their results, from more than 1,000 participants, revealed that the community and undergraduates showed no difference in self-reported IU, but the clinical sample scored significantly higher than both of these groups. Their study provides useful cut-points in determining if an individual has a self-reported IU score is suggestive of pathology.

With a substantial body of evidence documenting and describing transdiagnostic variables, including IU, an important next step is to determine how our knowledge of these variables can help inform treatment. In terms of board transdiagnostic approaches to treatment, Barlow and colleagues have developed a Unified Protocol (UP) for treating internalizing disorders, which has received extensive attention in the literature and has helped to reshape how the field conceptualized therapeutic interventions (Barlow et al., 2011; Barlow et al., 2017). Transdiagnostic variables should, in theory, respond to similar interventions regardless of the individual's diagnosis. The development of the UP has been a major advancement, as it allows for a more parsimonious treatment approach, and limits the number of interventions that clinicians need to be familiar with to appropriately treat their patients (Farchione et al., 2012).

In line with this streamlined approach, researchers have examined how the UP modulates IU across diagnostic presentations. In a 2013 randomized control trial (RCT), researchers compared the UP to a waitlist condition in a sample of patients with anxiety and depression to examine changes in self-reported IU following treatment (Boswell et al., 2013). As expected, a significant reduction in IU scores were observed for the UP treatment condition, while no reduction was observed in the waitlist condition, and the magnitude of IU change was a significant predictor of post-treatment symptom severity across pathologies (Boswell et al., 2013).

The growth of research examining the effectiveness of transdiagnostic treatments is encouraging, as some researchers have expressed concerns with current cognitive-behavioral therapy (CBT) approaches to treating anxiety disorders, as they view the treatments as too symptom focused, rather than examining underlying constructs that perpetuate the pathology (Gillett et al., 2018). Gillett and colleagues (2018) suggested that CBT, with an explicit focus on addressing IU could be a promising treatment alternative for individuals who do not respond to traditional cognitive-behavioral approaches. To date, evidence exists that CBT interventions with added IU treatment components (CBT-IU) have been effective in reducing symptom severity in patients with GAD and OCD (Boswell et al., 2013; Robichaud, 2013; Whittal et al., 2010). In a recent study, researchers explore the efficacy of a self-directed smart phone treatment specifically focused on addressing IU regardless of diagnosis or severity in children aged 13-17 years (Wahlund et al., 2020). The intervention as effective in modulating IU and overall functioning. These findings provide growing evidence that IU can be impacted through intervention, and that it might be an appropriate treatment target across presenting concerns.

With these studies suggesting the efficacy of parsimonious treatments, such as UP and CBT-IU, the field may shift away from diagnostic specific interventions, and look to adopt more universally applicable treatments that address factors that cause psychopathology. Both the UP and IU specific interventions appear consistent with the aims of a transdiagnostic approach established by Nolen-Hoeksema and Watkins (2011). It is likely that transdiagnostic treatment approaches will receive more attention in upcoming years, as the underlying constructs that perpetuate pathology become less elusive (Gillet et al., 2018).

Intolerance of Uncertainty and Related Constructs

Since IU commonly seen across a wide range of psychopathologies, it should not be surprising that IU is related to other constructs associated with psychopathology. Intolerance of ambiguity (IA) is a construct first conceptualized by Frenkel-Brunswik (1948), and is defined as “tendency to perceive (i.e. interpret) ambiguous situations as sources of threat” (Budner, 1962, p. 29). On the surface, this construct appears conceptually similar to IU, however, there is a paucity of empirical literature that has directly compared IU and IA. Despite this relative gap in the literature, researchers have posited that these two constructs are related, but that they have distinct characteristics that allow us to differentiate them from one another (Grenier et al., 2005). Regarding their similarities, Grenier and colleagues (2005) suggested that the shared use of the word “intolerance” to describe how individuals interpret the environment (presumably as threatening or dangerous) results in inherent overlap in our understanding of IU and IA. Furthermore, individuals with high IU and IA both engage in cognitive, behavioral and emotional strategies to help ameliorate distress associated with "intolerance" of uncertain or ambitious situations (Greiner et al., 2005). Despite these similarities, Greiner and colleagues (2005) recommended that IU and IA should be considered distinct from one another, where individuals with high levels of IA are unable to tolerate present moment ambiguity, and individuals with high levels of IU are more concerned with future-oriented uncertainty and find the possibility of adverse events occurring in the future to be distressing (Dugas et al., 2001; Greiner et al., 2005).

The future-oriented concern that is characteristic of IU, and not IA, is conceptually similar to *worry*, a process by which individuals engage in future-oriented fixation, expectation and preparation for adverse outcomes (Barlow, 2002). The relationship between IU and worry seems intuitive, as worry is one of the hallmark characteristics of GAD, a pathology where elevated levels of IU are also common (Dugas et al., 1998). In a recent meta-analysis of 31 published studies, researchers documented that IU was strongly correlated with worry in children (Osmanağaoğlu et al., 2018). Additionally, Dugas and colleagues (2004) sampled undergraduate, finding additional support that IU and worry are positively correlated with one another. While this is not intended to be an exhaustive account of all of the literature linking IU to worry, these findings have been supported across studies, and it is well established that worry and IU are associated and conceptually similar to one another with their shared future oriented concern (Boelen et al., 2010; de Bruin et al., 2007).

In addition to IA and worry, anxiety sensitivity (AS) is another transdiagnostic variable that is theoretically similar to IU, and may also be related to IU. AS is defined as the tendency to interpret somatic symptoms, worry-related thoughts, and adverse social interactions as inherently harmful and negative (Taylor, 2014). Because AS and IU are found across anxiety disorders, including both panic disorder and GAD (Dugas et al., 2001; Holaway et al., 2006), they are believed to be related constructs. Carleton, Sharpe, and Asmundson (2007) sampled close to 300 undergraduates, and surprisingly and conducted a confirmatory factor analysis, which showed that AS and IU were independent from one another (i.e. no higher order factor could be identified). Despite this finding, the two constructs were correlated with one another, and the researchers suggested that IU may be necessary for AS, but that two are distinct constructs (Carleton, 2012; Carleton et al., 2007).

Collectively, IU appears as a distinct construct of pathology, with evidence suggesting it is related to, but unique from AS, IA, and worry (Carleton et al., 2007; Greiner et al., 2005; Osmanağaoğlu et al., 2018). Carleton and colleagues (2007) stated that because IU is transdiagnostic and associated with other transdiagnostic variables, it may in fact be a fundamental component of anxiety (and other) disorders. If this is indeed the case, then future research should look to incorporate IU into theoretical models of pathology (e.g. Barlow, 2014). Once the field is able to develop models of pathology that incorporate IU, we may be in a position to better identify IU and treat it with more specific and effective interventions.

Measures of Intolerance of Uncertainty

Self-report measures

While clinicians and researchers ask about and observe how individuals respond to uncertainty, relying solely on these qualitative approaches limit the field's ability to more fully understand IU. Fortunately, IU researchers have developed scales to appropriately measure this important construct. The Intolerance of Uncertainty Scale (IUS) is a 27-item measure, first developed and validated in French-speaking Canada in order to measure cognitive, emotional and behavioral reactions to uncertainty, and the assumed implications and outcomes of uncertain situations (Freeston et al.,1994). A 2002 study by Buhr and Dugas sought to validate the original IUS in English. They had the original items translated from French to English by two independent translators, then had a third individual compare the two translations, and back-translate them to French. After the IUS-27 items were appropriately translated, they were administered to a sample of undergraduates, with results revealing excellent internal consistency, good test-retest reliability, and a strong four-factor structure [(1) Uncertainty leads to inability to act; (2) Uncertainty is stressful and upsetting; (3) Unexpected events are negative and should be avoided; and (5) Being uncertain about the future is unfair], which was conceptually similar to the five-factor structure [(1) Beliefs that uncertainty is unacceptable and should be avoided; (2) Being uncertain reflects badly on a person; (3) Uncertainty results in stress; (4) Uncertainty results in frustration; and (5) Uncertainty prevention action] observed in the original French version (Buhr & Dugas, 2002).

Following the advent of the English version of the IUS (Dugas & Buhr, 2002), researchers developed a shortened 12-item version of the IUS. Carleton and colleagues (2007) developed the IUS-12 by administering the original IUS-27 items to a large sample of undergraduates and removed redundant items, resulting in a 12-item measure with excellent internal consistency that was divided into two-factors, Prospective Anxiety and Inhibitory Anxiety. Prospective Anxiety was defined as fear and anxiety related to future events, while Inhibitory Anxiety was defined as the inhibition of behaviors due to anxiety (Carleton et al., 2007).

In 2010, a group of researchers directly compared the 27- and 12-item IUS scales in clinical and non-clinical samples (Khawaja & Yu, 2010), with results revealing that the two measures showed nearly identical psychometric properties, and that both scales were highly correlated with worry, with which IU is often associated in other literature. Even though both the IUS-12 and IUS-27 are reliable and valid measures of IU, researchers and practitioners may prefer the more efficient IUS-12. Since the development of the IUS-12 in English (Carleton et al., 2007), it has been translated and validated in Italian (Lauriola et al., 2016), and Dutch (Helsen et al., 2013), which has allowed for researchers in different countries to help contribute to understanding how IU affects individuals.

