1-1-2018

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Daniel Stephen Lumian
University of Denver

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Document Type

Dissertation

Degree Name

Ph.D.

Department

Psychology

First Advisor

Kateri McRae, Ph.D.

Second Advisor

Timothy Sweeny

Third Advisor

Peter Sokol-Hessner

Keywords

Binocular rivalry, Emotion, Facial expressions, Perception

Subject Categories

Experimental Analysis of Behavior | Psychology

BINOCULAR RIVALRY OF EMOTIONAL EXPRESSIONS

A Dissertation

Presented to

the Faculty of Social Sciences

University of Denver

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

Daniel S. Lumian

March 2018

Advisor: Kateri McRae, Ph.D.

Author: Daniel S. Lumian
Title: BINOCULAR RIVALRY OF EMOTIONAL EXPRESSIONS
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Acknowledgements

This dissertation would not have been possible without the help and support of numerous people. I would like to thank my advisor, Dr. Kateri McRae, for her support and guidance throughout graduate school and this dissertation project. I would also like to thank the entire Automaticity, Affect, Control and Thought Lab at the University of Denver, especially Dr. Paree Zarolia and Dustin Weilbach, for their help and support throughout the years. Thanks also to Dr. Tim Sweeny and the Visual Perception, Emotion, and Cognition Lab at the University of Denver for all their support in figuring out the mysteries of binocular rivalry. My appreciation also to Dr. Peter Sokol-Hessner and the Sokol-Hessner Lab for useful feedback throughout this project. I would also like to recognize Dr. Sarah Watamura and the Child Health and Development Lab, especially Dr. Lisa Schlueter and Dr. Marina Mendoza, at the University of Denver for starting me on my research journey.

Finally, thanks to my friends and family, especially my parents, for all their love and support throughout this process. I wouldn’t have been able to do it without you, and for that I am eternally grateful.

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Chapter One: Introduction

Defining emotion, and what constitutes an emotion, has been a persistent challenge in affective psychology (Mulligan, & Scherer, 2012) since William James first published “What is an Emotion?” in 1884. Among the most commonly posited and questioned assumptions about emotions are that they are 1) innate, 2) discrete (as opposed to continuous), 3) under volitional control and 4) that negative emotions are preferentially processed compared to positive ones (Rozin & Royzman, 2001). Emotional faces have been used to probe the nature of emotion and were used here in combination with binocular rivalry (BR) to show that a) emotional stimuli are preferentially processed compared to neutral stimuli, b) positive emotions dominate over negative ones, c) fear dominates over other negative emotions and d) that these processing biases can be modulated by volitional control in the context of BR. These findings contribute to our understanding of how emotions are structured and lend support to a categorical account of emotions.

The way that conflict is induced and resolved is one tool to investigate the nature and structure of emotions. Conflict can be defined as the competition between incongruent signals and frequently occurs in the presence of multiple sources of emotional information. Quantifying varying degrees of conflict elicited by emotional stimulus pairs can help inform models of emotions. BR offers a unique paradigm in which to investigate aspects of conflict which can help resolve questions about perceptual similarity of emotional expressions. Additionally, this paradigm allows for manipulation of both bottom-up and top-down influences to ascertain the degree to which each contribute to emotional processing.

Structure of emotion

Theoretical models. Although not the express purpose of theoreticians, theoretical models of emotion often implicitly or explicitly make predictions about the role of conflict that is present between emotions. The two primary models for describing the structure of emotion are categorical (discrete) emotion theory and continuous (circumplex) models of emotion. These models organize emotions by different criteria and therefore have differing predictions about sources of conflict and similarity in emotions.

Continuous models of emotion. Continuous models of emotion emphasize dimensional similarity between emotions. Many continuous theories are based on circumplex models which contain multiple dimensions, anchored by dichotomous pairs. Circumplex models propose *N*-dimensional spaces in which emotions exist between typically two or three dichotomies such as arousal (high or low), valence (positive or negative) or behavioral tendency (approach or avoid). Most of these models assume that emotions can be vague and overlapping, including shared physiological signals (Russell & Barrett, 1999). The most heavily studied circumplex model maps emotions along the independent dimensions of arousal and valence (e.g., Russell, 1980). Such models have been heavily supported empirically (see Barrett & Russell, 1999; Posner, Russell, & Peterson, 2005). In these models, emotions which differ along the proposed dimensions, such as opposites, should be the least similar and display the most conflict. Overall, the basic circumplex model of emotion predicts the highest level of conflict for cross-valence pairs (i.e., happiness and sadness), while within-valence pairs should be more similar, especially if both emotions are similar on another dimension, such as on arousal (i.e., fear and disgust would share qualities of high arousal and negative valence).

***Basic emotion theory*.** Basic emotion theory posits that specific emotions (e.g., fear, disgust) serve evolutionarily adaptive responses that prime behavior and carry unique psychophysiological signatures (Ekman, 1992). This prominent concept arose as early as Darwin (1872/1965; reviewed in Barrett, 2011) and assumes that emotions are: universal (e.g., shared across cultures and species); have distinct expressions (e.g., facial and physiological responses); generate automatic appraisals; and require response coherence (e.g., synchronized response across systems; Ekman, 1992). Considerable support for basic emotion theory comes from categorical classification paradigms, such as labeling emotional facial expressions (e.g., Ekman, 1993; Russell, 1994). Indeed, cross-cultural similarities in emotion facial generation and categorization was central to the concept of 'universal' emotions and suggests that such categorization processes may be, at least in part, inherent (i.e., have a genetic basis; Ekman, 1993). Theoretically, the function of emotions in motivation and behavior may best be conceptualized with discrete groupings, such as approach or avoidance behaviors, which depend on synchronized responding across levels (Carver & Harmon-Jones, 2009; Elliot & Thrash, 2002; Scherer, 2001). Restated, a coherent behavioral response (e.g., fleeing a predator) requires multiple systems act in a coordinated way, across multiple levels of processing (e.g., behavioral, psychophysiology). In basic emotion theory, conflict can arise within same-valence pairs as well as cross-valence pairs, as discrete emotions are not always assumed to lie along similarity dimensions (e.g., valence). However, discrete emotions can be imposed on continuous dimensional spaces, incorporating aspects of basic emotion theory, and discrete categorization may be adaptive at certain levels of processing (Toscano, McMurray, Dennhardt, & Luck, 2010). For example, perceptual information may be encoded continuously but perceived categorically.

***Functional emotional expressions*.** Face processing in general has been described as one of the most highly developed visual skills in humans and relies on a distributed neural network (Haxby, Hoffman, & Gobbini, 2000). Facial expressions can serve as important sources of emotional information (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003; Ekman & Friesen, 1971; Ekman 1993; Susskind et al., 2008). Evidence suggests that specific neural regions may be specialized for evaluating emotional faces belonging to discrete emotion categories (Anderson et al., 2003). For instance, the amygdala has been shown to be critical for the evaluation of fear (Adolphs, Tranel, Damasio, & Damasio, 1994; Whalen et al., 1998) and the anterior insula is specialized for disgust evaluation (Calder, Keane, Manes, Antoun, & Young, 2000; Phillips et al., 1997; Phillips et al., 1998). Susskind and colleagues showed that machine learning classifiers trained on discrete emotional expressions alone were able to produce similarity judgments consistent with human raters using six discrete emotions. This suggests that similarity in expression meaning is supported by superficial similarities in expression appearance (Susskind, Littlewort, Bartlett, Movellan, & Anderson, 2007). In other words, training on discrete facial emotions allowed for a continuous model of emotion to be computed suggesting that both models of emotion may co-exist and highlighting the importance of facial expressions in understanding emotional space.

This functional view of emotional expressions (FEE) model, which can be considered an alternative continuous emotion theory, predicts both cross- and within-valence conflict. Happiness and sadness, as in the valence-arousal circumplex model, were categorized as least similar and therefore most likely to induce conflict, consistent with the valence distinction predicted by all models of emotion discussed so far. Critically, fear and disgust are within-negative oppositional pairs, as fear serves the purpose of expanding sensory input, while disgust works to minimize it (Lee & Anderson, 2017; Susskind, Lee, Cusi, Feiman, Grabski, & Anderson, 2008). This opposition is not predicted by the valence-arousal circumplex model of emotion, as disgust and fear share valence, arousal and avoidance tendencies. If the processing of emotional expressions is influenced by the same similarity dimensions (e.g., valence, sensory functions), then it should be possible to predict differential patterns of conflict between more and less similar pairs of emotions. If conflict follows with the surface similarity as measured by Susskind et al., (2007) happiness and sadness as well as fear and disgust should show the greatest amount of conflict as they are dimensional opposites. If, however, the more basic valence-arousal based circumplex model of emotion is correct, fear and disgust should not exhibit large amounts of conflict.

Methodological concerns

Several separate literatures have measured conflict in the presence of different emotional stimuli. However, the majority of these studies are interested in documenting the conflict induced by the presence of emotional (rather than neutral) information, which distracts from the task at hand. Rarely are emotions pitted against one another in these paradigms, and when they are, typically the emotions vary in valence, so the conflict elicited by within-valence emotion pairs is vastly understudied. In addition, the use of static, single responses and forced-choice options in emotional research (e.g., labelling or categorization tasks, single bipolar ratings of affect, dot-probe) is pervasive and may be of concern when trying to measure conflict (see Cacioppo, Gardner, & Berntson, 1999; Russell & Carroll, 1999). Research using single categorical outcomes are unable to capture conflict as such paradigms only reveal the dominant, or the strongest, response (Russell, 1994). For example, labeling a face as angry reveals the strongest association but cannot inform whether other emotions (e.g., fear, happy) produced conflicting associations. Even in the case of mis-categorization (e.g., labeling an angry face as fearful), the outcome only reflects the strongest association. Although it may seem reasonable to infer that such mis-categorization suggests a functional association between two emotions (e.g., fear is more related to anger than happy if more often confused with anger than happy), these designs have difficulty quantifying the relatedness of emotional expressions and to what extent they may conflict.

Binocular rivalry

Binocular rivalry (BR) is a well-validated method for examining competing signals and has offered insight into how emotion and perception interact. BR paradigms present different images to each eye, resulting in spontaneous switching between the two percepts, although integration or mixing of the percepts can occur (Blake, 1989; Blake, 2001; Blake & Logothetis, 2002). Integration is more likely to occur when stimuli are congruent, or more similar, and dominance (gaining subjective awareness) relies on bolstering of the attended-to signal, rather than suppression of competing signal (Hohwy, Roepstorff, & Friston, 2008). That is, both percepts are encoded at lower levels of visual processing, but the signal from the dominant percept gets additional processing to achieve subjective awareness. BR allows the examination of perceptual switching while maintaining consistent retinal stimulation.

BR paradigms produce several dependent measures, including initial predominance, dominance duration, mixed predominance, mixed dominance, response latency and number of oscillations, which allow for dynamic measurement of the competitive process. Initial predominance refers to the image that gains subjective awareness first and may be a proxy for initial attentional biases (e.g., towards threat; Singer, Eapen, Grillon, Ungerleider, and Hendler, 2012). Dominance duration refers to the proportion of time a percept is perceived, and may reflect greater overall processing or strength regardless of initial preference. Additionally, integration (mixing) of the two images is possible and increases with percept similarity, possibly reflecting another distinct method of resolving conflict. Mixed predominance refers to the proportion of initial percepts that were mixed and mixed duration refers to the total amount of time that mixed percepts were perceived. Number of oscillations refers to the total switches between the two percepts. More rapid oscillation may potentially index increased competition between the two percepts. Therefore, BR paradigms allow for dynamic modeling of several key components of perception, subjective awareness and conflict.

BR models have offered considerable insight into visual awareness and suggest dissociable neural regions are associated with subjective perception and retinal stimulation. Tong and colleagues used a functional magnetic resonance imaging (fMRI)

BR task to examine conflict between faces and houses and found activation in higher-level visual processing areas, the fusiform face area (FFA) and parahippocampal place area (PPA), reflected perceptual switching even though retinal stimulation remained constant (Tong, Nakayama, Vaughan, & Kanwisher, 1998). That is, greater activity of these regions was more associated with the dominant percept, suggesting some forms of conflict are already resolved by this level. The primary visual pathway begins with lower-level encoding (e.g., spatial frequency) in V1 and V2 and proceeds to higher level feature encoding in V3, V4 (e.g., texture), and V5 (e.g., motion). More specialized processing happens in a distributed network such as face representation in the superior temporal sulcus (FFA/STS) and determining parts of a whole in the infero-temporal area (IT; reviewed in Orban, 2008). There remains debate over whether competition occurs between low-level (V1) monocular representations or later visual processing reflecting incompatible pattern matching. Current models favor the idea of competition at multiple levels with reciprocal feedback (Tong, Meng, & Blake, 2006). There is also evidence to suggest that some types of pattern coding may be more dependent on awareness than others (Sweeny, Grabowecky, & Suzuki, 2011). Taken together, the mechanisms and network models supporting BR may offer insight into the ways in which the brain hierarchically encodes and resolves competing signals to ameliorate perceptual conflict.

Stochastic resonance and binocular rivalry

Stochastic resonance (SR) is a phenomenon found in many natural and man-made systems including particle physics, machine learning and basic physiology (Moss, Ward, & Sannita, 2004; Wiesenfeld & Moss, 1995). SR models have been proposed to explain neurodynamics on both the perceptual level and as a mechanism for modeling competing and nested input systems (Braun & Mattia, 2010; Hänggi, 2002; Aihara, Kitajo, Nozaki, & Yamamoto, 2010). Stochastic resonance systems have at minimum three basic components: a weak coherent input (signal), a threshold allowing a non-linear response (discrete outcome), and at least one source of noise (Gammaitoni, Hanggi, Jung, & Marchesoni, 1998). Noise in the same frequency as the signal will function additively, bolstering the signal, while noise not aligned will dampen the signal by decreasing the signal-to-noise ratio (SNR). Bolstering of the signal can result in threshold events, achieving non-linear effects (e.g., discrete change) and has been proposed to play a role in many perceptive processes (e.g., increase SNR to reach a categorical decision; Wiesenfeld & Moss, 1995). One of the first studies to suggest an evolutionary based SR system demonstrated that paddlefish have electroreceptive fields to detect prey (signal) which are optimized by the water (external) noise levels generated by their prey (Russell, Wilkens, & Moss, 1999). In this model, the weak input from the prey is coupled with noise from the environment to optimize prey detection. However internally generated noise can also modulate signal. For example, selective attention may influence internal noise resulting in bolstered attended signals and diminished suppressed signals.

Bistable SR systems are common and offer considerable explanatory power in terms of handling and resolving competing or incongruent signals (see Braun & Mattia, 2010). Briefly, two or more signals, which can be in conflict (e.g., alternative ways of interpreting an image), are resolved through threshold events (transitions between stable-states) on the subjective awareness level while both maintain a sub-threshold signal. BR offers an example of bistable SR as it alternates between two competing percepts.

BR has been characterized as a bistable SR system where perception switches between the two percepts based on signal strength (e.g., contrast, emotionality) but with both inputs still being encoded (Kim, Grabowecky, & Suzuki, 2006). Miller and Katz (2010) found evidence for such noise-induced changes between discrete neural states when deciding on the palatableness of stimuli reflected in behavioral responses (e.g., spit or swallow). Additionally, SR systems have found support in neural models of decision-making and may be optimal given the inherent noise in both our environments and perception (Duan, Chapeau-Blodeau, & Abbott, 2014; Longtin, 1993; Miller & Katz, 2013). SR systems, especially bistable systems, may offer unique insight into general affective processing and can be understood through BR.

Bistable systems have been framed as a double-well potential, in which dynamic oscillations between the two stable states (i.e., percepts) in the system depend on the strength of the competing signals (e.g., contrast intensity, affective-content) and the current dominant (perceived percept) period cannot be predicated based on prior dynamics (Kim, et al., 2006; Richards, Wilson, & Sommer, 1994). This perceptual switching between relative stable states (threshold events) has been characterized as a bistable SR system and may be extended to affective processes. Here the input signals are the two face stimuli, coupled with internal noise, resulting in threshold perception switching between the alternative interpretations.

The laws of binocular rivalry

Four laws to explain the dynamics of binocular rivalry were proposed by Levelt (1965) and revised by Brascamp, Klink, & Levelt (2015). The revised laws according to Brascamp et al., (2015) state:

> I. Increasing stimulus strength for one eye will increase the perceptual dominance of that eye's stimulus.
> II. Increasing the difference in stimulus strength between the two eyes will primarily act to increase the average perceptual dominance duration of the stronger stimulus.
> III. Increasing the difference in stimulus strength between the two eyes will reduce the perceptual alternation rate.
> IV. Increasing stimulus strength in both eyes while keeping it equal between the eyes will generally increase the perceptual alternation rate, but this effect may reverse at near-threshold stimulus strength. (p. 27)

These laws can aid in the interpretation of the various outcome measures of BR, although it should be noted they do not address mixed percepts.

Based on laws 1 and 2, stimuli with greater predominance and dominance may be said to possess greater signal strength or salience. This increased signal strength could be due to a variety of psychological factors including whether a stimulus is a particularly good exemplar of a stimulus category or perceptual biases, such as a negativity bias. It should be noted predominance likely reflects initial processing biases, while dominance reflects greater overall processing. Predominance also appears to be more influenced by attentional manipulations than dominance durations (Dieter & Tadin, 2011). Based on law 3, when the brain perceives a stimulus pair as discrepant in their signal strength, oscillations between the percepts should be reduced. However, increasing the overall strength of the stimulus pair to both eyes, while maintaining their discrepancy, will increase oscillation rate. That is, images which the perceiver considers to be similar and strong in signal strength should result in increased oscillations. For instance, when viewing a happy and sad face, an individual who considers valence bipolar (i.e., happy and sadness are opposites, as one goes up the other of necessity goes down) may show greater oscillations than an individual who views valence as more bivariate (i.e., possible to have high levels of both happiness and sadness). Therefore, stimuli which are classified as oppositional should show greater rates of oscillation. Similarly, stimulus pairs with greater overall salience should also induce greater oscillations. For the purposes of this project, mixed perceptions are considered an index of similarity, with more similar stimulus pairs producing more mixed percepts. That is, fusion of the images by the perceivers reflects a similarity between the percepts. Reaction time may also be an index of the difference in signal strength, with faster reaction times to more discrepant stimulus pairs. That is, the more dissimilar the images, the quicker the perceiver should select a single percept to dominate.

The revised laws of binocular rivalry (Brascamp et al., 2015) can be combined with the double-well potential model for a better understanding of the dynamics underlying binocular rivalry. For example, when two identical images are viewed binocularly, or a single image is view monocularly without competing input, perception should fall into a single well and not oscillate. That is, predominance and dominance should be absolute, while oscillations or changes between the percepts are nonexistent. By comparison, when two highly dissimilar images with similar signal strength (e.g., similar on contrast and arousal but different on valence) are competing, predominance and dominance should be split between the two images with a high rate of oscillation. That is, perception should be split between the two perceptual wells with frequent alternations. When two different neutral faces are presented as compared to a neutral face and a sad face, oscillations may be similar between the two conditions or slightly lower in the neutral-sad condition, but dominance would be expected to increase for the sad face. That is, the emotional face should have a slightly deeper well, or greater salience, than the neutral face, shifting rivalry dynamics. By contrast, comparing a low arousal happy-sad stimulus pair and a high arousal happy-sad pair would likely yield similar dominance durations but a higher oscillation rate for the high arousal pair. That is, in both cases dominance may be split between the percepts, but in the high arousal cases, under Levelt's 4th law, the stimulus strength has increased resulting in increased oscillations. Therefore, the multiple outcome measures of BR can be placed within the context of a bistable, double-well potential model to help understand how stimulus pairs relate to each other.

Emotion in binocular rivalry

Although limited in volume, BR research with emotional and face stimuli has revealed several consistent results. Face stimuli are preferentially processed compared to non-face stimuli (i.e., houses; Bannerman, Milders, De Gelder, & Sahraie, 2008). Emotional stimuli as compared to neutral stimuli show preferential processing in both initial percept and total dominance for both scenes (Alpers & Pauli, 2006) and faces (Alpers & Gerdes, 2007; Bannerman, et al., 2008; Yoon, Hong, Joormann, & Kang, 2009). These effects provide converging evidence for emotional salience when combined with other paradigms showing similar biases towards attention including dot-probe tasks (Alpers & Gerdes, 2007; Staugaard, 2009) and emotional pop-out effects in visual search paradigms (Ohman, Flykt & Esteves, 2001).

Research has also begun to examine how emotion-emotion pairs are processed and to assess the role of individual differences in BR paradigms. For instance, Yoon et al., (2009) compared disgust, happy and neutral faces and found that positive expressions predominate (positivity bias) over disgust and neutral faces and that higher depressive symptoms were associated with lower emotional predominance, interpreted as increased attention paid to neutral faces. However, no within-valence pairs were studied. Research has also shown that anxious individuals are more likely to perceive threatening than positive stimuli (Gray, Adams, & Garner, 2009; Singer, et al., 2012). These results suggest that certain biases, such as a preference for faces over non-face information, may be universal, while others, such as a threat bias within faces, may be more related to clinically-relevant individual differences.

The results of top-down manipulation of binocular rivalry dynamics have been mixed (Meng & Tong, 2004; Dieter & Tadin, 2011). However, evidence exists showing sensitivity to higher cognitive and affective properties consistent with top-down influence. For example, pairing neutral faces with negative information, as compared to neutral or positive information, can increase dominance (Anderson, Siegel, Bliss-Moreau, & Barrett, 2011) but this effect remains contested (Stein, Grubb, Bertrang, Suh, & Verosky, 2017). Longer dominance for positive faces has also been observed following a positive mood induction using images (Anderson, Siegel, & Barrett, 2011). Overall, BR appears sensitive to emotional attributes of stimuli and offers potential insights into how competing signals are resolved which may depend on individual differences and whether the stimulus is subjectively perceived.

The current studies

The current studies sought to capitalize upon the competition of emotional expressions induced via BR to test competing hypotheses about cross- and within-valence conflict. Specifically, based upon the functional emotional expressions model defined by Susskind et al., (2007), I tested whether high conflict pairs (i.e., opposites such as happy-sad and fear-disgust) exhibit different patterns of perception than medium conflict pairs (i.e., happy-fear, disgust-sad) and low conflict pairs (i.e., disgust-happy and fear-sad; Table 1). Both the valence-arousal circumplex and FEE accounts of emotion predict high levels of conflict between happy and sad expressions. The valence-arousal circumplex model does not predict that fear and disgust should result in high levels of conflict, while the FEE model does. Indirect support for a categorical model of emotion may be implied if neither valence nor conflict level (perceptual distance) consistently predict perception. Additionally, after exploring normative patterns, I examined the degree to which these responses can be modulated with a top-down manipulation (i.e., directed attention).

The first aim (Study 1 and Study 2) of these studies was to replicate previously documented emotional bias effects, such that emotional faces compared to neutral faces show both predominance (i.e., are seen first more often) and dominance (i.e., are seen more overall). Emotional bias was expected for each of the test emotions: fear, disgust, happy and sad, when compared to neutral.

The second aim (Study 2) of these studies was to extend previous research by comparing emotion-emotion pairs to detect processing biases (i.e., dominance and predominance effects between emotions), differences in conflict (i.e., the number of oscillations between pairs) and differences in conflict resolution (i.e., greater mixed percepts). Based on previous BR research (Yoon et al., 2009), a positivity bias was expected such that happy would dominate and predominate over fear, disgust and sadness. For high conflict pairs compared to low conflict pairs, conflict, as indexed by oscillations, was expected to be higher and integration, or mixed perceptions, was expected to be lower. These findings address a current gap in the literature about how discrete emotions relate to and conflict with each other in a perceptual framework.

The third aim (Study 3) of the present project was to address the role of directed attention on these emotional biases. To examine the impact of top-down, directed attention on these bottom-up biases, participants were asked to focus on a specific kind of attribute (e.g., positive) and make responses about that attribute (e.g., "Are you seeing a positive face?"). This simple attentional effect was expected to increase the predominance and dominance of evaluation congruent stimuli (e.g., more likely to see a happy face when focused on positive). This effect was examined in the presence of low (happy-disgust), medium (happy-fear) and high (happy-sad) conflict pairs to explore potential interactions of conflict with directed attention.

These three aims validate previous research, use BR to explore emotional conflict and address the extent to which attentional biases can be manipulated via directed attention. The use of a task with dynamic responses across time offers several advantages over more traditional forced-choice paradigms and should allow for several indices of conflict. This work also addresses current gaps in terms of processing biases between emotional pairs, which has been much less explored than biases of emotional stimuli compared to neutral stimuli. The use of emotionally expressive faces should engage a distributed neural network (Haxby, et al., 2000) and reliably reflect how affective information is processed.

Chapter Two: Study 1

Study 1 sought to replicate prior work showing predominance and dominance of emotional faces compared to neutral faces (Alpers & Gerdes, 2007; Bannerman et al., 2008). Four emotional faces (fear, disgust, happy and sad) were compared to neutral faces using a BR paradigm with a fifth control condition that paired two identical neutral faces together. Participants were asked to report whether they were seeing an 'emotion' face, a 'neutral' face, or a 'mixed' percept in all conditions. In all conditions, except the control, it was hypothesized that emotional faces would predominate and dominate over neutral ones. These results validate stimulus selection and confirm that emotionally salient faces receive preferential processing over neutral ones.

Methods

Participants. The target sample size was made based on an estimate by G*Power for a small effect (.2) with 80% power for a repeated-measures within subject effect with 1 group and 4 observations. This yielded an estimate of 36 participants. However, to increase power and decrease type II error, guard against unusable data, and because participants were readily available, a larger sample size was recruited. Participants were 47 undergraduates from the University of Denver participating for course credit. Four participants were excluded for not completing the task, leaving 43 usable participants.

The average age of the sample was 19.23 (SD=1.27) and the sample was predominately female (N=30, 70%).

Procedure. Upon arrival for the session, participants provided informed verbal consent, before completing a few brief psychometric surveys (i.e., Beck's Depression Inventory and Beck's Anxiety Inventory). Once these were completed, participants were given instructions for the task. They were told they would see pictures of faces, instructed about the response options, and were asked to make a response as often as the image changed. Participants were taken to the experiment room and set up in the stereoscope. Participants were asked to practice making responses a few times while sitting with their head in the chin rest. Participants then completed the approximately 20-minute task, were debriefed and allowed to leave. One break was taken mid-task to allow participants to rest. All procedures were approved by the Institution Review Board (IRB) at the University of Denver.

Task and stimuli. Four Caucasian, male actors were selected from the NimStim Facial Expression set (Tottenham, Borscheid, Ellertsen, Marcus, & Nelson, 2002). Each image was displayed on a grey background and surrounded by a checkered box to facilitate spatial alignment. The same actor was presented to each eye within a trial and trials were shown twice, with stimulus-eye mapping counterbalanced. That is, if a neutral image was shown to the right eye and a sad image to the left eye, a counter-balanced trial was also presented with sad shown to the right eye and neutral to the left. A randomized color overlay of either green or red was applied to each image, such that per trial one image was always green and one was always red. Image display size was 8.5 cm by 8.5 cm (see Figure 1).