Even though the IUS-27 (Freeston et al., 1994) and IUS-12 (Carleton et al., 2007) have been the primary assessment tools, more recent scale development studies have sought to develop additional assessment measures of IU. Gosselin and colleagues (208) developed the Intolerance of Uncertainty Inventory (IUI) after noting that the original IUS-27 lacked sufficient factor stability and the instrument measured reactions to uncertainty, rather than the tendency to evaluate uncertainty as unacceptable (Gosselin et al., 208). While the IUI does exhibit appropriate psychometric properties for clinical and research use, it consists of 45 items, which may make it less preferable than the more efficient IUS-12 (Carleton et al., 2012). Even though researchers may be competing to develop the ideal IU scale, the growth of research in this area bodes well for the future, as the presence of so many assessment tools will help researchers and practitioners better understand how to address IU. While the scale development research on IU is exciting, other methodologies are also being used to measure IU, including human physiology.

Physiological Measures in Experimental Research

Peripheral measures of IU

Emotions are capable of eliciting robust physiological responses, and because of this, human physiology has been used as proxy measures of emotion over half of a century (Bradley & Lang, 2000; Levenson, 1992). Compared to other measure of emotion, such as self-report or behavioral observations, physiological measures are relatively unbiased, as these reactions are difficult to inhibit or voluntarily control. Physiological measures are unable to discern specific emotions from one another (e.g. happiness, sadness, anger, or excitement), but are sensitive to both arousal and valence, two emotional constructs that may be related to certainty and uncertainty (LaBar & Cabeza, 2006).

The startle eyeblink is an automatic, defensive reaction that is elicited following the presentation of an intense stimulus, such as an electric shock, a loud white-noise burst, or a puff of air directed at the eye (Filion et al.,1998; Vrana et al., 1988). This reaction can be measured using electromyography (EMG) to record electrical activity at the surface level that originates from muscles around the eyes (Cacioppo et al., 1986). The startle eyeblink can be reliably modulated depending on a participant's affective state. Vrana and colleagues (1988) demonstrated this by pairing pleasant, neutral and unpleasant images with a loud white noise burst, and recorded the subsequent eyeblink that was elicited by the auditory stimulus. As expected, they found that startle responses were largest following the presentation of unpleasant images paired with the white noise burst, followed by neutral and pleasant image paired with white noise bursts, respectively. Other researchers have paired startle-eliciting electric shocks with affective images, and have found that images influence the startle response in a similar manner to when they are paired with white-noise bursts (Davis, 1986). These findings are consistent with the *affective-match hypothesis* (Lang et al., 1990), which suggests that reflexes are potentiated when paired with a stimulus that matches the reflex valence, and attenuated by a stimulus that has incongruent valence with the reflex. Collectively, this has been influential, as Lang and colleagues' hypothesis (1990) has been supported by empirical findings that affective states can modulate a largely involuntary reaction, and that the modulated reaction can be measured using human physiology. These manipulations of the startle eyeblink with affective stimuli have been referred to as the affect-modulated startle (AMS; Grillon & Baas, 2003), and have been a promising measure to help researchers understand how IU affects a largely involuntary emotional reaction.

Nelson and Shakman (2011) examined the relationship between IU and startle eyeblink using a paradigm where participants were exposed three conditions where they heard a startle tone after either receiving an electric shock at a predictable time, receiving no electric shock, or receiving an electric shock at an unpredictable time. Counterintuitively, results from the study revealed that IU was negatively associated with startle eyeblink amplitude during the uncertain condition, and showed no relationship during the predictable shock or no shock conditions. The researchers interpreted these results to mean that individuals with higher levels of IU exhibited emotional blunting when faced with uncertainty, which may have been used to help protect themselves from the discomfort associated with uncertainty. When the stimuli were predictable, or participants knew they would hear a startle tone without an electric shock, there was no relationship between IU and startle amplitude (Nelson & Shankman, 2011).

Using a similar threat of shock design, a 2014 study examined individuals with panic disorder (PD) and health controls, during a threat-of-shock paradigm (Gorka et al., 2014). Results from this study indicated that at low levels of IU, PD and controls exhibited identical startle responses in predictable shock conditions, but at high levels of IU, PD participants exhibited exaggerated startle response during the cueing period and shock inter-stimulus-interval (ISI) compared to controls (Gorka et al., 2014). The authors referred to their predictable shock condition as a "safety condition" and note that high IU was associated with exaggerated startle response in PD individuals because they interpret the ISI as a "distal threat," and low IU individuals interpreted it as a "safety signal." (Gorka et al., 2014).

These finding are inconstant with a more recent study demonstrating that IU is associated with greater startle amplitude during uncertainty. More specifically, a fear conditioning study showed that higher levels of IU were positively associated with startle amplitude during a condition where participants had a 50% chance of receiving an electric shock, but not during a condition where there was a 75% chance of receiving an electric shock (Chin et al., 2016). The increased uncertainty associated with the 50% shock condition appeared to facilitate the startle eyeblink in individuals with higher levels of IU. This finding is in contrast with Nelson and Shankman, (2011), as well as Gorka et al. (2014) that showed the startle eyeblink was smaller during uncertain conditions, and larger during certain conditions, respectively.

Methodological differences may be responsible for the disparate findings across these studies. In the designs used by Nelson and Shankman (2011) and Gorka and colleagues (2014), participants received electric shocks during both the certain (referred to as "safety" condition in Gorka et al., 2014) and uncertain conditions. The researchers simply manipulated *when* participants would be shocked during the conditions, whereas Chin and colleagues (2016) manipulated *if* participants would be shocked during the uncertain condition. From this, it can be argued that Nelson and Shankman's uncertain condition was not an actual uncertain condition, because participants knew they would be shocked. Similarly, Gorka and colleagues may not have had an actually safety condition, because participants also knew when they would be shocked during the safety condition. Taken together, these findings suggest that future researchers need to be cognizant of how their manipulations of uncertainty during tasks affect their interpretation of the role that IU plays in the startle eyeblink.

While there are discrepancies between results, a more recent study provide additional evidence of the unique impact IU may have on startle eyeblink and related EMG supercilli activity. In this conditioning and extinction task, participants were presented with two separate colored squares and were not provided any information about their meaning (Morris, 2019). One of the colored squares (CS+) was paired with a startle scream, while the other (CS-) was not. As expected, EMG activity was greater for CS+ compared to CS- during acquisition, however, differences emerged during the extinction phase were the CS+ was no longer paired with the startling scream. Of note, Individuals with higher levels of IU showed large differences in EMG activation between CS+ and CS- conditions, while individual with lower IU exhibited attenuated EMG activation for both CS+ and CS- stimuli, suggesting that individuals with higher levels of IU have difficulty updating and encoding new information regarding safety and threat (Morris, 2019).

While the relationship between IU and the startle eyeblink remains elusive and likely contingent on how uncertainty is manipulated, other measures of physiology have been used to further understand affective processes related to IU. Heart rate variability (HRV) is defined as the variation between cardiac inter-beat intervals, which fluctuates in order to meet environmental demands, and is a measure of both parasympathetic and sympathetic activity (Appelhans & Luecken, 2006). Even though HRV is a measurement of autonomic activity, it is sensitive to processes of the central nervous system, such as emotion regulation and decision-making (Geisler et al., 2010). The central nervous system communicates to the autonomic organs through the vagus nerve, allowing the brain to appropriately modulate both respiration and cardiac output (Lane et al., 2009; Thayer & Brosschott, 2005). When cardiac output needs to be increased, sympathetic signals are sent via the vagus nerve that subsequently increase the heart rate and decreases the inter-beat intervals. Conversely, when cardiac output needs to be slowed, a parasympathetic signal is relayed via the vagus nerve, and heart rate is decreased while the inter-beat intervals are increased. The fluctuation of these inter-beat intervals during a given period is what is referred to as HRV (Thayer et al., 2009).

To date, a small body of literature has used HRV as a measure of IU. In a 2014 study, Ottaviani and colleagues recruited two groups of individuals with high and low levels of self-reported worry, and had them perform (1) a distraction task, (connect-the-dots puzzle), (2) a worry task, during which they fixated on a present worry, and (3) a reappraisal task, during which they thought of their worry in more helpful way. Across these three tasks, participants were randomly presented with a loud white noise-burst while cardiac activity was recorded. In their sample of worriers, high IU was associated with a greater low-frequency/high-frequency HRV ratio (LF/HF-HRV) during the worry task (Ottaviani et al., 2014). Greater LF/HF-HRV is thought to reflect general arousal, as LF signals originate from SNS activation, while HF signals originate from PNS activation (Shaffer & Ginsbeg, 2017). The results of this study by Ottaviani and colleagues (2014) are influential, as they demonstrate that when worriers with high levels of IU engage in worry, that there is greater physiological reactivity suggestive of an unpleasant affective state, as index by LF/HF-HRV activity. This effect was not found in worriers with low levels of IU, demonstrating that this IU construct may have an additive on the emotional impact of worrying, in worriers.