The task was Python-based and used PsychoPy (Peirce, 2009) for stimulus display. The task consisted of five conditions: neutral-neutral, fear-neutral, disgust-neutral, happy-neutral and sad-neutral. Participants initially viewed a fixation cross to allow for calibration of the stereoscope, followed by several instruction screens. Each condition had 8 trials (4 actors, shown twice) which were randomized in order and lasted 25 seconds. There was a total of 40 trials. Trials were separated by a 2 second instruction screen. Participants were instructed to report whether they were seeing an emotional or neutral face using the left and right arrow keys (response-key mappings were counterbalanced across participants). The down arrow key was used to report a mixed percept.

Apparatus. The task was displayed on a CRT screen with a resolution of 1024x768 with one image placed on each side of the screen. Participants were seated at a stereoscope approximately 115 cm from the screen with a black divider running from the stereoscope to the screen to ensure each eye only perceived a single image.

Analytic plan. Given the interdependence of duration and initial percept responses, emotional predominance and dominance were computed to reflect an emotional bias and a mixed percentage. Emotional predominance was computed as $(Predominance_{emotion} - Predominance_{neutral}) / (Predominance_{emotion} + Predominance_{neutral})$. Mixed predominance was calculated as the number of trials on which mixed was the first reported percept divided by the total number of usable trials.

Emotional dominance was calculated as $(Duration_{emotion} - Duration_{neutral})\ /$ $(Duration_{emotion} + Duration_{neutral})$. Therefore, values over 0 reflect an emotional bias and values under 0 reflect a neutral bias for predominance or dominance. Mixed dominance was calculated as the total duration of that response over the 25s period. Across all emotion conditions and for each condition, emotional dominance and predominance were tested against 0. Emotional bias was expected in all except the neutral-neutral condition.

A RMGLM with one within subject factor (condition) with four levels (fear-neutral, happy-neutral, sad-neutral, disgust-neutral) was run for emotional dominance, emotional predominance, mixed dominance, mixed predominance, response latency, and oscillations. Response latency was the initial delay before the first response. Oscillations refers to the total number of changes reported during the trial. These analyses address the degree of conflict observed between-conditions.

Results

Neutral-neutral: manipulation check. The first analyses were conducted to ensure that neutral stimuli were being reported as neutral. For neutral-neutral pairs, there was an effect of predominance, $t(42)=-14.33$, $p<.001$, $d=2.19$, such that neutral was reported more than emotion (M=-.77, SD=.35, 95% CI =[-.88, -.66]). There was also an effect of dominance, $t(42)=-13.95$, $p<.001$, $d=2.12$, such that neutral was reported more than emotion (M=-.77, SD=.34, 95% CI =[-.88, -.66]) (Table 2). These results validate that our neutral stimuli were largely rated as neutral.

Emotion-neutral. Next, all emotion-neutral conditions were tested for an overall emotional bias compared to neutral as outlined in the analytic plan. As predicted, there was an effect of emotional predominance, $t(42)=15.88$, $p<.001$, $d=2.43$ such that emotion was reported substantially more than neutral (M=.58, SD=.24, 95% CI =[.51, .65]). There was also an effect of emotional dominance, $t(42)=11.53$, $p<.001$, $d=1.76$, such that emotion was reported substantially more than neutral (M=.48, SD=.27, 95% CI =[.39, .56]). Similar dominance and predominance effects were observed in each condition as well and are reported in Table 2. These results support the hypothesis that emotions would be preferentially processed compared to neutral faces.

Separate RMGLMs, each with one within-subject factor, condition, with four levels was run for emotional predominance, emotional dominance, mixed dominance, mixed predominance, response latency and oscillations (Table 3). There was a main effect of condition on emotional predominance, $F(3, 126)=13.44$, $p<.001$, $\eta^2=.24$. This effect was driven by sad-neutral (M=.32, SD=.48, 95% CI=[.17, .46]) having less emotional predominance than disgust-neutral (M=.58, SD=.35, 95% CI=[.47, .69]), $t(42)=3.11$, $p<.005$, $d=.47$, fear-neutral (M=.70, SD=.28, 95% CI=[.61, .78]), $t(42)=4.96$, $p<.001$, $d=.76$, and happy-neutral (M=.71, SD=.36, 95% CI=[.60, 82]), $t(42)=4.86$, $p<.001$, $d=.74$. Disgust-neutral predominance was also lower than fear-neutral, $t(42)=2.35$, $p<.05$, $d=.36$, and lower than happy-neutral at the trend level, $t(42)=2.00$, $p=.051$, $d=.31$. There was also a main effect of condition on emotional dominance, $F(3, 126)=18.22$, $p<.001$, $\eta^2=.30$. This effect was driven by sad-neutral (M=.24, SD=.47, 95% CI=[.10, .39]) having less emotional dominance than both fear-neutral (M=.59, SD=.30, 95% CI=[.50, .69]), *t*(42)=5.30, *p*<.001, *d*=.81, and happy-neutral (M=.65, SD=.28, 95% CI=[.56, .73]), *t*(42)=5.80, *p*<.001, *d*=.89. Disgust-neutral (M=.40, SD=.38, 95% CI=[.28, .51]) also showed less emotional dominance than both fear-neutral, *t*(42)=4.04, *p*<.001, *d*=.62, and happy-neutral, *t*(42)=4.68, *p*<.001, *d*=.63.

There was a main effect of condition on mixed predominance, *F*(3, 126)=4.73, *p*<.005, $\eta^2 =$.10. This effect was driven by less mixed predominance in the happy-neutral condition (M=.14, SD=.14, 95% CI=[.09, .18]) than the fear-neutral (M=.18, SD=.18, 95% CI=[.13, .24]), *t*(42)=2.38, *p*<.05, *d*=.36, disgust-neutral (M=.19, SD=.23, 95% CI=[.12, .26]) , *t*(42)=2.04, *p*<.05, *d*=.31, and sad-neutral conditions (M=.25, SD=.23, 95% CI=[.17, .32]), *t*(42)=3.66, *p*<.005, *d*=.56. There was also less mixed predominance in the fear-neutral condition than the sad-neutral condition, *t*(42)=2.15, *p*<.05, *d*=.33. There was a main effect of condition on mixed dominance, *F*(3, 126)=5.52, *p*<.005, $\eta^2 =$ .12. This effect was driven by less mixed dominance in the happy-neutral condition (M=3.17, SD=3.33, 95% CI=[2.15, 4.20]) than the fear-neutral (M=4.37, SD=3.85, 95% CI=[3.47, 5.84]), *t*(42)=3.52, *p*<.005, *d*=.54, disgust-neutral (M=4.31, SD=3.78, 95% CI=[3.15, 5.48]), *t*(42)=2.07, *p*<.05, *d*=.32, and sad-neutral conditions (M=5.38, SD=4.83, 95% CI=[3.89, 6.87]) (see Table 3 for means).

There was also an effect of condition on response latency, *F*(3, 126)=4.02, *p*<.01, $\eta^2 =$.09. This effect was driven by faster responses to happy-neutral (M=2.87, SD=1.55, 95% CI=[2.39, 3.34]) than sad-neutral (M=3.49, SD=1.84, 95% CI=[2.92, 4.05]), *t*(42)=2.90, *p*<.01, *d*=.44, and disgust-neutral (M=3.36, SD=2.27, 95% CI=[2.67, 4.05]), *t*(42)=2.05, *p*<.05, *d*=.31. There were also faster responses to fear-neutral (M=3.09, SD=1.56, 95% CI=[2.61, 3.57]) than sad-neutral, *t*(42)=-2.50, *p*<.05, *d*=.38.

Finally, there was an effect of condition on oscillations, *F*(3, 126)=9.52, *p*<.001, $\eta^2 =$ .19, driven by more changes in the disgust-neutral condition (M=3.28, SD=2.58, 95% CI=[2.49, 4.08]) than the fear-neutral (M=2.21, SD=1.55, 95% CI=[1.74, 2.69]), *t*(42)=5.03, *p*<.001, *d*=.77, sad-neutral (M=2.60, SD=2.33, 95% CI=[1.87, 3.31]), *t*(42)=2.66, *p*<.05, *d*=.41, and happy-neutral conditions (M=2.49, SD=1.95. 95% CI=[1.89, 3.09]), *t*(42)=3.41, *p*<.005, *d*=.52. There were also more changes in the sad-neutral than fear-neutral condition, *t*(42)=2.10, *p*<.05, *d*=.32. Overall, these results suggest that different mechanisms of resolving conflict (e.g., integration vs. oscillation) may be employed based on percept similarity.

Discussion

Study 1 replicated prior research showing predominance and dominance for emotional faces as compared to neutral faces (Alpers & Gerdes, 2007; Bannerman et al., 2008). Emotional face stimuli receive preferential processing compared to neutral face stimuli (Bannerman et al., 2008; Yoon et al., 2009). In terms of a double-well potential model, the brain perceives emotional faces as having a deeper well, or possessing greater signal strength, than neutral faces. These data provide converging evidence, along with dot-probe tasks (Alpers & Gerdes, 2007) and visual search tasks (Ohman et al., 2001), for greater attention being allocated to emotional as compared to neutral stimuli. The between-condition analyses suggest that different types of conflict resolution may occur based on the similarity of the emotional expressions. Specifically, happy integrated the least with neutral faces while disgust and sadness integrated more as indexed by mixed predominance and mixed dominance. This implies that sad and disgust faces are perceived as more similar to neutral faces than happy or fearful faces, as mixed percepts are considered an index of similarity. There were also more oscillations for the disgust-neutral and sad-neutral conditions, than the happy-neutral and fear-neutral conditions, suggesting that these stimulus pairs were perceived as more equivalent in signal strength.

It remains unknown how attention is allocated in the presence of competing emotional stimuli. While Study 1 replicated previous research, the use of ‘emotion’ and ‘neutral’ labels cannot be employed in emotion-emotion rivalry paradigms. However, these emotion-emotion comparisons may offer insight into the relationships between emotions and allow a test of the levels of conflict predicted by different emotion theories. Therefore, it was necessary to change response options to further investigate emotion-emotion conflict and examine conflict in the context of competing models of emotion.

Chapter Three: Study 2

Study 2 sought to expand on the results of Study 1 by including emotion-emotion pairs. Specifically, the same experimental design was used but response options for each condition were changed to be the emotions portrayed (e.g., “sad” or “happy”, “fear” or “neutral”) and to “red” or “green” for the neutral-neutral condition. As in Study 1, an emotional bias in the emotion-neutral conditions in both predominance and dominance was hypothesized. No effect of color was hypothesized for the neutral-neutral condition. The three cross-valence pairs were hypothesized to show a positivity bias for happy over disgust, fear and sadness. In line with the predictions of the FEE and circumplex models, the oppositional pair of happy-sad was again expected to demonstrate the most conflict (i.e., most oscillations and least mixing). In line with the FEE model, but not in line with the circumplex model, within the negative-negative pairs, fear was expected to predominate and dominate over disgust and was hypothesized to show the most conflict and least integration. Based off the FEE model, linear effects of conflict (high, medium, low) were expected to be found in greater predominance, dominance, and oscillations and decreased mixed predominance and dominance.

Methods

Participants. The target sample size was made based on an estimate by G*Power for a small effect (.2) with 80% power for a repeated-measures within subject effect with

1 group and 4 observations. This yielded an estimate of 36 participants. However, to increase power and decrease type II error, guard against unusable data, and because participants were readily available, a larger sample size was recruited. Participants were 45 undergraduates from the University of Denver participating for course credit. 6 participants were excluded for not completing the task, leaving 39 usable participants. The average age of the sample was 19.41 (SD=1.19) and the sample was predominately female (N=27, 69%).

Procedure. The procedure was identical to Study 1 except now the task was 40 minutes long and included 3 breaks.

Task and stimuli. The stimuli were identical to Study 1. The task was identical except it now employed a blocked design, trial duration was 20s (as compared to 25s in Study 1) and response options were changed to reflect the specific emotions in each condition (e.g., "neutral" or "disgust", "fear" or "happy").

Apparatus. The apparatus was identical to Study 1.

Analytic plan. Analysis of the neutral conditions followed the analytic plan used in Study 1 with the exception that now the neutral-neutral condition was used to test color bias between red and green. To compare the emotion-emotion conditions, additional predominance and dominance calculations were required. Predominance for emotion-emotion pairs was computed as $(Predominance_{emotion1} - Predominance_{emotion2})/(Predominance_{emotion1} + Predominance_{emotion2})$. Dominance for emotion-emotion pairs was computed such that $(Duration_{emotion1} - Duration_{emotion2})/(Duration_{emotion1} + Duration_{emotion2})$.These values were tested against 0 to determine whether emotional pairs displayed stable patterns of dominance and predominance.

For the emotional pairs, a 2x3 RMGLM was conducted to examine the relationship of pair type (cross- or within-valence) and conflict type (high, medium, low; see Table 1) for predominance, dominance, mixed perceptions, mixed predominance, response latency and oscillations. As predominance and dominance have different anchors between-conditions, the absolute values of these measures were used to facilitate comparison. A main effect of conflict type was expected such that the high conflict (fear-disgust and happy-sad) pairs show the least mixing and most conflict.

Results

Neutral-neutral manipulation check. The first analyses were conducted to check whether color biased reporting on the neutral-neutral trials. For neutral-neutral pairs, there was no effect of predominance, $t(38)=-1.83$, $p>.05$, $d=.29$, such that red was not reported more than green (M=-.17, SD=.59, 95% CI=[-.37, .02]). There was also no effect of dominance, $t(38)=1.15$, $p>.05$, $d=.18$ such that red was not reported more than green (M=.06, SD=.34, 95% CI=[-.048, .17]). These results suggest that the color overlays were not biasing reporting.

Emotion-neutral. First, all emotion-neutral conditions were collapsed across to assess any emotional bias in predominance and dominance. There was an effect of predominance, $t(38)=6.05$, $p<.001$, $d=.97$, such that emotional faces were more likely to be the initial percept (M=.25, SD=.26, 95% CI=[.17, .33]). There was also an effect of dominance, $t(38)=5.67$, $p<.001$, $d=.91$, such that emotional faces were seen longer than neutral faces (M=.17, SD=.18, 95% CI=[.11, .23]). Next, the emotion-neutral pairings were examined individually and are reported in Table 4. Briefly, there were predominance and dominance effects for the fear-neutral and happy-neutral conditions, all *p*'s <.001, but not for the disgust-neutral and sad-neutral conditions (Table 4). These results offer a partial replication of the emotional bias effect observed in Study 1. Overall these effects support the expected emotional bias effects, driven primarily by happy and fearful expressions.

A RMGLM with one within subject factor, condition, with four levels was run for emotional predominance, emotional dominance, mixed predominance, mixed dominance, response latency and oscillations (Table 5). There was a main effect of condition on emotional predominance, $F(3, 114)=11.76$, $p<.001$, $\eta^2=.24$. This effect was driven by sad-neutral (M=.12, SD=.50, 95% CI=[-.04, .28]) having less emotional predominance than fear-neutral (M=.31, SD=.37, 95% CI=[.19, .43]), $t(38)=-2.29$, $p<.05$, $d=.37$, and happy-neutral (M=.48, SD=.39, 95% CI=[.36, .61]), $t(38)=-3.64$, $p<.005$, $d=.58$. Disgust-neutral (M=-.02, SD=.44, 95% CI=[-.16, .13]) also displayed less predominance than the fear-neutral, $t(38)=-3.69$, $p<.005$, $d=.59$, and happy-neutral conditions, $t(38)=-5.16$, $p<.001$, $d=.83$. There was also a stronger predominance in the happy-neutral condition than the fear-neutral condition, $t(38)=-2.06$. $p<.05$, $d=.33$.

There was a main effect of condition on emotional dominance, $F(3, 114)=16.66$, $p<.001$, $\eta^2=.31$. This effect was driven by disgust-neutral (M=-.06, SD=.30, 95% CI=[-.15, .04]) having no emotional dominance, which was significantly less than the dominance observed for fear-neutral (M=.19, SD=.27, 95% CI=[.10, .27]) , $t(38)=-3.41$.

p<.005, *d*=.55, and happy-neutral (M=.43, SD=.33, 95% CI=[.32, .54]), *t*(38)=-6.72. *p*<.001, *d*=.1.08. There was also stronger dominance in the happy-neutral condition than the fear-neutral condition, *t*(38)=3.54. *p*<.005, *d*=.57, and the sad-neutral condition (M=.05, SD=.37, 95% CI=[-.07, .17]), *t*(38)=5.12, *p*<.001, *d*=.82.

There was no significant effect of condition on mixed predominance, *F*(3, 114)=1.07, *p*>.05, $\eta^2 = .03$. There was no significant effect of condition on mixed dominance, *F*(3, 114)=.25, *p*>.05, $\eta^2 = .01$. There was no significant effect of condition on response latency, *F*(3, 114)=2.03, *p*>.05, $\eta^2 = .05$.

There was an effect of condition on oscillations, *F*(3, 114)=6.00, *p*<.005, $\eta^2 = .14$. This effect was driven by disgust-neutral (M=3.95, SD=2.99, 95% CI=[2.98, 4.92]) having more changes than both fear-neutral (M=3.04, SD=2.36, 95% CI=[2.27, 3.80]), *t*(38)=2.94, *p*<.01, *d*=.47, and sad-neutral (M=2.58, SD=1.82, 95% CI=[1.99, 3.17]), *t*(38)=3.41, *p*<.005, *d*=.55. Happy-neutral (M=3.26, SD=2.17, 95% CI=[2.56, 3.96]) also had more oscillations on average than the sad-neutral condition, *t*(38)=2.56, *p*<.05, *d*=.41. These effects replicate those observed in Study 1 for the most oscillations in the disgust-neutral condition.

Emotion-emotion. For the six emotional pairs, predominance and dominance ratios were first tested against 0 (Table 4). For the cross-valence pairs, happy predominated over disgust (M=.20, SD=.40, 95% CI=[.08, .33]), *t*(38)=3.21, *p*<.005, *d*=.51, and, at a trend level, sadness (M=.16, SD=.51, 95% CI=[-.01, .33]), *t*(38)=1.94, *p*<.10, *d*=.31. Happy did not predominate over fear (M=.05, SD=.47, 95% CI=[-.10, .20]), *t*(38)=.70, *p*>.05, *d*=.11. For the within-valence pairs, fear predominated over disgust (M=.20, SD=.50, 95% CI=[.04, .36]), $t(38)=2.57$, $p<.05$, $d=.41$, and sadness (M=.45, SD=.43, 95% CI=[.31, .59]), $t(38)=6.44$, $p<.001$, $d=1.02$. There was no significant effect of predominance for sad over disgust (M=.03, SD=.41, 95% CI=[-.10, .17]), $t(38)=.51$, $p>.05$, $d=.08$.

For the cross-valence pairs, happy dominated over disgust (M=.26, SD=.27, 95% CI=[.17, .34]), $t(38)=5.95$, $p<.001$, $d=.95$, sadness (M=.25, SD=.31, 95% CI=[.15, .35]), $t(38)=5.07$, $p<.001$, $d=.81$, and, at the trend level, fear (M=.10, SD=.33, 95% CI=[-.01, .20]), $t(38)=1.87$, $p>.10$, $d=.30$. For the within-valence pairs, fear dominated over disgust (M=.23, SD=.36, 95% CI=[.12, .35]), $t(38)=4.02$, $p<.001$, $d=.64$, and sadness (M=.26, SD=.36, 95% CI=[.14, .37]), $t(38)=4.51$, $p<.001$, $d=.72$. There was no significant effect of dominance for sad over disgust (M=.06, SD=.27, 95% CI=[-.03, .15]), $t(38)=1.39$, $p>.05$, $d=.22$.

For the emotional pairs, a 2x3 RMGLM was conducted to examine the relationship of pair type (cross or within valence) and conflict level (high, medium, low; see Table 1) for absolute predominance, absolute dominance, mixed perceptions, mixed predominance, response latency and oscillations (See Table 6 for means). There was a main effect of conflict on predominance, $F(2, 76)=10.31$, $p<.001$, $\eta^2=.21$ (Figure 2 A), but in the opposite direction as predicted. The lowest level of conflict (M=.33, SD=.26, 95% CI=[.24, .41]) had more predominance than both the high (M=.18, SD=.31, 95% CI=[.08, .28]), $t(38)=-2.11$, $p<.05$, $d=.34$, and medium conflict levels (M=.04, SD=.32, 95% CI=[-.06, .15]), $t(38)=-4.52$, $p<.001$, $d=.72$. There was also more predominance in the high compared to medium conflict level, $t(38)=2.50$, $p<.05$, $d=.40$.

There was a main effect of conflict on dominance, $F(2, 76)=10.66$, $p<.001$, $\eta^2 =$ .22 (Figure 2 B). This was driven by the medium level of conflict (M=.08, SD=.23, 95% CI=[.00, .15]) having less emotional dominance than both the high (M=.24, SD=.23, 95% CI=[.17, .32]), $t(38)=5.04$, $p<.001$, $d=.81$, and low conflict levels (M=.26, SD=.24, 95% CI=[.18, .34]), $t(38)=3.58$, $p<.005$, $d=.57$.

There was no significant effect of conflict or valence on mixed predominance.

There was an interaction of conflict and valence on mixed duration, $F(2, 76)=4.29$, $p<.05$, $\eta^2 = .10$ (Figure 3). Within the cross-valence pairs, this was driven by disgust-happy (low conflict; M=3.98, SD=3.16, 95% CI=[2.95, 5.00]) having lower mixed durations compared to both happy-sad (high conflict; M=4.80, SD=3.02, 95% CI=[3.82, 5.77]), $t(38)=-2.29$, $p<.05$, $d=.37$, and happy-fear (medium conflict; M=5.58, SD=3.56, 95% CI=[4.42, 6.73]), $t(38)=-3.53$, $p<.005$, $d=.57$. Within the within-valence pairs, there were no differences in mixed duration between fear-disgust (high conflict; M=4.06, SD=2.86, 95% CI=[3.13, 4.98]), disgust-sad (medium conflict; M=4.24, SD=2.47, 95% CI=[3.44, 5.04]), and fear-sad (low conflict; M=4.55, SD=2.96, 95% CI=[3.59, 5.51]), all *p*'s >.05.

For response latency, there was a main effect of valence, $F(2, 76)=9.71$, $p<.005$, $\eta^2 = .20$ (Figure 4). This was driven by cross-valence pairs (M=2.86, SD=1.59, 95% CI=[2.35, 3.38]) having faster responses than within-valence pairs (M=3.25, SD=1.52, 95% CI=[2.76, 3.75]), $t(38)=-3.12$, $p<.005$, $d=.50$.

For oscillations, there was a main effect of valence, $F(1, 38)=9.04$, $p<.01$, $\eta^2 =$ .19, a main effect of conflict, $F(2, 76)=6.51$, $p<.005$, $\eta^2 = .15$, and an interaction, *F*(2, 76)=6.43, *p*<.005, $\eta^2 = .15$ (Figure 5). To break down the two-way interaction, effects of conflict were examined at each level of valence (cross- and within-). For the cross-valence pairs, there was no effect of conflict on oscillations, *F*(2, 76)=1.45, *p*>.05, $\eta^2 = .04$. For the within-valence pairs, there was an effect of conflict, *F*(2, 76)=9.83, *p*<.001, $\eta^2 = .21$. This was driven by fewer changes in the fear-sad (low conflict; M=2.38, SD=1.85, 95% CI=[2.08, 3.28]) than the fear-disgust (high conflict; M=3.43, SD=2.68, 95% CI=[2.57, 4.30]), *t*(38)=-3.08, *p*<.005, *d*=.49, and the disgust-sad (medium conflict; M=3.61, SD=2.52, 95% CI=[2.79, 4.43]), *t*(38)=-3.95, *p*<.001, *d*=.63. Overall, these findings offer support of the effects observed in Study 1 and extend them to included emotion-emotion pairs. Limited support was found for linear effects of conflict, although limited to the within-valence pairs, and non-linear conflict effects were observed in predominance, dominance, and mixed duration.

Discussion

The aim of this study was to replicate the effects of Study 1 (i.e., demonstrate preferential processing of emotional compared to neutral stimuli) and expand results to include emotion-emotion pairs (e.g., establish emotion-emotion preferential processing). Results of Study 2 partially replicate those of Study 1. Specifically, emotional predominance and dominance were observed, however, they were limited to the happy and fearful expressions. This discrepancy between Study 1 and Study 2 may best be understood in terms of changing the criteria of the task. As mentioned previously, SR systems contain at minimum three components: a weak coherent input (signal), a threshold allowing a non-linear response (discrete outcome), and at least one source of noise (Gammaitoni, et al., 1998). In this model, there could be different thresholds for classifying a face as generally emotional, as in Study 1, and as a specific emotion (i.e., sad or fearful), as in Study 2. Additionally, within the emotion-neutral pairs, disgust-neutral again displayed the most oscillations of any pair, suggesting those stimulus pairs have the most similarity in terms of signal strength.

This study also assessed emotion-emotion conflict allowing me to address one central question of my project. Namely, are there stable emotion-emotion biases and if so, can their degree of conflict be indexed via the dynamic measures of binocular rivalry. Results do support processing biases, namely a positivity bias and a fear bias, but do not support the linear effects of conflict predicted by the FEE model. This suggests that specific emotional expressions may vary in their signal strength, resulting in stable perceptual biases. High conflict in the happy-sad condition is predicted by both models, while only the FEE model predicts high levels of conflict during the fear-disgust condition. Results do not strongly support either a valence-arousal circumplex model or the FEE model, but rather suggest a discrete, hierarchy of emotions such that happy expressions are preferentially processed, followed by fear, and then sad and disgust.

Now that emotion-emotion response patterns have been established, exploring the impact of top-down, directed attention on this dynamic conflict could offer insight into the degree to which such biases may be volitionally modulated. As BR paradigms are sensitive to both bottom-up and top-down processes (Anderson, et al., 2011a, Anderson, et al., 2011b), it may be possible to influence emotional conflict as it unfolds.

Chapter Four: Study 3

Study 3 examined the role of a top-down, directed attention manipulation on this binocular rivalry task by asking participants to focus on a key parameter of the stimuli with appropriate response ratings. Previous research has shown that pairing neutral faces with negative information, as opposed to neutral or positive information, can increase dominance (Anderson, et al., 2011b) and longer dominance for positive faces is observed following a positive mood induction using images (Anderson, et al., 2011a). However, yet to be examined in the context of BR is the effect of directed attention on dominance and predominance. Amygdala activation has been shown to track with stimulus attributes congruent with evaluative goals (Cunningham, Van Bavel, & Johnsen, 2008; Lumian & McRae, 2017). That is, more amygdala activation is seen in response to positive stimuli when participants focused on positive attributes than when focused on negative. Using cross-valence stimuli, allows for valence-specific directed attention which should change how the images are processed.