Similarly, Deschênes and colleagues (2016) conducted a study where cardiac activity was recorded during a seven-minute baseline period, a five-minute “free worry” period where participants fixated on a recent worry, and during a semi-structured “worry catastrophizing interview.” Results revealed that HF-HRV was relatively consistent across the three tasks for individuals with low IU, and that high levels of IU were associated with greater HF-HRV decrease during both worry and worry catastrophizing tasks relative to the baseline recording (Deschanes et al., 2016). Taken together, the findings from these studies suggest that individual differences in IU may affect how the SNS and PNS respond during worry, which ultimately affects cardiac activity and is suggestive of unpleasant affective states in individuals with higher levels of IU (Deschanes et al., 2016; Ottaviani et al., 2014).

Skin conductance response (SCR) is another measure of SNS activity that has been used to better understand differences associated with IU. Generally, SCR is recorded by placing electrodes on the volar surface of the phalanges, thenar and hypothenar surfaces of the hand, or on the inner portion of the foot, with one electrode emitting a small electrical signal while the other electrode records the strength of the current (Boucsein et al., 2012). In affective research, individuals may exhibit increased arousal following stimulus presentation, which results in perspiration, reducing electrical impedance and increases the SCR signal recorded at the electrode receiving the electrical current. SCR is one of the most widely used indices for studying emotion (Kreibig, 2010; Lang, 2014), and with this, researchers have begun to examine how IU is related SCR in different emotion eliciting paradigms.

In a 2015 study by Morriss and colleagues, SCR was recorded while participants completed a fear conditioning task, where solid-colored slides were either paired with an affectively unpleasant sound (CS+), or with no additional stimulus (CS-). The researchers found that individuals low in IU exhibited an attenuated SCR response from early-to-late extinction phases of the study, while individuals with high IU showed no change across extinction phases of the study. During these extinction phases, the CS+ was no longer paired with the unpleasant auditory stimulus. The SCR data from this study suggest that individuals with high IU have a more difficult time habituating to conditioned, unpleasant stimuli, potentially due to greater generalization of threat (Morriss et al., 2015). Additional studies finding similar evidence that individuals high in IU appear to show generalized fear responses that are more difficult to extinguish than individuals with lower levels of IU (Morriss et al., 2016; Morriss et al., 2016).This finding was most recently replicated by Morris in a 2019 during a conditioning task, where higher levels of IU were also associated with slowed extinction and habituation, as reflected by SCR. Interestingly this same study found evidence during an image viewing paradigm, where cues preceded aversive or neutral images, that higher levels of *worry,* and not IU, were associated with greater SCR activation during periods of uncertainty. Similar effects have been observed in other research (e.g. Bennett et al., 2018; Grupe & Nitschke, 2011), where higher levels of IU are not associated with greater physiological reactivity. Morriss (2019) notes that a potential explanation may be that in these studies, participants are not necessarily uncertain, as the stimuli following cues are aversive or natural, which may reduce task engagement. It is plausible to suggest that if greater uncertainty can be introduced to these tasks, individuals with higher levels of IU may exhibited heightened reactivity.

These findings regarding GSR responses during conditioning tasks (Morriss et al., 2015; Morriss, 2019) fit nicely with clinical findings and anecdotes from clinicians who treat individuals with pathologies characterized by elevated levels of IU. An exhaustive body of literature has provided evidence that IU is strongly associated with internalizing disorders (e.g. Carleton et al., 2012). Morris and colleagues (2015) suggest that individuals high with IU exhibit difficulties habituating to conditioned stimuli, even when they are no longer paired with an unpleasant stimulus. This appears analogous to clinical settings, where individuals with panic disorder exhibit slowed affective habituation to somatic symptoms in the absence of true danger, or individuals with obsessive-compulsive disorder show heighted physiological reactivity and slowed habituation to benign stimuli that they have been conditioned to interpret as aversive (Taylor et al., 2007). This is a clear example of laboratory research providing empirical evidence of what is observed in clinical treatment settings.

Central measures of IU

While peripheral physiology has been influential in understanding how IU affects individual responses during periods of uncertainty, central measures of physiology have also played an important role. Each measurement method has relative strengths and weaknesses, and accounting for these and using multi-modal assessments allows for better understanding of how brain processes are associated with IU. Both experimental fMRI and review literature provide strong evidence that IU is associated with anterior insular cortex and amygdala activation during periods of uncertainty in both adults and children (DeSerisy et al., 2020; Tanovic et al., 2018). While this alone provides evidence for specific brain regions that may be associated with IU, fMRI is only one measurement tool that can be used to elucidate the neural processes associated with IU.

Event-related potentials (ERPs) have received increasing attention over the years as a measure sensitive to individual differences in IU. These neural signals are averaged measures of electoral activity originate from the brain and are recorded at the scalp using electroencephalography (EEG) during specific time intervals following an event or stimulus (Luck, 2005; Luck, 2014). ERPs are non-invasive measures of human brain activity, they provide excellent temporal resolution with millisecond precision, and are relatively inexpensive compared to other measures of brain activation, such as fMRI and MEG (Lopez-Calderon & Luck, 2014).

Because ERPs are relatively easy to measure, researchers have used different ERP components to help advance our understanding of affective and cognitive processes associated with IU. A 2012 study by Gole and colleagues examined ERP components in a sample of individuals with high and low levels of IU during the anticipation of and viewing of affective images. The researchers found exaggerated P200 amplitude for the high IU group compared to the low IU group during exposure to cues that provided no information about upcoming affective images. Additionally, in the high IU group, the researchers found that unpleasant images preceded by uninformative cues resulted in LPP attenuation compared to unpleasant images preceded by informative cues (Gole et al., 2012). During the anticipation phase, the exaggerated P200 for the individuals with high IU suggest these participants were allocating more of their attention to the cue, while the findings of the LPP component during image exposure suggest that high IU individuals may disengage from the task if they do not know what the upcoming stimulus will be. Collectively, these results demonstrate that IU is associated with great cognitive processing of both cues and affective stimuli during situations of uncertainty (Gole et al., 2012). A more recent study found similar effects on P200, N200 and LPP after the presentation of unpredictable affective images in a sample of individuals with OCD, a group who often report greater IU, compared to healthy controls (Dieterich et al., 2017).

Along with the aforementioned ERP components, other ERP components have been examined in relation to IU. Error-related negativity (ERN) is a negative going waveform that is elicited approximately 50ms after the commission of an error during dichotomous decision-making tasks, such as a flaker task, or go-no-go task (Holroyd & Coles, 2002). This ERP component tends to be exaggerated in individuals who are sensitive to mistakes, including anxious individuals (Moser et al., 2013; Weinberg et al., 2010). Furthermore, these anxious individuals who are sensitive to making mistakes also tend to report greater levels of IU (Carleton et al., 2012). With this, Jackson and colleagues (2016), examined the relationship between ERN and IU during a flanker task, arguing that the commission of an error is unpredictable, and therefore, the unpredictable nature associated with errors should be associated with greater sensitivity to mistakes, as reflected by exaggerated ERN. The researchers found that *Prospective IU*, a subscale measure of the IUS-12 that assesses the urge to act in the face of uncertain situations (Carleton et al., 2007), was positively associated with ERN. The authors note that their findings are consistent with existing literature linking ERN to different constructs associated with anxiety (e.g., *worry*), suggesting that Prospective IU and enhanced ERN reflect greater salience of errors and greater desire to correct the uncertain and unpredictable mistakes (Jackson et al., 2016).

Recently, the relationship between ERN and IU was reexamined during a flanker task (Ruchensky et al., 2020). At lower levels of IU, depression appeared as a significant predictor of ERN difference between *error* and *correct* response trials, however this relationship was not present at higher levels of IU. While the authors expected to see ERN facilitation associated with IU, it possible that the presence of depressive symptoms dampened the ERN response in individuals with higher levels of IU, as prior literature has demonstrated the suppressive nature of depression ERN (Weinberg et al., 2012). In the absence of ERN facilitation, they did find that IU was inversely related to response time during both error and correct trials, even though IU showed no relationship to the proportion of correct trials, suggesting an eagerness to perform well during the task (Ruchensky et al., 2020).

The ERP literature reviewed to this point has focused on image viewing and behavioral tasks (e.g., flanker task), and how IU is associated with different components during such tasks. Relying on a unique experimental manipulation of emotion, MacNamara (2018) exposed participants to 10-second audio recordings with either neutral or unpleasant affective content. Following the audio clip, participants were encouraged to visualize the scene form the audio clip for an additional 10-seconds while EEG data were recorded. Results from this study demonstrated that LPP, a neural measure of emotion that is generally greater for arousing compared to neutral stimuli, was negatively associated with Prospective IU during the mental imagery phase following unpleasant audio clips. This finding suggests that Prospective IU is associated with emotional blunting, which participants may rely on to control their emotional experience when visualizing the unpleasant audio (MacNamara, 2018). These results and interpretation are consistent with the findings by Gole and colleagues (2012), along with others who have demonstrated individuals with GAD, a pathology reliably marked by elevated levels of IU compared to healthy controls, exhibit attenuated LPP following the presentation of unpleasant image (Weinberg & Hajcak, 2011).