The three cross valence stimuli pairings were used: happy-sad, happy-fear, and happy-disgust. Three attentional goal conditions were used: no focus, focus on positivity and focus on negativity. Their respective response options were: “positive” or “negative”, “positive” or “not” and “negative” or “not”. Again, a blocked design with breaks to practice the new rating scale was employed and condition order was randomized across participants. The primary comparisons of interest were the no focus evaluation conditions with the focus positive and focus negative. Evidence of top-down control was taken as any significant difference that aligns with directed attention. That is, increased happy reported in the positive focus or more negative percepts reported in the negative focus condition as compared to the no focus condition. I hypothesized that fit effects would be observed, such that there is greater dominance and predominance for the attended to stimulus.

Methods

Participants. Based on the same power analysis as Study 1, a target sample of at least 36 people was selected. However, due to time constrains, a slightly smaller sample was recruited. Participants were 31 undergraduates from the University of Denver participating for course credit or monetary compensation. Two participants were excluded for not completing the task, and one participant was excluded for having outlying values (>3SD) on dominance ratios, leaving 28 usable participants. The sample was college-aged (M=19.85, SD=2.59) and just over half female (n=17, 59%).

Procedure. The procedure was identical to Study 2, except that different evaluative goals were explicitly given before each appropriate block of trials. Before the experiment participants were informed they would be seeing faces and be asked to change their evaluative focus of the stimuli. During the no focus condition, participants were told to give even focus to both positive and negative stimulus features and rated stimuli as either "positive", "negative", or "mixed". During the positive focus, block participants were told to focus on positive stimulus features and rated stimuli as either "positive", "not positive", or "mixed". During the negative focus block, participants were told to focus on the negative stimulus features and rated the stimuli as "negative", "not negative", or "mixed". Given the blocked design and changing response options, a break occurred each block so that participants could practice the new response options prior to that condition.

Task and stimuli. The stimuli and task used were identical to Study 2 with the following changes: responses were paired with an evaluative goal and only cross-valence stimuli were used (happy-disgust, happy-sad, happy-fear). Therefore, participants viewed each of the trials 3x (once per evaluative condition) for a total of 9 conditions.

Apparatus. The apparatus was identical to Study 1 and Study 2.

Analytic plan. Unlike Study 1 and Study 2, there was no neutral-neutral control condition to analyze. Within-condition analyses on dominance and predominance were conducted as outlined in Study 2. Response options were changed to be appropriate with the new responses (e.g., positive, negative, and mixed). Namely, dominance and predominance indices were calculated and tested for each condition against 0.

Differences in the evaluative conditions were tested using a 3x3 RMGLM for each conflict level (high/happy-sad, medium/happy-fear and low/happy-disgust) and each evaluative condition (no focus, positive and negative) for both dominance and predominance. Effects were also examined for evaluative condition and conflict level on response latency, mixed perceptions, mixed predominance and oscillations. These analyses address the degree of influence of top-down goals observed and a main effect of evaluative condition was expected. That is, dominance and predominance should show fit effects based on the evaluative goal (e.g., more positive (negative) dominance in the positive (negative) focus condition).

Results

Within-condition. Based on Study 2 results, happy was expected to predominate and dominate over disgust, fear, and sadness. The first set of analyses examined the predominance and dominance ratios within each evaluative condition. For happy predominance, as expected, there was an effect across all conditions (M=.20, SD=.21, 95% CI=[.12, .28]), $t(27)=4.98$, $p<.001$, $d=.94$. This predominance effect was observed in the no focus condition (M=.18, SD=.26, 95% CI=[.08, .28]), $t(27)=3.71$, $p<.005$, $d=.70$, the positive focus condition (M=.31, SD=.28, 95% CI=[.20, .42]), $t(27)=5.90$, $p<.001$, $d=1.11$, and in the negative focus condition (M=.13, SD=.30, 95% CI=[.02, .25]), $t(27)=2.34$, $p<.05$, $d=.43$. Means for each condition are reported in Table 7.

For happy dominance, there was an effect across all conditions (M=.18, SD=.13, 95% CI=[.13, .23], $t(27)=7.05$, $p<.001$, $d=1.33$. This dominance effect was observed in the no focus condition (M=.18, SD=.17, 95% CI=[.11, .24]), $t(27)=5.64$, $p<.001$, $d=1.06$, the positive focus condition (M=.26, SD=.23, 95% CI=[.17, .35]), $t(27)=5.81$, $p<.001$, $d=1.10$, and in the negative focus condition (M=.13, SD=.24, 95% CI=[.03, .22]), $t(27)=2.77$, $p<.05$, $d=.52$. Within each focus condition, there were effects of predominance and dominance such that positive was reported more often than negative perception. Means for each condition are reported in Table 8.

Between-condition. An effect of evaluative condition was hypothesized such that positivity biases were expected to be stronger in the positive focus condition than in the no focus condition and weaker in the negative focus groups. 3x3 RMGLM's with evaluative condition (no focus, focus positive, focus negative) and conflict level (high/disgust-happy, medium/fear-happy, and low/sad-happy) were run on predominance ratios, dominance ratios, mixed predominance, mixed dominance, response latency, and oscillations. For happy predominance, there was a main effect of evaluative condition, $F(2, 54)=5.76$, $p<.01$, $\eta^2=.18$, and a trend level main effect of conflict, $F(2, 54)=2.55$, $p<.10$, $\eta^2=.09$ (Table 7 and Figure 6 A). The effect of evaluative condition was driven by greater happy predominance in the positive focus condition (M=.33, SD=.28, 95% CI=[.22, .44]) compared to the negative focus condition (M=.12, SD=.31, 95% CI=[-.01, .24]), $t(27)=2.50$, $p<.05$, $d=.47$, and the no focus condition (M=.18, SD=.27, 95% CI=[.08, .28]), $t(27)=2.20$, $p<.05$, $d=.42$. The trend effect of conflict was driven by greater happy predominance in the high conflict, sad-happy condition (M=.27, SD=.30, 95% CI=[.16, .39]) compared to the medium conflict, fear-happy condition (M=.14, SD=.29, 95% CI=[.02, .25]), $t(27)=2.20$, $p<.05$, $d=.41$. The low conflict, disgust-happy condition (M=.19, SD=.26, 95% CI=[.09, .29]) did not differ from either of the other two conditions, all *p*'s>.05. This effect of conflict on happy predominance replicates the effects observed in Study 2, with the medium conflict, happy-fear condition showing the least predominance.

For happy dominance, there was a main effect of evaluative condition, $F(2, 54)=3.60$, $p<.05$, $\eta^2=.12$, and a main effect of conflict, $F(2, 54)=5.21$, $p<.01$, $\eta^2=.16$ (Table 8 and Figure 6 B). The effect of evaluative condition is best characterized by greater happy dominance in the positive focus condition (M=.26, SD=.23, 95% CI=[.17,

.35]) compared to the no focus condition (M=.18, SD=.17, 95% CI=[.11, .24]), *t*(27)=1.66, *p*=.11, *d*=.31, and the negative focus condition (M=.13, SD=.24, 95% CI=[.03, .22]), *t*(27)=1.89, *p*=.07, *d*=.36, although pairwise comparisons failed to reach traditional significance thresholds (*p*<.05). The effect of conflict was driven by greater happy dominance in the high conflict, sad-happy condition (M=.28, SD=.21, 95% CI=[.20, .36]) compared to the medium conflict, fear-happy condition (M=.12, SD=.21, 95% CI=[.04, .20]), *t*(27)=3.81, *p*<.005, *d*=.73, and the low conflict, disgust-happy condition (M=.15, SD=.21, 95% CI=[.07, .24]), *t*(27)=2.40, *p*<.05, *d*=.45.

There was no significant effect of evaluative focus on mixed predominance but there was an effect of conflict level, *F*(2, 54)=4.91, *p*<.05, $\eta^2 = .15$ (See Table 9 for means). The effect of conflict was driven by greater mixed predominance in the medium conflict, fear-happy condition (M=30.51, SD=20.88, 95% CI=[22.41, 38.60]) compared to the low conflict, disgust-happy condition (M=24.11, SD=19.52, 95% CI=[16.54, 31.68]), *t*(27)=2.95, *p*<.01, *d*=.56, and, at the trend level, from the high conflict, sad-happy condition (M=26.49, SD=19.42, 95% CI=[18.96, 34.02]), *t*(27)=2.02, *p*<.01, *d*=.40.

There was a main effect of conflict level on mixed dominance, *F*(2, 54)=4.73, *p*<.05, $\eta^2 = .15$. This effect was driven by the medium conflict, fear-happy condition (M=4.33, SD=2.97, 95% CI=[3.18, 5.49]) displaying more mixed dominance than the low conflict, disgust-happy condition (M=3.58, SD=2.85, 95% CI=[2.47, 4.68]), *t*(27)=2.95, *p*<.01, *d*=.56 and, at the trend level, the high conflict, happy-sad condition (M=3.86, SD=2.99, 95% CI=[2.70, 5.02]), *t*(27)=1.88, *p*<.01, *d*=.36.

There was a trend level main effect of evaluative condition on response latency, $F(2, 54)=2.54$, $p<.10$, $\eta^2=.09$. This effect was driven by a trend for faster responses in the no focus condition (M=2.53, SD=1.13, 95% CI=[2.13, 2.99]) compared to the negative focus condition (M=2.87, SD=1.30, 95% CI=[2.36, 3.37]), $t(27)=1.88$, $p<.10$, $d=.35$. The positive focus condition (M=2.69, SD=1.27, 95% CI=[2.19, 3.18]) did not differ from the other two conditions, all *p*'s>.05.

There was no significant effect of evaluative condition or level of conflict on oscillations.

Discussion

The aim of Study 3 was to ascertain the degree to which emotional biases may be modulated by top-down, directed attention instructions. This task expands on Study 2 by examining the role of directed attention using three cross-valence emotional pairs. The no-focus condition mirrored the results from Study 2 for the corresponding conditions. That is, happy predominated and dominated fear, disgust and sadness in the no focus condition. These attentional biases were expected to be modulated by top-down evaluative goals such that stronger negative (positive) dominance occurs in the negative (positive) focus condition. In line with other work on similar evaluative goals (Cunningham et al., 2008; Lumian & McRae, 2017), increased perception was expected, and found, to be given to the attended-to evaluative goal. Specifically, attending to positive attributes boosted the predominance and dominance of happy perception, while attending to negative attributes failed to change any measure of binocular rivalry. This asymmetrical effect, in line with previous work (Cunningham et al., 2008; Lumian &

McRae, 2017), suggests that it may be easier to boost positivity biases than to reduce negative biases. In terms of a SR system, these effects may have been obtained by either shifting the threshold for a given response or modulating internal noise to boost the SNR for the positive stimuli in the positive focus condition. The lack of effect for negativity suggests that positivity may be the more malleable of the two. Therefore, support was found for a modulation of positivity but not for negativity.

Chapter Five: Discussion

Emotional faces were used here in combination with BR to show that a) emotional stimuli are preferentially processed compared to neutral stimuli, b) positive emotional expressions dominate over all negative expressions, c) fear dominates over other negative expressions and d) that these processing biases can be modulated by top-down attention in the context of BR. In line with other work (Alpers & Gerdes, 2007; Bannerman, et al., 2008; Yoon, et al., 2009), Study 1 offered clear support of a processing bias favoring emotional compared to neutral faces, an effect partially replicated in Study 2. Of note, the disgust-neutral and sad-neutral comparisons showed relatively weak effects in Study 1 and no effects in Study 2, while fear-neutral and happy-neutral showed robust effects in both Study 1 and Study 2. A positivity bias was demonstrated in both predominance and dominance for both Study 2 and Study 3, replicating previous work by Yoon and colleagues (2009). In Study 2, fear was also shown to predominate and dominate over other negative emotions (i.e., sad, disgust). This fear dominance helps bolster claims for the preferential processing of fearful stimuli (see Öhman & Mineka, 2001), but is novel in the sense that there are few previous reports of within-valence emotion comparisons. Finally, Study 3 also showed that the positivity bias observed in Study 2 (and the no focus condition in Study 3) can be facilitated by asking participants to attend to positivity. This study adds to a small body of literature showing top-down manipulation effects in BR paradigms (Anderson, et al., 2011a, Anderson, et al., 2011b) and is consistent with other effects of top-down manipulation of emotional information processing (Cunningham et al., 2008; Lumian & McRae, 2017).

Emotional bias

The emotional bias observed in Study 1 and Study 2 suggests that emotional stimuli are processed preferentially or, in terms of Levelt's revised laws (Brascamp et al., 2015), have greater stimulus strength than neutral stimuli. That is, perceivers direct more attention, whether implicitly or explicitly, to certain stimulus groups. Furthermore, results suggest that happy and fearful expressions are stronger than sad and disgust faces given their greater dominance durations and more robust effects (i.e., being observed in Study 1 and Study 2). That is, perceivers are more likely to allow fearful and happy expressions to reach conscious awareness than other specific emotion categories. In terms of a double-well potential system, these effects can be explained as the emotional input having a deeper well, or greater attraction potential, than the neutral stimuli resulting in the emotional percept being dominance more often. Psychologically, this salience may be related to better or more examplars for some categories. For example, the emotional bias observed for sad and disgust in Study 1 but not Study 2 may be related to the fact that in Study 1 participants were asked to categorize faces as emotional or not, whereas in Study 2 they were asked to categorize specific emotions. That is, the category of "emotional face" may have better examplars and therefore more salience than the specific emotion labels. It may be easier for individuals to classify faces by the more general emotion-neutral criterion than by specific emotion criterion.

It was also observed that oscillations for the emotion-neutral pairs were highest for the disgust-neutral pairings in both Study 1 and Study 2. This would suggest, according to Levelt's 3rd law, that these stimuli were the most similar. In terms of a double-well system, this would mean that the competing wells were close to equivalent resulting in high levels of oscillations since perception is equally split between both wells/percepts. In these cases, the brain has trouble remaining in a stable percept because the competition between the competing wells is so strong. Whereas, for strongly mismatched stimuli, such as the happy-neutral conditions, there was more unequal dominance and fewer oscillations.