Despite the different observed relationships between LPP and IU, the association by MacNamara (2018) appears similar to the results and interpretation by Jackson and colleagues (2016), who state that ERN has been associated with a number of characteristics of anxiety, and therefore, it is only logical that Prospective IU, a construct linked to anxiety, is also related to ERN. From these studies, it may be argued that ERP components associated with constructs of anxiety should also be related to IU, as a large body of literature has found IU to be related to anxiety.

The LPP component has also been examined during a conditioning and extinction paradigm (Bauer et al., 2020). Consistent with prior findings examining both EMG and GSR responses (Morriss, 2019; Morriss et al., 2015), Bauer and colleagues (2020) found that during extinction, individuals with higher levels of IU exhibited greater discrimination, as reflected by LPP, between CS+ and CS- stimuli, suggesting difficulty learning new cue information. Collectively, these findings using different measures of physiology suggest IU as associated with delayed learned and heightened anticipation of threat (Bauer et al., 2020; Morris, 2019; Morriss et al., 2016)

The reviewed literature on IU and human physiology is not intended to provide an exhaustive account of the association between IU and physiology. Rather, this review is intended to demonstrate that human physiology has been and can used to assess individual differences across participants to understand cognitive and affective processes. Central and peripheral measures of physiology show relationships to IU across a variety of tasks, and both startle eyeblink and LPP appears as two measures sensitive to individual difference where additional research is necessary. While notable, these are not the only measure that have elusive relationships with IU. *Stimulus preceding negativity* is another ERP component that researchers believe should be related to IU, however, research findings to date have not supported this prediction.

Contingent Negative Variation (CNV) was one of the first observed ERP components, and was originally identified by W. Grey Walter and colleagues (1964). Generally, this ERP component has been elicited in simple reaction time (RT) tasks, where a slow, negative potential shift is observed following the onset of a warning stimulus, and becomes maximal right before an imperative stimulus (van Boxtel & Böcker, 2004). The early negativity observed with the CNV is thought to reflect orienting and processing of the initial warning stimulus (Loveless & Sanford, 1974a; Loveless & Sanford, 1974b), while the later negativity in this waveform is thought to reflect perpetration and anticipation for the imperative stimulus (Hajcak et al., 2012). Interestingly, this two-part, negative going ERP component can be elicited even when a motor response is not required.

Stimulus preceding negativity (SPN) is an ERP component that can be elicited following the presentation of a cue that provides information about an upcoming relevant stimulus, and is thought to reflect the same orienting and anticipatory processes associated with the CNV (Böcker et al., 2001; van Boxtel & Böcker, 2004). These two ERP components are conceptually similar to one another, with CNV used to describe the negativity prior to a motor response, and SPN used to describe the negative potential shift observed prior to a stimulus that does not require a motor response. Generally, researchers have relied on two-stimulus paradigms to elicit SPN, where a cue (S1) serves as a warning signal for the relevant upcoming second stimulus (S2) (Poli et al., 2007). Researchers who have studied SPN in S1-S2 paradigms have been able to identify four different types of anticipation that can reliably elicit an SPN waveform, including: (1) anticipation of feedback on past performance, (2) anticipation of upcoming task instructions, (3) anticipation of probe stimuli in simple math tasks, and (4) anticipation of an affectively relevant stimulus (van Boxtel & Böcker, 2004).

Damen and Brunia (1987) were able to demonstrate that SPN can be elicited while participants anticipate feedback regarding prior task performance. In their study, they asked participants to press a button every 20-22s, after which, they received a "knowledge of response" (KR) stimulus that provided them feedback about their task performance. As expected, Damen and Bruina (1987) saw a readiness potential (RP) prior to the button press, but what was novel was the presence of a negative going waveform (i.e., SPN) that was observed immediately before to the KR stimulus, which they believe reflected the anticipation of feedback on task performance. Researchers have since replicated this finding, reliably demonstrating that SPN is elicited during the anticipation of feedback on past performance (Brunia, 1993; Brunia, 1999; Damen et al., 1996).

In addition to the anticipation of feedback on task performance, researchers have provided evidence that SPN appears when individuals anticipate instructions for an upcoming task. Notably, van Boxtel and Brunia (1994) demonstrated this by providing participants with a warning stimulus (S1), followed by an instruction stimulus (S2) which told them how to respond to an upcoming imperative stimulus (S3). As expected, the researchers observed the SPN before the instruction stimulus (S2) suggesting that the participants were preparing themselves for the upcoming instruction.

This relationship between SPN and anticipation of instructions was replicated by Hillman et al., (2000) who presented participants with an alerting auditory stimulus (S1) that informed participants of the level of difficulty for an upcoming visual discrimination task (S2), followed by a final stimulus (S3) which alerted participants that they can provide their response to the S2 visual discrimination stimulus. The researchers replicated the findings of van Boxtel and Brunia (1994a & 1994b) by identifying SPN immediately after S1, but extended their findings by demonstrating that SPN amplitude was equivalent regardless of whether S1 indicated that S2 would be an easy or difficult visual discrimination task (Hillman et al., 2000). The authors interpreted this finding to mean that SPN is a measure of anticipation and that it may be unaffected by the cognitive demands of the upcoming task (Hillman et al., 2000).

Consistent with the literature already reviewed, there is evidence to suggest that SPN can be elicited in the anticipation of probe stimuli during mathematical tasks (van Boxtel & Böcker, 2004). Early SPN research found that participants showed a negative going waveform in parietal regions in an interval between the presentation of a string of numbers, which they had to use to complete a mathematical operation, and before a probe stimulus asking them to provide their answer (Ruchkin et al., 1988). Even though the mathematical task Ruchkin and colleagues (1988) had participants perform is conceptually different from a button pressing or visual discrimination task, the fact that all of these paradigms can reliably elicit a SPN waveform suggests this response is not task-dependent, but rather a reflection of anticipation for an upcoming stimulus.

Most relevant to the present study, research has demonstrated that SPN can be used as a measure of anticipation and preparation for upcoming and affectively relevant information and stimuli. Threat-of-shock paradigms have been paramount for understanding how SPN can be used as a measure of anticipation prior to affective stimuli. Böcker and colleagues (2001) documented the effect that a threat-of-shock has on SPN amplitude by presenting participants with four different visual cues, three of which were benign, and one of which was paired with a subsequent mild electrical shock. Böcker and colleagues (2001) found that SPN amplitude following the threatening stimulus was significantly greater than SPN amplitude following the three safety stimuli. From this, they posit that threat stimuli are more motivationally relevant, thus requiring greater attention, resulting in larger neural responses (i.e. SPN) (Böcker et al., 2001).

More recently, SPN was measured during an NPU-threat task where participants were provided a cue informing that they would receive no shock (N), receive a predicable shock (P) with a reliable onset following cue presentation, or an uncertain shock (U), where an electrical shock was presented at pseudorandom time intervals following cue presentation (MacNamara & Barley, 2018). Greater SPN amplitude was observed for both of the threatening cues (P & U) relative to the no threat (N) cues, but no difference in SPN amplitude was observed between predictable (P) and unpredictable (U) threat cues, suggesting that presence of a future threat, predictable or unpredictable in onset, is emotionally salient and attention capturing.

While MacNamara and Barley (2018) found no difference in SPN amplitude between predictable and unpredictable threat cue conditions, and that both conditions resulted in SPN facilitation relative to no threat, newer research has relied on a similar paradigm to reassess these effects. Tanovic and Joormann (2019) conducted a threat of shock task where participants were presented with one of three cues signaling an imperative electric shock, safety from an electric shock, or the possibility of a shock. Their data reveal SPN facilitation for unpredictable shock relative to both predictable shock and no shock conditions, which is in contrast with MacNamara and Barley (2018). The authors note this discrepancy may be due to different methodologies, and that SPN could be sensitivity to *how* uncertainty is manipulated. MacNamara and Barley (2018) presented electric shocks at random times following unpredictable cues, while electric shocks were delivered at consistent time intervals for Tanovic and Joormann (2019).

The SPN waveform that appears during the anticipation of pain is not specific to the threat-of-shock, but is also sensitive to the anticipation of pain through other somatosensory systems. A 2007 study compared SPN amplitude following cues informing participants of an electric or mild laser stimulus on their forearm, finding that SPN amplitude was greater following cues warning participants of the laser stimulus (Babiloni et al., 2007). Babiloni and colleague (2007) interpreted their finding to suggest that SPN amplitude was greater during anticipation of the laser stimulus because skin burns are more biologically relevant compared to electric shocks, thus requiring more attention. It was evolutionarily advantageous for our ancestors to be aware of the threat of skin burns from UV sunrays or fire, but were likely less concerned with electric shocks, as these were relatively rare. Taken together, these studies suggest that information in our environment that alerts us to the potential of pain is emotionally salient, and that biologically relevant types of pain may be even more salient.

While the affective literature has provided a robust evidence documenting that SPN is affected by the anticipation of pain, there is an equally as robust literature demonstrating that the anticipation of other affective stimuli can modulate SPN amplitude. Affective image viewing paradigms have been a hallmark of ERP research, with over 50-years of literature demonstrating that ERP components reflecting different affective and cognitive processes can be manipulated by image arousal, valence and latency (Olofsson et al., 2008). Since neural activity can be influenced by the presence of affective images, it seems only natural that neural activity would also be influenced by the anticipation of affective images.