Positivity bias

The positivity bias observed in Study 2 and Study 3 suggests that positive stimuli are preferentially processed compared to negative stimuli. In a double-well potential framework, this suggests that positive stimuli have a deeper well or are stronger attractors of attention than negative stimuli. This expands on previous research which has shown an attentional bias for positive compared to neutral stimuli (Pool, Brosch, Delplanque, & Sander, 2015). Despite considerable theoretical and empirical evidence to support a negativity bias (see Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Rozin & Royzman, 2001), our results support a preferential bias towards positive stimuli. This bias was previously reported in Yoon et al., (2009) with disgust and happy facial expressions in a BR paradigm. Theoretically, a *positivity offset* has been proposed such that, at low levels of arousal, the positive motivational system responds more strongly than the negative motivational system (Cacioppo, Gardner, & Berntson, 2997; Ito & Cacioppo, 2005). There is also evidence for faster processing of positive compared to negative information (Unkelbach, Fiedler, Bayer, Stegmuller, & Danner, 2008) proposed to be driven by a higher density of positive information in memory. These data add to a growing literature on the preferential processing of positive compared to negative information, such as faster recognition for happy faces than negative emotion faces (Hugdahl, Iversen, & Johnsen, 1993; Kirita & Endo, 1995), and challenge the negativity bias observed in many psychological processes.

Fear bias

Also observed in Study 2 was a fear bias compared to sadness and disgust. This bias suggests that fearful stimuli are preferentially processed, or are stronger attractors, compared to other negative emotions and is in line with accounts of fear stimuli eliciting automatic and rapid appraisals (Ohman & Mineka, 2001). Of note, this is not a threat distinction, as disgust, which is also a threat response (Curtis, Aunger, & Rabie, 2004), failed to dominate over sadness. However, it should also be noted that research has indicated that fearful stimuli are preferentially processed compared to happy stimuli (Yang, Zaid, & Blake, 2007) and theoretically a negativity bias is strongly supported (Baumeister, et al., 2001; Rozin & Royzman, 2001). While it's hard to integrate these conflicting results, the current studies put the emotion pairs into direct competition as compared to Yang et al., (2007) in which emotion types were compared across trials under continuous flash suppression. Therefore, the presence of ambivalence, or the co-occurrence of positive and negative emotional information, may play a role in understanding these discrepant results. Overall these studies suggest a fear bias compared to other negative emotions, but not compared to positive emotions.

Structure of emotion

These studies were designed to investigate the perceptual relatedness of emotional expressions using BR. Specifically, degree of conflict, as predicted by distance in the FEE model, was expected to be indexed via the multiple outcomes of BR. Although linear effects supporting the FEE model were not found (e.g., increased mixed perception with decreasing distance), the multiple assessments of BR did offer novel insight into how emotional conflict is resolved. Predominance and dominance effects were found for emotional compared to neutral stimuli, for positive compared to negative stimuli and for fear over disgust and sadness. These effects offer insight into how the brain encodes competing signals and resolves emotional conflict. Differences in mixed perceptions were also found for some stimulus pairs, suggesting different ways of resolving perceptual conflict (e.g., happy-neutral had less mixing than other stimulus pairs in Study 1). Increased mixed percepts in this context were considered indices of similarity, with stimuli pairs which are perceived as more similar yielding greater mixed perceptions. From a double-well potential framework, mixed perceptions may arise from an overlap of the two perceptual wells. Oscillations may index a different aspect of conflict, as oscillations were highest in the disgust-neutral condition in Study 1 and Study 2 compared to the other emotion-neutral conditions. No other measures showed the strongest effects for the disgust-neutral condition. This effect, interpreted in Levelt's 3rd proposition (discussed above; Brascamp et al., 2015), resulted from very similar stimuli strength of the percept pairs. That is, the brain encodes them similarly. Also of note, in Study 2 there were more oscillations for cross-valence as compared to within-valence pairs. This effect is likely due to the oppositional nature of positive and negative valence, which may result in greater mutual inhibition and therefore faster adaptation between the attractor states. In terms of Levelt's revised 4th proposition (Brascamp et al., 2015), these oppositional pairs are perceived as having higher competing signal strength than within valence pairs. Despite the lack of clear support for either a valence-arousal or FEE dimensional model of emotion, BR remains useful as a tool for investigating emotional conflict.

Because the results from these studies fail to unambiguously support either dimensional model, they may be interpreted as support for discrete emotion theory. The valence-arousal model would have been supported by strong cross-valence effects and the FEE model would have been supported by strong linear conflict effects. Lack of consistent effects may suggest that the target emotions are not organized in a continuous way, therefore indirectly supporting a categorical model of emotion. One argument for discrete emotion theories is that some neural regions appear partially specialized for evaluating specific categories of emotion. The amygdala is thought to be critical for fear evaluation (Adolphs et al., 1994; Whalen et al., 1998) and the anterior insula for disgust evaluation (Calder, et al., 2000; Phillips et al., 1997; Phillips et al., 1998). Response to happy faces have also been documented in the amygdala (Breiter, et al., 1996), however, its likely smiling faces, as a form of social reward (Shore & Heerey, 2011), recruit additional reward related circuitry, such as the striatum (Izuma, Saito, & Sadato, 2008). Responses to sad faces have been observed in the amygdala (Blair, Morris, Frith, Perrett, & Dolan, 1999), however, the subcallosal cingulate is also commonly associated with sadness (Phan, Wager, Taylor, & Liberzon, 2002). Specific neural substrates for each emotion may suggest that they do not operate in a continuous space (i.e., there are not valence and arousal substrates) but rather have unique idiosyncratic relationships to each other. However, emotion localization remains controversial and more recent theories implicate large brain networks as underlying emotion processing (Barrett & Satpute, 2013; Chang, Gianaros, Manuck, Krishnan, & Wager, 2015). Therefore, these results could suggest either localized competition between neural regions or competition within a more general emotion network.

Top-down influences

Top-down influences (i.e. directed attention) can greatly impact visual processing (Gilbert & Li, 2013). Despite this fact, prior researchers have suggested that BR paradigms are more influenced by bottom-up than top-down influences (Meng & Tong, 2004; Dieter & Tadin, 2011). Contrary to these claims, in Study 3 we found support for top-down modulation of high-level visual stimuli (i.e., face stimuli) by manipulating the response options and attention to particular stimulus features. Specifically, perception of positive stimuli was facilitated when response options emphasized positivity, while no change was observed when response options emphasized negativity. This effect suggests that the positivity bias observed in Study 2 may be malleable and under the influence of top-down mechanisms. In terms of a SR system, these effects can be explained as either a shifting of the threshold or modulation of internal noise to bolster the attended to signal. As a double-well potential system, this can be conceptualized either as an explicit deepening of the attended to well or a slight tilting of the wells which biases perception towards the attended to percept. These results replicate asymmetrical influences of top-down manipulations on emotion processing (Cunningham et al., 2008; Lumian & McRae, 2017). It is unknown whether this asymmetry indicates natural prioritization of positivity from the top-down or merely that the attended-to stimulus attributes receive preferential processing, an effect that could be mediated by the amygdala, which feeds back into visual cortex processing (Adolphs, 2004). Also of note was the lack of emotion domination for sad and disgust faces in Study 2, which failed to replicate the emotional bias observed in Study 1. It is possible that changing response options that were used in Study 2 (compared to Study 1), while holding the stimuli constant had an impact on task performance. Specifically, it's possible that the more general emotion-neutral response options used in Study 1 directed attention in a way that emphasized emotion vs. neutral differences, while the specific emotion labels used in Study 2 might have resulted in a higher criterion for selection. That is, individuals may be more willing to classify a face as generally emotional (or not neutral) than as a specific emotion. It is also possible that changing from a randomized trial order to a blocked-design altered performance on the task. Therefore, it is important to consider response options, directed attention, trial order and potential framing effects when conducting BR future studies.

Limitations

There are several limitations to the current studies. First, the face stimuli used are not the same as those used by Susskind et al., (2007) whose model was the basis for the hypothesized perceptual differences. Use of the NimStim set added more variability in data collected as the facial expressions were not as standardized, classified with the Facial Action Coding System (FACS), or staged as those used previously. However, use of the NimStim did help to generalize from previous BR research (e.g., Bannerman et al., 2008, Yoon et al., 2009) which employed different face sets (e.g., from Ekman & Friesen, 1976). The emotional bias and positivity bias observed with the NimStim faces helps generalize from previous research through the use of a novel stimulus set. Future research may want to include better controlled face stimuli, such as schematic faces.

The stimuli used in the current design were also not balanced for luminance and contrast, nor were the color overlays, which could bias results. However, our neutral-neutral comparisons from Study 2 support the concept that the color overlays were not strong enough to drive effects. The stimuli used were also all Caucasian males, which could limit generalizability as emotions are differentially attributed by gender (Plant, Hyde, Keltner, & Devine, 2000). The samples were also largely female which could bias results as women are generally better at recognizing facial emotions (Hoffman, Kessler, Eppel, Rukavina, & Traue, 2010). These potentially biases could be addressed with the use of different stimuli, or hypotheses about gender differences could be tested by fully crossing perceiver gender and target gender.

This research can also only address the structure of perception of facial emotion expression and not induced or felt emotions, although it is possible that they follow the same structure. Future research will need to examine whether induced emotional experiences show similar patterns of conflict and/or integration. Utilizing a similar design but with non-face stimuli, such as IAPS images (e.g., Alpers & Pauli, 2006), could help expand the scope of the current work.

Another potential limitation of this work is the mixed results from Study 2, which only partially support previously replicated emotional bias effects (Alpers & Gerdes, 2007; Bannerman et al., 2008). That is, no emotional bias effect was observed for the disgust-neutral and sad-neutral pairings in Study 2. These results suggest that changing the response options, even while holding the stimuli constant, can drastically impact the nature of the task. While unexpected and hard to integrate with the other study results, this effect, combined with the results of Study 3, may build evidence against conclusions from prior research arguing that BR paradigms are more influenced by bottom-up than top-down influences (Meng & Tong, 2004; Dieter & Tadin, 2011).

Finally, in Study 3 two variables were manipulated simultaneously. Namely, both explicit focus instructions were given as well as different response options. Ideally, these two effects could be manipulated separately to examine the role of merely changing response options versus also explicitly changing evaluative goal. However, as top-down effects are generally weak in BR paradigms (Meng & Tong, 2004), the inclusion of two relatively subtle changes seemed appropriate. It is possible also that the effects observed in Study 3 reflect a demand effect, rather than changes in actual perception. That is, participants may have shifted their response threshold based off instructions rather than changes in perception. However, if this were the case, a symmetrical effect might be expected as the demands were the same for the positive and negative focus conditions.

Future directions

Follow-up research on these phenomena could come in several forms. The inclusion of neuroimaging methodology (i.e., fMRI) with this paradigm could help investigate the neural mechanisms of emotional conflict and neural regions more associated with perceptual switching between emotions. For instance, certain neural regions such as the dorsal anterior cingulate cortex may show greater activation when resolving high vs. low conflict emotional stimuli (Botvinick, Cohen, & Carter, 2004). Additionally, regions which demonstrate some specificity in response to certain emotions (e.g., the anterior insula with disgust; Calder et al., 2000; Phillips et al., 1998) may show perceptual switching despite retinal stimulation remaining constant throughout the task. Emotion localization is controversial and alternative models propose more general emotional processing regions (see Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012) or whole-brain patterns which better reflection emotional experiences (Chang, et al., 2015). These measures would add another level of discrimination in organizing emotional space.

Future research could also examine emotional space using non-face stimuli in emotion-emotion pairs to better understand emotional space (Alpers & Pauli, 2006). For instance, do disgust and fear inducing scenes show similar dynamics to disgust and fear faces in a BR paradigm? Such research would extend these implications from facial perception only to a more general emotion model.

Conclusion

Using dynamic measurements can more fully characterize conflict, which can help test theories of perceptual distance offered by different models of emotion. Binocular rivalry is an ideal paradigm for examining such conflict. Conflict, in the current paradigms, reflects perceptual closeness, or the ability of two competing stimuli to be integrated. Although results failed to conclusively support either of the proposed continuous models of emotion (i.e., circumplex and FEE), the positivity and fear biases observed offer support for a hierarchy of emotional processing which may be supported by a neural hierarchy. For instance, these results support the concept that positive stimuli are preferentially processed compared to negative stimuli. These results can be interpreted in terms of a discrete emotion model which prioritizes happy and fearful stimuli compared to disgust, sad and neutral stimuli. Importantly these biases can be modulated by top-down influences, such that attended to attributes receive additional processing. This effect was observed for positive, the dominant signal, but not negative, the weaker signal, stimuli. Overall, these results suggest that BR is an appropriate mechanism for probing the nature of emotion and future research should expand upon this work with other emotional stimuli.

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Appendix A: Tables

Table 1. Emotion-Emotion Pairs 3x2 Design

	Cross-valence	Within-valence
High Conflict	Happy-Sad	Fear-Disgust
Medium Conflict	Happy-Fear	Disgust-Sad
Low Conflict	Happy-Disgust	Fear-Sad
Emotion-emotion pairs arranged by valence and conflict level according to the FEE model. Cross-valence pairs include happy with a negative emotion and within-valence pairs include two negative emotions. High conflict pairs are more perceptually dissimilar than low conflict pairs.		

Table 2. Study 1 Within-Condition Effects

Condition	Measure	*t* statistic	*p* statistic	Cohen's *d*	Means (SD)		
					Emotion	Neutral	Mixed
Disgust-Neutral	Predominance (%)	*t*(42)=10.95	<.001	1.67	61.92 (18.89)	18.80 (15.63)	19.28 (22.70)
	Dominance (s)	*t*(42)=6.86	<.001	1.05	11.83 (3.74)	5.58 (3.87)	4.31 (3.78)
Fear-Neutral	Predominance (%)	*t*(42)=16.27	<.001	2.48	68.85 (17.50)	12.79 (11.73)	18.36 (17.95)
	Dominance (s)	*t*(42)=11.56	<.001	1.96	14.15 (3.91)	3.19 (2.58)	4.65 (3.85)
Happy-Neutral	Predominance (%)	*t*(42)=12.97	<.001	1.98	74.29 (21.56)	12.00 (14.51)	13.70 (14.38)
	Dominance (s)	*t*(42)=15.23	<.001	2.34	15.93 (4.23)	3.07 (2.53)	3.23 (3.35)
Sad-Neutral	Predominance (%)	*t*(42)=4.39	<.001	0.67	49.58 (19.88)	25.71 (18.79)	24.71 (22.74)
	Dominance (s)	*t*(42)=3.43	.001	0.51	10.25 (4.35)	5.97 (4.32)	5.38 (4.83)
Neutral-Neutral	Predominance (%)	*t*(42)=-14.33	<.001	2.19	9.59 (13.59)	76.74 (24.93)	13.66 (21.27)
	Dominance (s)	*t*(42)=-13.95	<.001	2.12	1.88 (3.01)	17.22 (5.29)	2.79 (4.29)

Table 2 shows means for dominance in seconds and predominance as percent of total trials. T-test statistics for all emotion-neutral conditions in Study 1 are reported as tested against 0. Overall effects were observed for all conditions for both dominance and predominance. Positive t-statistics reflect emotion being the more commonly reported percept.

Table 3: Study 1 Results Between-Condition Effects

Measure	*F* statistic	*p* statistic	Partial Eta Squared	Means (SD)			
				Disgust-Neutral	Fear-Neutral	Happy-Neutral	Sad-Neutral
Predominance Ratio	*F*(3, 126)=13.44	<.001	0.24	.58 (.35)[abc]	.70 (.28)[ad]	.71 (.36)[be]	.32 (.48)[cde]
Dominance Ratio	*F*(3, 126)=18.22	<.001	0.30	.40 (.38)[ab]	.59 (.30)[ac]	.65 (.28)[bd]	.24 (.47)[cd]
Mixed Predominance (%)	*F*(3, 126)=4.73	<.005	0.11	19.28 (22.69)[a]	18.35 (17.94)[bc]	13.70 (14.38)[abd]	24.71 (22.74)[cd]
Mixed Dominance (s)	*F*(3, 126)=5.52	<.005	0.12	4.31 (3.78)[a]	4.66 (3.85)[b]	3.18 (3.33)[abc]	5.38 (4.83)[c]
Response Latency (s)	*F*(3, 126)=4.02	<.01	0.09	3.36 (2.24)[a]	3.09 (1.56)[b]	2.87 (1.55)[ac]	3.49 (1.84)[bc]
Oscillations	*F*(3, 126)=9.52	<.001	0.19	3.28 (2.58)[abc]	2.22 (1.55)[ad]	2.49 (1.95)[b]	2.60 (2.33)[cd]

Results for the between-condition RMGLM's are reported here. Higher predominance and dominance scores reflect greater emotional bias. Significant ($p<.05$) pairwise comparisons are marked row-wise with the same superscript.

Table 4: Study 2 Results Dominance and Predominance

Condition	Measure	*t* statistic	*p* statistic	Cohen's *d*	Means (SD)		
					Emotion1	Emotion2	Mixed
Disgust-Neutral	Predominance (%)	*t*(38)=-0.23	>.05	.04	37.62 (21.22)	36.98 (20.49)	25.40 (25.89)
	Dominance (s)	*t*(38)=-1.15	>.05	.18	6.48 (2.99)	6.56 (2.28)	4.06 (3.50)
Fear-Neutral	Predominance (%)	*t*(38)=5.28	<.001	.85	50.65 (18.21)	27.10 (14.68)	22.23 (19.92)
	Dominance (s)	*t*(38)=4.32	<.001	.69	7.86 (2.61)	5.09 (1.92)	4.08 (2.46)
Happy-Neutral	Predominance (%)	*t*(38)=7.71	<.001	1.23	58.65 (19.90)	22.12 (17.32)	19.23 (20.65)
	Dominance (s)	*t*(38)=8.14	<.001	1.30	9.88 (3.29)	3.85 (2.45)	3.67 (2.82)
Sad-Neutral	Predominance (%)	*t*(38)=1.53	>.05	.24	41.16 (21.75)	34.08 (22.72)	24.76 (23.53)
	Dominance (s)	*t*(38)=0.80	>.05	.13	6.92 (3.03)	6.10 (3.19)	3.89 (3.16)
Disgust-Happy	Predominance (%)	*t*(38)=-3.21	<.005	.51	29.49 (18.25)	44.55 (19.41)	25.96 (21.91)
	Dominance (s)	*t*(38)=-5.95	<.001	.95	4.89 (2.38)	8.37 (2.53)	3.98 (3.16)
Fear-Happy	Predominance (%)	*t*(38)=-0.70	>.05	.11	31.73(18.55)	35.90 (20.52)	32.37 (23.94)
	Dominance (s)	*t*(38)=-1.87	>.05	.30	5.18 (2.42)	6.43 (2.93)	5.58 (3.56)
Happy-Sad	Predominance (%)	*t*(38)=1.94	>.05	.31	39.42 (19.35)	28.53 (17.19)	32.05 (21.42)
	Dominance (s)	*t*(38)=5.07	<.001	.81	7.65 (2.46)	4.81 (2.46)	4.80 (3.02)
Fear-Sad	Predominance (%)	*t*(38)=6.44	<.001	1.03	52.56 (21.68)	19.55 (16.92)	27.88 (21.55)
	Dominance (s)	*t*(38)=4.51	<.001	.72	7.88 (2.95)	4.50 (2.43)	4.55 (2.96)
Disgust-Sad	Predominance (%)	*t*(38)=-0.51	>.05	.08	35.05 (15.97)	39.55 (19.92)	25.40 (15.54)
	Dominance (s)	*t*(38)=-1.39	>.05	.22	5.94 (2.00)	6.72 (2.57)	4.24 (2.47)
Disgust-Fear	Predominance (%)	*t*(38)=-2.57	<.05	.41	30.97 (20.76)	44.52 (21.90)	24.52 (23.94)
	Dominance (s)	*t*(38)=-4.02	<.001	.64	4.81 (2.25)	7.83 (2.99)	4.08 (2.86)
Red-Green	Predominance (%)	*t*(38)=-1.83	>.05	.29	33.97 (25.83)	23.72 (22.36)	42.31 (29.47)
	Dominance (s)	*t*(38)=-1.15	>.05	.18	5.79 (3.27)	4.86 (3.03)	6.94 (3.98)

Table 4 shows means for dominance in seconds and predominance as percent of total trials. T-test statistics for all conditions in Study 2 are reported as tested against 0. Positive t-statistics reflect Emotion 1 being the more commonly reported percept. Low, medium and high conflict pairs are highlighted in light grey, grey and dark grey respectively.

Table 5: Study 2 Results Between Emotion-Neutral Condition Effects

Measure	*F* statistic	*p* statistic	Partial Eta Squared	Means (SD)			
				Disgust-Neutral	Fear-Neutral	Happy-Neutral	Sad-Neutral
Predominance Ratio	*F*(3, 114)=11.76	<.001	0.24	-.02 (.44)^{ab}	.31 (.37)^{acd}	.48 (.39)^{bce}	.12 (.50)^{de}
Dominance Ratio	*F*(3, 114)=16.66	<.001	0.31	-.06 (.30)^{ab}	.19 (.27)^{ac}	.43 (.33)^{bcd}	.05 (.37)^{d}
Mixed Predominance (%)	*F*(3, 114)=1.07	>.05	.03	25.32 (25.89)	22.22 (19.92)	19.23 (20.65)	24.73 (23.54)
Mixed Dominance (s)	*F*(3, 114)=.25	>.05	.01	4.05 (3.50)	4.07 (2.46)	3.67 (2.82)	3.88 (3.16)
Response Latency (s)	*F*(3, 114)=2.03	>.05	.05	3.00 (1.60)	3.07 (1.98)	2.70 (1.51)	3.18 (1.53)
Oscillations	*F*(3, 114)=6.00	<.005	.14	3.95 (2.99)^{ab}	3.04 (2.36)^{a}	3.26 (2.17)^{c}	2.58 (1.82)^{bc}

Results for the emotion-neutral pairs between-condition RMGLM's. Higher predominance and dominance scores reflect a stronger emotional bias. Significant (p<.05) pairwise comparisons are marked row-wise with the same superscript.

Table 6: Study 2 Emotion-Emotion Condition Effects Means and SDs

	Means (SD)					
Valence	Cross			Within		
Conflict	Low	Medium	High	Low	Medium	High
Measure	Happy-Disgust	Happy-Fear	Happy-Sad	Fear-Sad	Sad-Disgust	Fear-Disgust
Predominance Ratio	.20 (.40)[c]	.05 (.47)[b]	.16 (.51)[a]	.45 (.43)[abcde]	.03 (.41)[e]	.20 (.50)[d]
Dominance Ratio	.26 (.27)[ce]	.10 (.33)[acd]	.25 (.31)[ab]	.26 (.36)[dg]	.06 (.27)[befg]	.23 (.36)[f]
Mixed Predominance (%)	25.96 (21.91)	32.37 (23.94)[cd]	32.05 (21.42)[ab]	27.89 (21.55)	25.36 (15.54)[bd]	24.47 (23.94)[ac]
Mixed Dominance (s)	3.98 (3.16)[abe]	5.58 (3.56)[bcd]	4.80 (3.02)[a]	4.55 (2.96)	4.24 (2.47)[d]	4.06 (2.86)[ce]
Response Latency (s)	2.85 (1.89)[c]	2.90 (1.55)[b]	2.84 (1.62)[a]	3.17 (1.55)	3.19 (1.57)	3.40 (1.82)[abc]
Oscillations	3.76 (2.46)[c]	3.83 (2.53)[b]	3.53 (2.62)[a]	2.68 (1.85)[abcde]	3.61 (2.52)[e]	3.43 (2.68)[d]

Results for the emotion-emotion pairs between-condition RMGLM's are reported here. Cross-valence pairs included pairs with happy and a negative emotion. Within-valence pairs were also two negative emotions. Low, medium and high conflict are defined by the FEE model. Significant ($p<.05$) pairwise comparisons are marked row-wise with the same superscript. Low, medium and high conflict pairs are highlighted in light grey, grey and dark grey respectively.

Table 7: Study 3 Happy Predominance Means and SDs

	Means (SD)		
Trial Type	Negative Focus	No Focus	Positive Focus
Happy-Disgust	0.20 (.42)	0.09 (.41)	0.29 (.44)
Happy-Fear	-0.04 (.45)	0.15 (.40)	0.30 (.44)
Happy-Sad	0.17 (.60)	0.28 (.38)	0.39 (.38)

Predominance means for each evaluative condition and trial type Higher scores reflect a stronger happy bias. All trial types are cross-valence. Low, medium and high conflict pairs are in light grey, grey, and dark grey respectively.

Table 8: Study 3 Happy Dominance Means and SDs

	Means (SD)		
Trial Type	Negative Focus	No Focus	Positive Focus
Happy-Disgust	0.13 (.33)	0.15 (.17)	0.19 (.38)
Happy-Fear	0.00 (.35)	0.12 (.23)	0.23 (.33)
Happy-Sad	0.23 (.32)	0.25 (.31)	0.35 (.30)

Dominance means for each evaluative condition and trial type. Higher scores reflect a stronger happy bias. All trial types are cross-valence. Low, medium and high conflict pairs are in light grey, grey, and dark grey respectively.

Table 9: Study 3 Mixed Predominance Means and SDs

	Means (SD)		
Trial Type	Negative Focus	No Focus	Positive Focus
Happy-Disgust	24.55 (21.10)	22.32 (25.08)	25.45 (25.11)
Happy-Fear	32.59 (24.38)	28.13 (22.47)	30.80 (29.95)
Happy-Sad	28.13 (25.60)	25.00 (23.32)	26.34 (26.21)

Mixed predominance means for each evaluative condition and trial type. Higher scores reflect more mixed initial percepts. All trial types are cross-valence. Low, medium and high conflict pairs are in light grey, grey, and dark grey respectively.