Early affective image viewing and SPN literature has provided evidence that cues alerting participants to upcoming affective images result in facilitation of the SPN compared to cues alerting participants of affectively neutral images. Simons and colleagues (1979) demonstrated this by showing cues followed by images of nude females or affectively neutral images to male participants, and observed an exaggerated SPN leading up to the presentation of the nude images. This finding suggests that that image valence (positive versus neutral) affects SPN amplitude, and has since been replicated, with Amrhein and colleagues (2005) documenting exaggerated SPN following the presentation of highly arousing unpleasant images compared to neutral images.

Twenty-seven years after their finding (Simons et al.,1979) demonstration that SPN amplitude is sensitive to the anticipation of image valence, a group of researchers conducted a study to explicitly test whether or not SPN amplitude was uniquely affected by valence, or if anticipated image arousal could also impact SPN (Poli et al., 2007). To do this, Poli and colleagues (2007) used a S1-S2 paradigm, where participants were provided with a cue (S1) informing them of the content of an upcoming image (S2). The researchers had six different image categories with matching cues, including: erotic couples (high arousal-positive valence), nature (low arousal-positive valence), injuries (high arousal-negative valence), pollution (low arousal-negative valence), household objects (neutral) and non-affective people (neutral). Consistent with previous findings (e.g. Simons et al., 1979 & Amrhein et al., 2005), Poli and colleagues found that SPN amplitude was greater during the anticipation of positive and negative images compared to neutral. What was novel, however, was that this effect was driven by image arousal, as the anticipation of low arousal-positive and low arousal-negative trials resulted in indistinguishable SPN amplitudes when compared to SPN waveform of the two natural image category trials. Furthermore, these neutral and low arousal trials resulted in attenuated SPN amplitude compared to the arousing images, suggesting that highly arousing stimuli are particularly relevant and require more attention than low arousing stimuli (Poli et al., 2007).

Johnen and Harrison (2019; 2020) conducted two recent studies to further assess both SPN modulation during S1-S2 image viewing paradigms, along with image related ERPs following S2. In their 2019 study, participants were presented with positive and negative images that were preceded by two cueing conditions: the cue accurately identified upcoming stimulus valence or a condition where the cue was inaccurate and the opposite valenced image was presented after the cue. Of particular relevance, no differences were observed in SPN amplitude when presented with cues alerting of positive or negative images suggesting positive and negative stimuli are equally as relevant and require similar emotional preparation (Johnen & Harrison, 2019).

In their 2020 study, Johnen and Harrison used an S1-S2 image viewing paradigm with negative and neutral images, and the level of uncertainty was manipulated across conditions. They relied on cues signaling “uncertainty,” where there was a 50:50 chance of negative or neural image; a “fairly uncertain” cue that was followed by negative or neutral images with a 70:30 ratio; and “certain” conditions where the cue accurately signaled negative or neutral image. The researchers found SPN facilitation for certain compared to uncertain conditions, suggesting that the definitive nature of the cue allows for participants to engage in anticipatory processes to better prepare for the stimulus (Johnen and Harrison, 2020). This finding is inconsistent with those observed during threat-of-shock research (e.g Tanovic & Joormann, 2019). It is possible that the stimuli used (images versus electric shocks) are differentially relevant to participants, and that uncertainty prior to electric shocks is more important to participants than uncertainty prior to an image. Furthermore, the introduction of positive images into the paradigm by Johnen and Harrison (2020) could have changed task relevance and resulted in different findings regarding SPN.

With researchers widely agreeing that SPN is a measure of anticipation for emotionally relevant stimuli, emotion regulation researchers have also examined how the use of different emotion regulation strategies influence SPN amplitude. Broadly, emotion regulation refers to the different behaviors individuals engage in to influence when, how and what emotions they experience and express (Gross, 1998). The utilization of emotion regulation strategies varies from person-to-person with some individuals more reliant on certain strategies over others (Gross & John, 2003). Emotion regulation can include simple behaviors, such modifying the environment to influence emotion (e.g. turning off a scary movie), or complex behaviors, such as reappraising a difficult emotional experience (e.g. reinterpreting the loss of a family member to be *less* unpleasant) (Gross, 2013).

Since all emotion regulation strategies involve the modulation of an emotional experience, and we know that the anticipation of emotional stimuli can influence SPN, researchers were naturally led to examine how the anticipation and preparation of emotion regulation modulates SPN. In one such study, researchers had participants complete an S1-S2 image viewing study, where S1 was an instruction to either increase, decrease or respond as they naturally would to the S2 image (Moser et al., 2009). Moser and colleagues (2009) found grater negativity the early-SPN component during decrease condition compared to the other two conditions, suggesting that the cue to decrease an emotional experience is associated with enhanced orienting and preparation for upcoming unpleasant stimuli. This may suggest that the preparation to decrease emotional experiences is more effortful than the preparation of an emotional experience or the preparation to increase an emotional experience.

Following this study, another research group examined SPN in the context of an emotion regulation study where participants where instruction to perform one of two emotion regulation strategies or use no emotion regulation strategies (S1) and were subsequently presented with an affective image (S2) (Thiruchselvam et al., 2011). Prior to image exposure, Thiruchslvam and colleagues found greater SPN following the two emotion regulation cues (reappraisal and distraction) compared to the cue the control cue, and that SPN following the two emotion regulation cues were indistinguishable from one another. This finding has since been replicated, with additional evidence documenting SPN facilitation prior to the use of distraction (Shafir & Sheppes, 2018). These findings not only replicate the findings by Moser et al. (2009), but expands on them by demonstrating that anticipation and preparation for distraction, an emotion regulation generally thought to require minimal effort, may require similar preparatory resources as more complicated emotion regulation strategies, such as reappraisal (Shafir & Sheppes, 2018; Thiruchslvam et al., 2011).

Collectively, these studies provide ample evidence to suggest that SPN serves as a neural marker of anticipatory and preparatory processes for upcoming relevant stimuli. More specifically, SPN appears sensitive to the anticipation and preparation for: (1) feedback on past performance, (2) upcoming task instructions, (3) probe stimuli in simple math tasks, and (4) affectively relevant stimuli (van Boxtel & Böcker, 2004). Since SPN can be influenced by the anticipation of upcoming emotional information, IU, an individual difference characterized by negative evaluation of future uncertainty, may influence SPN. This neural measure (SPN) and construct of psychopathology (IU) have theoretical overlap, as one is a measure of anticipatory processes (SPN), and the other is a general tendency to anticipate adverse outcomes in the absence of information (IU). Despite the intuitive connection between this measure and construct, little research has sought to examine how different levels of IU may influence SPN amplitude during an S1-S2 image viewing study.

Current IU and SPN Literature

Even though existing literature has found relationships between ERPs and IU, the relationship between SPN and IU remains unclear. Researchers have noted that this construct and measure should be associated with one another, however, limited research has been conducted to formally examine their relationship. In a 2012 study, researchers sought to examine the moderating role of IU on different ERP components, including both SPN and LPP, during an S1-S2 image viewing paradigm (Gole et al., 2012). A median split on an IU self-report measure was performed, dividing the sample into two equal sized groups (High- and Low-IU). During the experiment, participants were presented with a series of unpleasant and neutral images, which were preceded by a cue signaling the upcoming image valence ("O" and "-", respectively), or a cue that provided no information about the upcoming image valence ("?"). Gole and colleagues (2012) predicted that the High-IU group compared to the Low-IU group would show greater SPN amplitude during the "?" condition compared to the other conditions, with SPN reflecting greater anticipatory and preparatory neural activity. Unfortunately, the researchers were unable to visually detect an SPN component following the cues and prior to image onset, which the researchers failed to discuss, and succinctly attribute this to having used non-normed images (Gole et al., 2012). The absences of an SPN component in this study is puzzling, as numerous S1-S2 image-viewing studies have found an SPN component following S1, prior to S2. The absence of SPN prevented researchers from testing their hypothesis regarding SPN and IU.

More recently, a group of researchers examined the role of IU on SPN during a rigged card game task, where participants were instructed to select cards with greater values than the computer in order to avoid an electric shock, but unbeknownst to the participants, card selection and outcomes were predetermined (Tanovic et al., 2018). In this task, participants selected cards from a deck ranging from 1-10, with two “special” cards, one of which resulted in an automatic win for the participant and a guarantee that they would not receive an electric shock, and the other resulting in an automatic loss regardless of what the computer drew, resulting in an electric shock for the participant. When pulling cards numbered 1-10, participants were told they had a 50% chance of being shocked if their card was a smaller than value than the computer’s card. Tanovic and colleagues (2018) predicted that IU would be associated with SPN facilitation during two anticipatory periods of the task; immediately after participants drew their card and anticipated the result of the computer’s choice, as well as the period after the computer’s card was revealed where participants anticipated the potential of an electric shock. During the first anticipatory phase, Tanovic and colleagues (2018) found that SPN was not affected by different levels of uncertainty associated with pulling higher or lower value cards, and that IU was a non-significant covariate in their model and did not modulate SPN as they expected. Results during the second anticipatory period demonstrated that SPN was greater during periods of threat uncertainty (50% chance of electric shock), compared to periods of threat certainty (100% chance of shock), and that IU scores, again, were a nonsignificant covariate in their model predicting SPN amplitude (Tanovic et al., 2018). While this study does explicitly test the effect of IU on SPN amplitude, it should be emphasized that this one study cannot be used to conclude that SPN and IU are unrelated. This non-significant finding may be the result of the experimental manipulation, where participants were uncertain whether or not they would receive a painful stimulus. It is unclear if the anticipation of a painful stimulus and an affectively relevant and unpleasant stimulus (i.e., an image) are interpreted in the same way.

To date, very little empirical research has examined the role of IU in modulating SPN amplitude at different levels of task certainty during the anticipation of affective stimuli. Both Gole and colleague (2012) and Tanovic and colleagues (2017) provide evidence that individual differences in IU do not play a role in modulating SPN amplitudes, however, these studies are not without limitations. As previously indicated, Gole and colleagues (2012) did not find an SPN component, which is surprising by itself, given the S1-S2 paradigm they used. Additionally, they report that they did not use normed images, so affective valence and arousal of the images may not have been sufficient to elicit an anticipatory response form participants. An extensive body of literature has demonstrated SPN is elicited in response to the anticipation affective information (van Boxtel & Böcker, 2004), and that SPN is exaggerated during the anticipation of aversive stimuli compared to neutral stimuli (e.g. Poli et al., 2007). The fact that Gole and colleagues (2012) were unable to detect an SPN component suggests that their stimuli were not emotionally relevant to participants, resulting in no need for them to anticipate and prepare for the upcoming images. Furthermore, the researchers did not include pleasant images in their paradigm, so even if they were able to elicit an SPN component, they would be unable to answer questions about how the potential for pleasant stimuli affects the anticipatory processes in individuals with different levels of

IU. With the researchers unable to measure SPN, it cannot be concluded that SPN is unaffected by IU during the anticipation of affective images.

Additionally, while Tanovic and colleagues (2018) found no evidence to suggest that IU affects SPN during the anticipation of electric shocks, it should not be concluded that this effect is universal. Most notably, the researches selected a relatively homogenous sample of participants in terms of IU, with mean participant Intolerance of Uncertainty Scale-12 (IUS-12) scores at 27.53. This mean IUS-12 score for an undergraduate sample is consistent with previous research, as earlier research on 428 undergraduate volunteers found comparable mean IUS-12 scores, at 27.52 (Carleton et al., 2012). This same study by Carleton and colleagues (2012) found mean IUS-12 scores for a sample of 332 individuals with obsessive-compulsive and a variety of anxiety disorders at 39.9. Even though Tanovic and colleagues (2017) were unable to provide evidence that IU affects SPN during the anticipation of electric shocks, this null finding may be attributed to sample selection, and that using an extreme-groups approach may help clarify how IU affects SPN.

Finally, both Gole and colleagues (2012), Tanovic and colleagues (2017) did not include pleasant stimuli in their study. This is notable, as participants anticipated either an unpleasant stimulus or no stimulus at all. From this, it is unclear how the possibility of a pleasant stimulus could affect the SPN component, and how this relationship could be modulated by different levels of IU.

APPENDIX B

EXPANDED METHODS AND MEASURES COLLECTED BUT NOT ANALYZED

Experimental Tasks

The current project was part of a much larger study where participants completed a total of 13 different laboratory tasks. In addition to the aforementioned hypotheses related to intolerance of uncertainty and ERP components, this larger project was also designed to assess individual differences in interoceptive awareness, that is, the awareness of internal bodily sensations (Herbert et al., 2011), as reflected by behavioral and physiological indices. A complete list and overview of these tasks are provided in Appendix B, Table A-2. The total time spent in the laboratory for each participant lasted between three and four hours, depending on length of breaks between tasks.

Once participants completed the previously reviewed screening and self-report measures (see Table A-1 for list of self-report measures collected but not analyzed in the present study), they presented to the laboratory, and were fitted with EEG and EOG electrodes, and additional equipment were applied, and procedures carried out. A three-dimensional (3-D) scan was created from each participant head using an iPad (Apple Inc., Cupertino, CA) and 3-D scanning software. These scans are to be used to create individual head models for each participant for source-localization, and processes by which EEG surface electrodes can be paired with models to estimate neural sources of EEG activity (Azizollahi et al., 2020). This estimating process cannot provide the same special resolution as other measure, such as fMRI, but it does allow researchers to maintain the high temporal resolution of EEG while making estimates of neural sources (Mahjoory et al., 2017).

Electrocardiogram (ECG) electrodes were also applied to participants prior to the start of the first task. An abrasive cleaning gel was applied directly below each collar bone, along with the lower-left portion of the participants ribcage in order to remove debris and oil. Conductive gel was applied to three reusable Ag/AgCl electrodes (Biopic Systems, Inc., Goleta, CA), which were then placed on the cleaned sites, and secured with medical tape. In respiration belt was also fitted around each participant's midsection in order to record inhalation and exhalation. Both ECG and respiration signals were recorded using a Biopac MP150 system, and AcqKnowledge software.

Following the fourth block of the image viewing task, participants were fitted with three additional electrodes to record EMG startle eyeblinks. This measure is a robust and reliable EMG signal that can be elicited following the perception of a loud, white noise burst, and is thought to reflect both attentional and affective processes (Duval et al., 2017). After preparing the skin, two reusable Ag/AgCl were placed on top of the orbicularis oculi muscle, located below the left eye. A third sensor was applied to the forehead and functioned as a ground electrode during the online recording. Startle EMG was recording using a fifth block of the image viewing task that was identical to the four previous blocks, except for the addition of an 80 dB white noise burst with near instant rise time, presented 2500ms following cue offset, with a +/- 200ms jitter in presentation (e.g. 2300-2700ms into the ISI). Startle EMG data were collected using a Biopac MP150 system, and AcqKnowledge software.

These measures collected but not analyzed have resulted in a rich dataset that can be used for future projects. In addition to the 31 individuals who completed all phases of the study, a total 79 participants completed all self-report measures, including the IUS-12 and the measures outlined in Table A-1. This sample is sufficient to perform meaningful correlation and regression analyses (VanVoorhis & Morgan, 2007) and may allow for exploration of how different psychiatric symptoms are associated with measures of interoceptive ability, a construct which is captured in self-report, behavioral, and physiological measures.

Research on interoceptive awareness has documented relationships between performance on interoceptive tasks and *trait anxiety*, as well as greater insular activation in fMRI research in those with higher levels of interoceptive awareness (Critchley et al., 2004; Pollatos et al., 2007). This is relevant for the current dataset, as prior literature has also highlighted relationship between insular activation and self-reported IU during periods of uncertainty, suggestion both IU and interoceptive abilities may have common neural sources (Simmons et al., 2007; Schienle et al., 2010). These measures are captured in the current dataset in self-report, as well as behavioral and physiological measures. Brief exploration of these variables even reveals moderate relationships between IU and interoceptive ability, as measured by the MAIA questionnaire (Mehling et al., 2012), $r = -.419$, $p < .05$. This alone is reason to suggest further investigation of the current dataset, specifically looking at ways in which IU and other constructs of pathology are associated with interoceptive abilities.

In addition to these potential questions the dataset may be able to answer, the existing startle eyeblink data should be revisited. A recent study provides evidence that IU is associated with greater auditory startle eyeblink during the anticipation of certain safety from electrical shock conditions relative to certain electrical shock conditions (Morriss et al., 2021). This differs from findings by Tanovic and colleagues (2018) who provide evidence that IU is associated with greater auditory startle during anticipatory periods marked by greater uncertainty for future electrical shock. Of note, neither of these studies included conditions where participants *are* or *could be* presented with positive stimuli, which raises concerns regarding the external validity of these studies. The present dataset could provide additional support of whether IU is associated with startle eyeblink facilitation during periods of certainty or uncertainty of threat, as well as provide evidence of how the presence of positive stimuli (i.e. IAPS images) impact these relationships.

The intention of this discussion is to highlight the richness of the existing dataset, rather than to define specific hypothesis regarding these data. This multimodal assessment of constructs of psychopathology, behavioral, and physiological indices of emotion and cognition has the potential to foster future manuscripts and additional research projects. Furthermore, ongoing collaborations between this writer and members of the committee make this increasingly likely. Further discussion of why one of these measures, startle EMG, was not examined for the current dissertation can be found in Appendix C.

Table A-1
Self-report measures used in the present study

Measure	Authors and publication date	Constructs Measured
Penn State Worry Questionnaire	Meyer et al., 1990	A single-factor scale designed to assess trait worry.
Metacognition Scale	Wells & Cartwright-Hatton, 2004	A five-factor measures to assess beliefs about thinking.
Depression Anxiety Stress Scale	Lovibond & Lovibond, 1995	A three-factor measure assessing depression, anxiety and stress.
Anxiety Sensitivity Index 3	Taylor et al., 2007	A three-factor scale assessing sensitivity to physical, cognitive and social components of anxiety.
State-Trait Anxiety Inventory	Spielberger et al., 1970	A two-factor scale assessing both state (current) and trait (overall) levels of anxiety.
Multidimensional Assessment of Interoceptive Awareness	Mehling et al., 2012	An eight-factor scale designed to assess trait-level awareness of bodily sensations.
Scale of Body Connection – Body Awareness Scale	Price et al., 2017	A single-factor measure assessing bodily awareness.
Body Responsiveness Questionnaire	Daubenmier, 2005	A single-factor ability to integrate body sensations into conscious awareness and decision making.
Breath Awareness Scale	Daubenmier et al., 2013	A single-factor measure designed to assess awareness of respiration.
Body Awareness Scale	Shields et al., 1989	A single-factor measure to assess attention to non-emotive bodily processes.
Attentional Control Scale	Derryberry & Reed, 2002	A two-factor measures used to assess attentional focus and attention shifting.
Perceived Stress Reactivity Scale	Schlotz et al., 2011	A five-factor scale used to measure reactivity to stressful events.