Appendix B: Figures

Figure 1. Example Trial

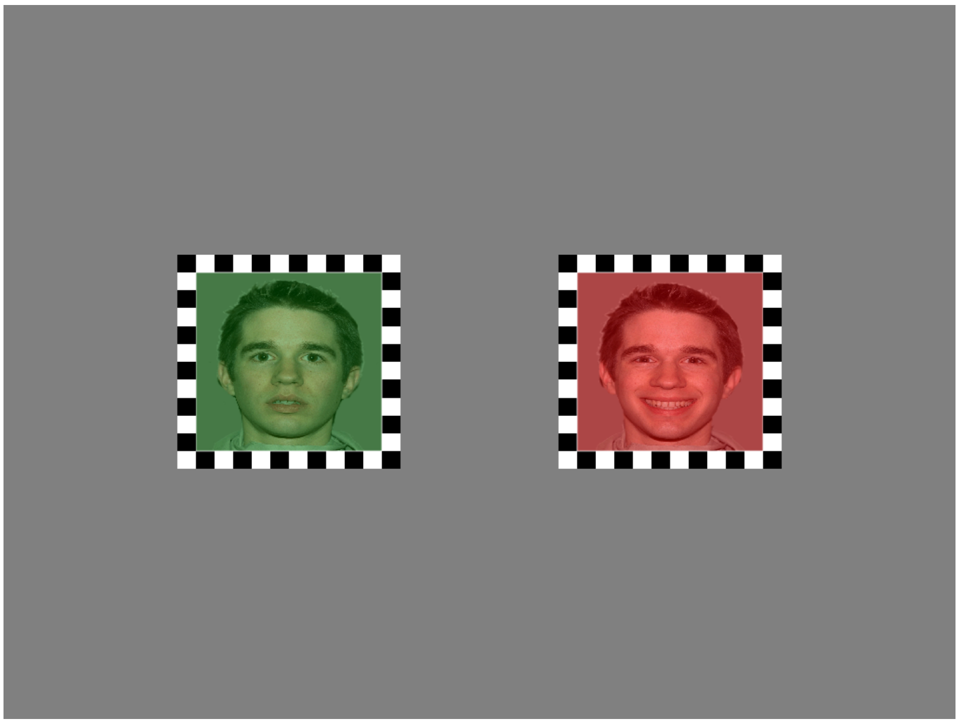

Figure 1. This figure shows an example trial from the binocular rivalry task. The task was displayed via a stereoscope with a black divider to ensure that only one image was shown to each eye. The left image shows a green, neutral face, while the right portrays a red, happy expression. Color overlays were randomized across trials, but within each trial one image was always red and the other green.

Figure 2: Study 2 Emotion-Emotion Predominance and Dominance

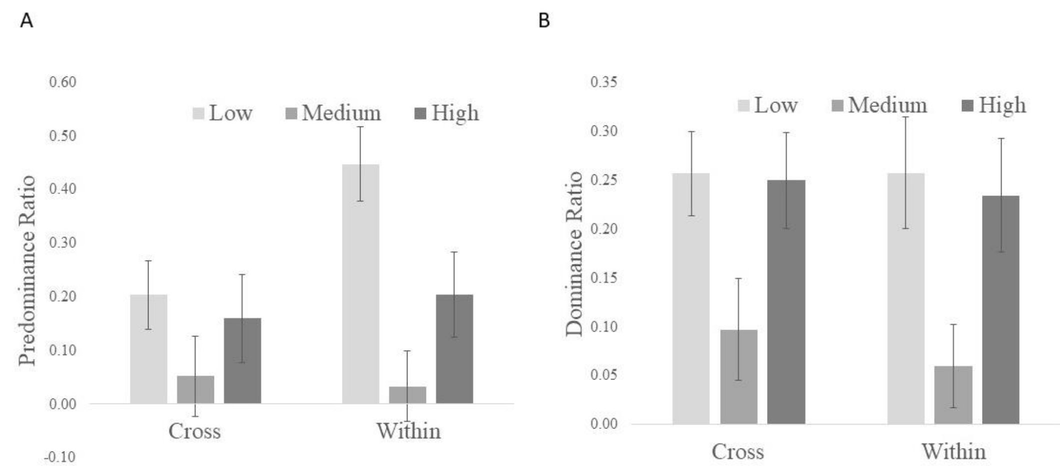

Figure 2. A) Predominance ratios for emotion-emotion pairs broken down by cross- or within-valence and conflict level. Predominance was calculated as $(Predominance_{emotion1} - Predominance_{emotion2})/\,(Predominance_{emotion1} + Predominance_{emotion2})$. As different anchors were used in the emotion-emotion pairs, the absolute value of each predominance ratio was taken to facilitate comparison. The medium conflict pairs (happy-fear and disgust-sad) displayed the least predominance, followed by the high conflict pairs (happy-sad and fear-disgust), and the largest predominance ratios were observed in the low conflict pairs (happy-disgust, fear-sad). B) Dominance ratios for emotion-emotion pairs broken down by cross- or within-valence and conflict level. Dominance was calculated as $(Dominance_{emotion1} - Dominance_{emotion2})/\,(Dominance_{emotion1} + Dominance_{emotion2})$. As different anchors were used in the emotion-emotion pairs, the absolute value of each dominance ratio was taken to facilitate comparison. There was a main effect of conflict driven by the medium conflict pairs (happy-fear, disgust sad) have lower dominance ratios than either the high conflict pairs (happy-sad, fear-disgust) or low conflict pairs (happy-disgust, fear-sad).

Figure 3: Study 2 Emotion-Emotion Mixed Duration

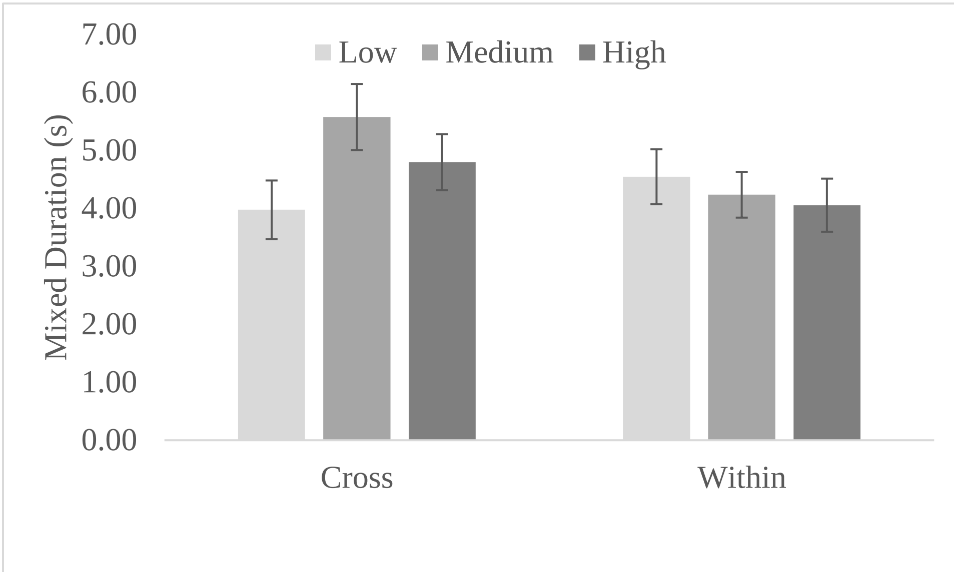

Figure 3. Mixed dominance, in seconds, for emotion-emotion pairs broken down by cross- or within-valence and conflict level. There was an interaction of conflict and valence type driven by the medium conflict, cross-valence pair (happy-fear) having greater mixed dominance than either the low conflict cross-valence pair (happy-disgust) or the high conflict, cross valence pair (happy-sad). There were no differences between the three within-valence pairs (low conflict: fear-sad, medium conflict: disgust-sad, high conflict: fear-disgust).

Figure 4: Study 2 Emotion-Emotion Response Latency

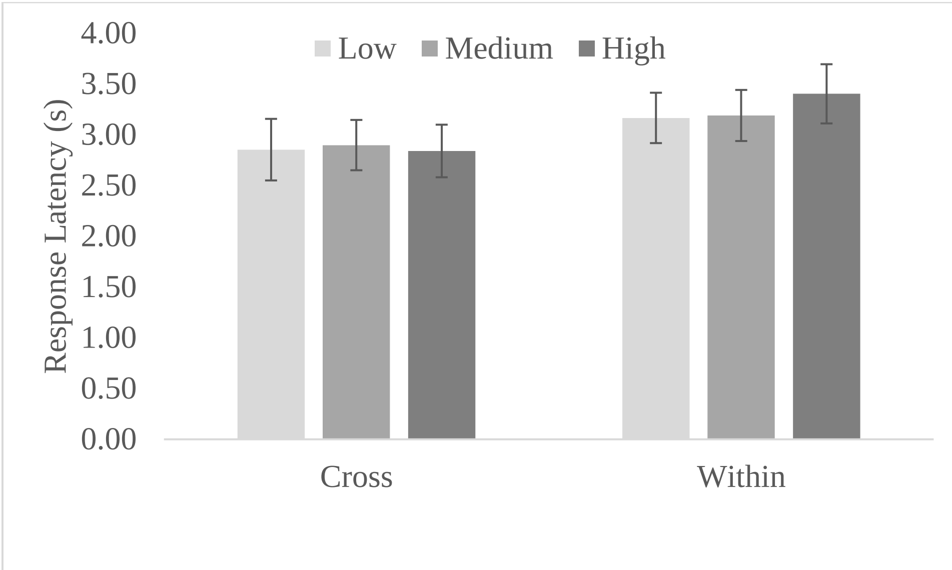

Figure 4. Response latency, in seconds, for emotion-emotion pairs broken down by cross- or within-valence and conflict level. Response latency was shorter for cross-valence (happy-sad, happy-fear, happy-disgust) than within-valence pairs (fear-disgust, disgust-sad, fear-sad).

Figure 5: Study 2 Emotion-Emotion Oscillations

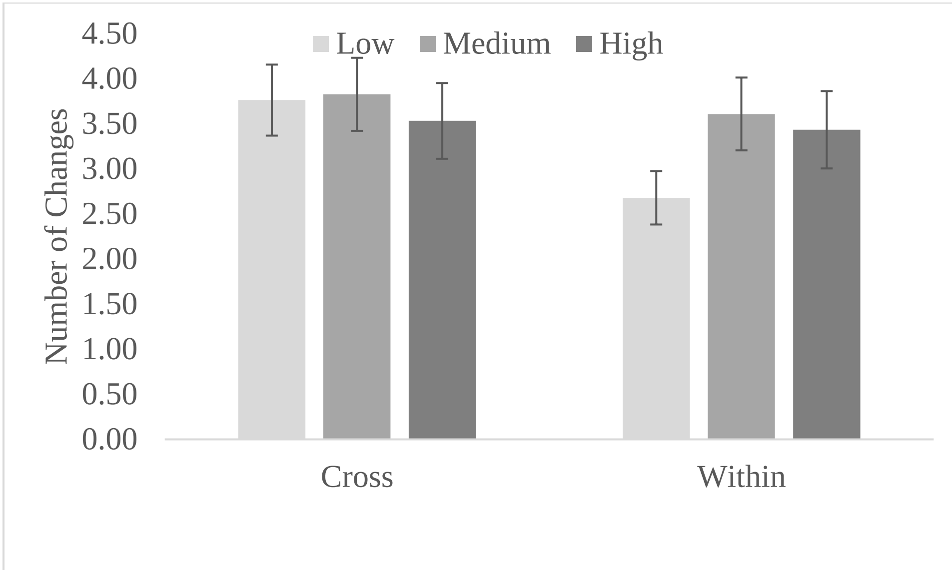

Figure 5. Oscillations, or the number of changes per trial, for emotion-emotion pairs broken down by cross- or within-valence and conflict level. For within-valence pairs, there were fewer oscillations in the low conflict, fear-sad condition, than the medium conflict, disgust-sad, and high conflict, fear-disgust pairs. Oscillations did not vary as a function of conflict for the cross-valence pairs.

Figure 6: Study 3 Happy Predominance and Dominance

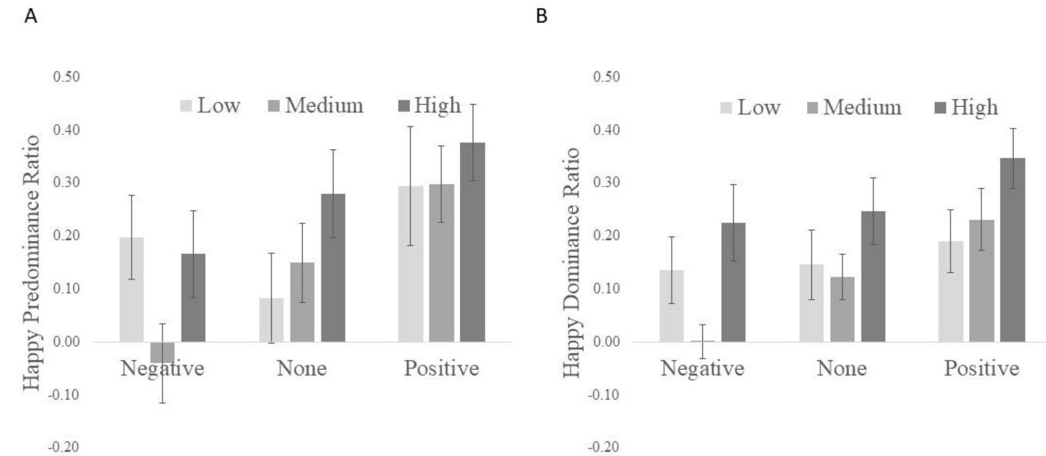

Figure 6. A) Happy predominance ratios for cross-valence pairs broken down by evaluative condition (negative focus, no focus, or positive focus) and conflict level (low, medium, high). Predominance was calculated as $(Predominance_{happy} - Predominance_{emotion2})/(Predominance_{happy} + Predominance_{emotion2})$. There was a main effect of evaluative focus driven by more happy predominance in the positive focus compared to the no focus and negative focus conditions. There was also an effect of conflict such that the high conflict, happy-sad pair displayed the greatest happy predominance. B) Happy dominance ratios for cross-valence pairs broken down by evaluative condition (negative focus, no focus, or positive focus) and conflict level (low, medium, high). Dominance was calculated as $(Dominance_{happy} - Dominance_{emotion2})/(Dominance_{happy} + Dominance_{emotion2})$. There was a main effect of evaluative focus driven by more happy dominance in the positive focus compared to the no focus and negative focus conditions. There was also an effect of conflict such that the high conflict, happy-sad pair displayed the greatest happy dominance.