Table A-2
Order and description of tasks completed during study protocol

Task	Description
Resting	Four, two-minute blocks where participants alternated between staring at fixation cross or resting with eyes closed.
Time Detection Task (TD)	Participants listened to white noise background and were asked to count the amount of time (in seconds) between two beeps.
Reaction Time Task (RT)	Participants listened to a series of repetitive and staggered beeps and were asked to press a button to every fifth beep they heard.
Heartbeat Counting Task 1[a] (HBC 1)	Participants were asked to count the number to count the number of heartbeats they detect between two beeps, signaling the start and end of a trial. These data were compared to ECG.
Heartbeat Reaction Task[a] (HBR)	Participants were asked to track their heartbeat and press a button for every fifth heartbeat they detected. Data were compared to ECG.
Heartbeat Discrimination Task[a] (HBD)	Participants were asked to attend to both their heartbeat and beeps and were asked to make a determination if they were occurring synchronously or asynchronously.
Heartbeat Counting Task 2 **(**HBC2)	This task was the same as HBC1
Multisensory Integration Task (MSIT)	Participants were asked to attend to string of three digits, and respond with a keypad to identify the deviant number.
Multisensory Integration Task with Titration (MSIT-2)	This task was equivalent as MSIT, however time for response was shortened for each successive correct response.
Image Viewing Task	Participants were presented with cues that either informed the participant of upcoming image valence, or no information about image valence.
Airflow Detection Task[b,c] (AFD)	Participants were asked to breathe through a respiratory circuit and respond with a button press every time their airflow was interrupted; percent airflow change was changed during each trial.
Flicker Detection Task[b] (FLD)	This task was the same as AFD, however participants were ask to respond with a button press when they noticed one of three fixation crosses on the screen flicker.

Note. [a] Presentation of these three tasks were counterbalanced across participants.
[b] Presentation of these two tasks were counterbalanced across participants.
[c] Order of airflow occlusion levels was randomized across participants for all participants.

APPENDIX C

IMACT OF SARS-COV-2 AND THE COVID-19 PANDMIC: CONSIDERATIONS AND LIMITATIONS OF THE CURRENT PROJECT

The ongoing global health crisis has had far-reaching and drastic effects on the current study and has limited the scope of the data presented. Following Chancellor Agrawal's initial email on March 12th, 2020 moving all in-person classes to online format, and subsequent updates from the University of Missouri – Kansas City Office of Research Services, it became apparent that data collection could not continue in its current format. The committee chair, Dr. Diane Filion; co-chair, Dr. Seung-Suk Kang; collaborator, Dr. Seung-Lark Lim; and this researcher, Andrew Wiese, all agreed that in-person laboratory visits would pose unnecessary risk to both participants and researchers and should be suspended indefinitely.

Immediately following the suspension of in-person data collection, participants were still recruited using UMKC's PsychPool service. These individuals were asked to complete self-report measures and agreed to present for the remaining portion of the study once it was determined that in-person data collection would be safe, per local and federal guidelines. A contingency plan was developed where data collection could continue, even in the absence of this researcher, as this researcher was required to re-locate to Houston, TX in June, 2020 in order to complete the doctoral requirement of a year-long clinical internship.

At the time of suspension, a total of 54 participants had been screened and completed all questionnaire measures, and of those, 32 presented to the lab with 31 completing all portions of the project; these 31 individuals were used for the current dissertation project. A an additional 25 met criteria for the study and completed the self-report measures during the remaining Spring, 2020, and Fall, 2021 semesters. Contact information was retained for these individuals, and they are aware they may be contacted in the future if in-person data collection can resume.

The indefinite suspension of in-person data collection has resulted in notable deviations from the original dissertation proposal. Firstly, the initial proposal sought to rely on an extreme-groups approach for differentiating High- and Low-IU groups. Cut-offs for these groups were to be based off a 2012 study (Carleton et al.) where IU scores were collected for university, community, and clinical samples, with notable differences when comparing university and community samples to clinical samples; Low-IU was to be defined as those with scores of 28 and below, and High-IU as those with scores of 40 and above. These criteria for defining High- and Low-IU were ultimately revised giving the limited sample size. Consistent with design of Gole and colleagues (2012), individuals were divided into High- and Low-IU groups based on a median-split of IUS-12 scores (Carleton et al., 2007). This artificial dichotomization can be problematic, resulting in reduction of power as well as greater risk of Type I errors (Iacobucci et al., 2015). To account for this, correlational analyses were also conducted to provide further support of relationships between IU, and SPN and LPP amplitudes.

In addition to the impact on sample size, the ongoing crisis affected the feasibility of analyzing EMG startle data in a timely manner. This decision was made after thoughtful consideration by all parties directly involved with the project, including the chair, co-chair and this researcher. Firstly, an instrumentation error was discovered that made it difficult to accurately identify event-markers for startle tones onset in the continuous EMG data. Because of suspension in-person data collection, these cases could not be replaced by recruiting additional participants after correcting the instrumentation error. Additionally, correcting these errors in the already recorded data would have been overly time consuming and would detract from the overall quality of the data presented. Finally, the remote-work context for the major parties involved in this project further contributed to the difficulty in correct for these errors. While these data are not presented in the current dissertation project, they can be analyzed for future publications. In lieu of presenting EMG startle data, self-reported arousal and valence data following image presentation are included in this project to provide further assess the role of IU on anticipatory and emotional processes.

Aside from changed analysis plans and limited sample size, the COVID-19 has had more far-reaching implications that affect the feasibility of continuing this project. The SARS-CoV-2 virus and resulting COVID-19 global pandemic present a context in which uncertainty is pervasive (Koffman et al., 2020; Rutter et al., 2020). This *new normal* in which we live exhibits many characteristics of *uncertainty*, including an inadequate understanding of what we face, feelings of incompleteness, ambiguity, and conflicting alternative or explanations (Lipshitz & Strauss, 1997). These new parameters cannot be addressed through experimenter control and make continuation of the current project impossible, at this time.

The current dissertation project was designed to assess anticipatory and affective processes during an experimental task where certainty was manipulated. Even if data collection were to resume, the constructs of interest (i.e. certainty and intolerance of uncertainty) have been fundamentally impacted by the heightened uncertainty related to the ongoing pandemic. This alone makes continuation of this project impossible. Researchers are only just starting to understand the relationships between IU, uncertainty, COVID-19 and overall wellbeing, and further advancements in these areas may help future researchers account for heightened uncertainty in experimental design.

Burgeoning research has attempted to expand understanding of these constructs. Large scale questionnaire research has uncovered that the relationship between IU and mental wellbeing during the COVID-19 pandemic is mediated by a *fear of COVID-19* (Satici et al., 2020). This finding that IU and COVID-19 specific concerns are inversely related to wellbeing has been identified by other groups as well. Notably, Bakioğlu and colleagues (2020) provide evidence that fear of COVID-19 is associated with elevated levels of IU and depression, and that this relationship is particularly strong amongst females. Findings from these two Turkish studies are also corroborated by research in the United States, showing associations between IU and fear and anxiety related to COVID-19, and that IU partially accounts for relationships between OCD symptom severity and fears related to COVID-19 (Wheaton et al., 2021). This is particularly relevant, as prior research has also documented that psychiatric conditions, including mood and anxiety disorders, can greatly impact ERP measures (Bruder et al., 2002; Proudfit et al., 2015). Collectively, the evidence that the ongoing public health crisis has worsened overall wellbeing and has created a context marked by uncertainty, and that ERP measures are greatly impacted by psychiatric illnesses presents significant barriers to continuing data collection.

While an the COVID-19 pandemic has resulted in major limitations on the current project, the impact it has on a granular level should not overshadow the effect it has had on a global scale. Prior public health crises, including both the HIV/AIDS epidemic in the 1980s and the 2009 H1N1 Swine Flu pandemic were negatively associated with psychiatric symptoms and overall wellbeing (Fisman & Walsh, 1994; Page et al., 2011; Wagner &

Sullivan, 1991). Early during the COVID-19 pandemic, a group published their predictions about the impact COVID-19 would have on psychiatric health, as well as recommendations to combat the unfortunate reality they predicted (Cullen et al., 2020). Of note, they predicted that those with pre-existing mental health conditions would be at greater risk for contracting disease and experience worsening of psychiatric symptoms, and that anxiety and depressive symptoms would become more common among those with no mental health history.

Even early in the pandemic, evidence began to grow in support of these predictions, with higher levels of anxiety, depression, and stress documented and attributed directly to the pandemic (Rajkumar, 2020; Wang et al., 2020). The pandemic has also caused very specific presentations of psychiatric conditions to emerge, including OCD, where individuals experience recurrent intrusive thoughts related to contraction SARS-CoV-2, and marked anxiety that persists despite the use of compulsive behaviors (e.g. excessive washing and waiting days before opening mail) (Candelari et al., 2021). This presentation could not exist in the absence of the current pandemic. Furthermore, increased rates of alcohol use to cope with COVID-related stress, and domestic violence as a result of the pandemic have also emerged (Chodkiewicz et al., 2020; Clay & Parker, 2020; Finlay & Harms, 2020). Alcohol use and domestic violence related to the pandemic are not only acute issues, but they will likely have long-lasting impacts on both mental and physical health. The overall impact of COVID-19 on wellbeing and psychiatric health appears to affect individuals of all ages, with literature also documenting these effects in older individuals, as well as children and adolescents (Golberstein et al., 2020; Parlapani et al., 2020).

The current project has been affected by the pandemic in ways that could not be predicted, and notable attempts were made to address limitations presented by the pandemic.

Additionally, the data presented here contribute in important ways, and most notably documenting relationships between IU and physiological measures of anticipation and emotional reactivity. Lastly, the global impact on psychiatric health and overall wellbeing cannot be ignored in this document. Mental health professionals find themselves with a unique circumstance where they must help those dealing with psychiatric illness, including pathologies marked by elevated IU. Symptom severity has generally increased as a direct result of the COVID-19 pandemic. Further complicating this is the fact that mental health professionals must figuring out how to address these this same stressor in their *own* lives; unfortunately, providers are particularly vulnerable to emotional distress resulting from the pandemic (Pfefferbaum & North, 2020). The context in which we find ourselves has far reaching implications for overall wellbeing, the wellness of patients and providers, and the feasibility of carrying out laboratory research. Only when vaccines are administered on a global scale will it be possible to return to a more certain context, where research focused on uncertainty and related constructs can be examined in laboratory settings.

APPENDIX D

SELF-REPORT MEASURES FOR THE CURRENT STUDY

Intolerance of Uncertainty Scale

	Not at all characteristic of me	**A little characteristic of me**	**Somewhat characteristic of me**	**Very characteristic of me**	**Entirely characteristic of me**
1. Unforeseen events upset me greatly.	1	2	3	4	5
2. It frustrates me not having all the information I need.	1	2	3	4	5
3. Uncertainty keeps me from living a full life.	1	2	3	4	5
4. One should always look ahead so as to avoid surprises.	1	2	3	4	5
5. A small unforeseen event can spoil everything, even with the best of planning.	1	2	3	4	5
6. When it's time to act, uncertainty paralyses me.	1	2	3	4	5
7. When I am uncertain I can't function very well.	1	2	3	4	5
8. I always want to know what the future has in store for me.	1	2	3	4	5
9. I can't stand being taken by surprise.	1	2	3	4	5
10. The smallest doubt can stop me from acting.	1	2	3	4	5
11. I should be able to organize everything in advance.	1	2	3	4	5
12. I must get away from all uncertain situations.	1	2	3	4	5

APPENDIX E

LIST OF IAPS IMAGES

Neutral Images					
IAPS Image No.	Arousal	Valence	IAPS Image No.	Arousal	Valence
7950	4.94	2.28	7491	4.82	2.39
7050	4.93	2.75	2397	4.98	2.77
7705	4.77	2.65	7080	5.27	2.32
7012	4.98	3	5500	5.42	3
9360	4.03	2.63	2850	5.22	3
7025	4.63	2.71	5530	5.38	2.87
7187	5.07	2.3	7031	4.52	2.03
2890	4.95	2.95	7059	4.93	2.73
7030	4.69	2.99	5130	4.45	2.51
7090	5.19	2.61	2038	5.09	2.94
2570	4.78	2.76	7000	5	2.42
2411	5.07	2.86	7026	5.38	2.63
7004	5.04	2	7035	4.98	2.66
5740	5.21	2.59			
7233	5.09	2.77			
5731	5.39	2.74			
2440	4.49	2.63			
7006	4.88	2.33			
7161	4.98	2.98			
2840	4.91	2.43			
2480	4.77	2.66			
2393	4.87	2.93			
7150	4.72	2.61			
5510	5.15	2.82			
7700	4.25	2.95			
2190	4.83	2.41			
7040	4.69	2.69			
7185	4.97	2.64			
7179	5.06	2.88			
7041	4.99	2.6			
2880	5.18	2.96			
7100	5.24	2.89			
7053	5.22	2.95			
7060	4.43	2.55			
7234	4.23	2.96			
7140	5.5	2.92			
5520	5.33	2.95			

Unpleasant Images								
IAPS Image No.	Arousal	Valence	IAPS Image No.	Arousal	Valence	IAPS Image No.	Arousal	Valence
2691	3.04	5.85	2055.1	3.15	4.95	3212	2.79	6.57
9395	3.21	4.22	9432	2.56	4.92	3005.1	1.63	6.2
6020	3.41	5.58	9419	2.55	5.19	6315	2.31	6.38
6940	3.53	5.35	2683	2.62	6.21	6570.1	2.54	6.12
9440	3.67	4.55	9940	1.62	7.15	9320	2.65	4.93
9433	1.84	5.89	3059	1.81	6.48	6563	1.77	6.85
6241	3.42	4.54	6300	2.59	6.61	9908	2.34	6.63
2110	3.71	4.53	3150	2.26	6.55	9620	2.7	6.11
9160	3.23	5.87	3069	1.7	7.03	6350	1.9	7.29
2692	3.36	5.35	3019	2.99	6.3			
9592	3.34	5.23	6415	2.21	6.2			
2455	2.96	4.46	6570	2.19	6.24			
9390	3.67	4.14	5972	3.85	6.34			
9322	2.24	5.73	3100	1.6	6.49			
3051	2.3	5.62	3063	1.49	6.35			
3216	3.28	5.37	9414	2.06	6.49			
9920	2.5	5.76	3500	2.21	6.99			
2745.2	3.91	5.17	8485	2.73	6.46			
9230	3.89	5.77	1040	3.99	6.25			
1274	3.17	5.39	6260	2.44	6.93			
1019	3.95	5.77	3071	1.88	6.86			
9090	3.69	4.8	3068	1.8	6.77			
1202	3.35	5.94	9187	1.81	6.45			
9495	3.34	5.57	3131	1.51	6.61			
6571	2.85	5.59	1930	3.79	6.42			
9182	3.52	4.98	9622	3.1	6.26			
9008	3.47	4.45	3266	1.56	6.79			
9530	2.93	5.2	8480	3.7	6.28			
9031	3.01	4.82	6230	2.37	7.35			
9000	2.55	4.06	3053	1.31	6.91			
3215	2.51	5.44	1304	3.37	6.37			
9452	3.19	5.14	6830	2.82	6.21			
9220	2.06	4	2352.2	2.09	6.25			

Pleasant Images								
IAPS Image No.	Arousal	Valence	IAPS Image No.	Arousal	Valence	IAPS Image No.	Arousal	Valence
2216	7.57	5.83	1460	8.21	4.31	4608	7.07	6.47
2655	6.88	4.57	7488	6.19	4.96	4660	7.4	6.58
8260	6.18	5.85	8118	6.14	4.9	4677	6.58	6.19
1590	7.18	4.74	4614	7.15	4.67	4681	6.69	6.68
8600	6.38	4.26	1650	6.65	6.23	4689	6.9	6.21
4520	7.04	5.48	5621	7.57	6.99	4698	6.5	6.72
7230	7.38	5.52	5626	6.71	6.1	4220	8.02	7.17
5994	6.8	4.61	5629	7.03	6.55	1710	8.34	5.41
2339	6.72	4.16	7405	7.38	6.28	5833	8.22	5.71
2070	8.17	4.51	7650	6.62	6.15			
5660	7.27	5.07	8030	7.33	7.35			
1850	6.15	4.06	8034	7.06	6.3			
2092	6.28	4.32	8080	7.73	6.65			
4599	7.12	5.69	8158	6.53	6.49			
4641	7.2	5.43	8163	7.14	6.53			
4574	6.62	4.25	8170	7.63	6.12			
7330	7.69	5.14	8178	6.5	6.82			
4520	6.16	4.8	8179	6.48	6.99			
2030	6.71	4.54	8180	7.12	6.59			
4180	6.21	5.54	8185	7.57	7.27			
2150	7.92	5	8186	7.01	6.84			
8162	6.97	4.98	8190	8.1	6.28			
2373	6.97	4.5	8191	6.07	6.19			
4606	6.55	5.11	8200	7.54	6.35			
2362	6.74	4.6	8206	6.43	6.41			
8320	6.24	4.27	8300	7.02	6.14			
8205	6.62	4.17	8341	6.25	6.4			
4610	7.29	5.1	8370	7.77	6.73			
7291	6.35	4.81	8400	7.09	6.61			
2217	6.24	4.08	8470	7.74	6.14			
7660	6.61	5.59	8490	7.2	6.68			
4090	6.17	5.39	8492	7.21	7.31			
7489	6.54	4.49	8501	7.91	6.44			

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