THE INFLUENCE OF APPETITIVE AND AVERSIVE STIMULI ON SUBJECTIVE TEMPORAL ACUITY

by

Kevin H. Roberts

B.Sc., The University of Toronto, 2012

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS
in
THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES
(Psychology)

THE UNIVERSITY OF BRITISH COLUMBIA
(Vancouver)

August 2017

Abstract

Anecdotal reports that time “flies by” or “slows down” during emotional events are supported by evidence that the motivational relevance of stimuli influences subsequent duration judgments. Yet it is unknown whether the subjective quality of events as they unfold is altered by motivational relevance. In a novel paradigm, we measured the subjective experience of moment-to-moment visual perception. Participants judged the temporal smoothness of high-approach positive (desserts), negative (e.g. bodily mutilation), and neutral images (commonplace scenes) as they faded to black. Results revealed approach-motivated blurring (AMB), such that positive stimuli were judged as smoother and negative stimuli as choppier relative to neutral stimuli. Participant ratings of approach-motivation predicted perceived fade smoothness after controlling for low-level stimulus features. Electrophysiological data indicated AMB modulated relatively rapid perceptual activation. Results indicate that stimulus value influences subjective temporal perceptual acuity, with approach-motivating stimuli eliciting perception of a “blurred” frame rate characteristic of speeded motion.

Lay Summary

People often experience distortions in their sense of time in their everyday life, where the emotional quality of the event seems to play a key role. When an individual is having fun, time might "fly by", but time might slow to a crawl when an individual is giving a speech to a large audience. Usually, people discuss these experiences in terms of how long the final duration seemed. People also sometimes report differences in how they process their surrounding visual environment during these emotional events. In this study, I present evidence that individuals judge their continuous visual experience as subjectively different in response to emotional stimuli; fading negative stimuli are judged as more "choppy" and fading positive images are judged as more "smooth" than neutral images. This indicates that people report more detailed temporal information for negative images, and less detailed information for positive images.

Preface

A version of chapters 1-6 will soon be published. Roberts, K. H., Truong, G., Kingstone, A., Todd, R. M. (in press). The Blur of Pleasure: Appetitively appealing stimuli decrease subjective temporal perceptual acuity. *Psychological Science*. I wrote the initial draft of the manuscript, G. Truong, Dr. A. Kingstone, and R. M. Todd provided comments and edits. The experiments laid out in this thesis were conducted in the Motivated Cognition Lab at the University of British Columbia. I developed the study concept and design with Dr. R. M. Todd and programmed the experiments. Data analysis was performed by me with supervision from my advisor, Dr. R. M. Todd. I was also supervised by Grace Truong for the multi-level model analyses. Permission to conduct this study was approved by the Behavioural Research Ethics Board (Certificate Number: H14-01218).

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AMB	Approach-Motivated Blurring
ERP	Event-Related Potential
IAPS	International Affective Picture System (Lang, Bradley, & Cuthbert, 2008)
LPP	Late Positive Potential

Acknowledgements

I would like to thank the Faculty of Arts at the University of British Columbia for financial support throughout my Master’s program. I would also like to thank Dr. Rebecca Todd, for being an encouraging and constant guide during my growth as a researcher for nearly as long as I can remember, and Dr. Alan Kingstone for providing a fresh perspective on this project in particular, and on research in general. Finally, thank you to my parents encouraging the pursuit of education, and my brothers for providing an enriching home environment that fostered my interest in science and technology.

Chapter 1: Introduction

People often speak of time as dragging or flying, attributing such changes in their experience of time to their affective states or features of the environment. A person can be enjoying their time with their friends so much that what feels like a half-hour may have been a full hour. Conversely, if an inexperienced speaker is required to give a 10-minute speech to a large audience, this relatively short talk may feel like an hour to the speaker. These characterizations of the influence of affect on the subjective experience of time do not seem controversial – people tend to accept that distortions in their subjective experience of time are relatively commonplace in everyday life.

In addition to reporting differences in subjective duration of events, people also sometimes report differences in their perception of their ongoing experience during these affective events. People in stressful situations may feel like they process information more quickly, making their environment and their body seem to move in slow motion relative to their increased rate of perceptual processing (Hancock & Weaver, 2005). The quality of the ongoing perceptual experience during an affectively salient event has received little attention in the psychological literature. Thus, the goal of this thesis is to investigate the phenomenon of distortions in the ongoing subjective perceptual experience in response to affective stimuli, contributing to our understanding of distortions of subjective time and visual perception more generally.

1.1 Review of relevant literature

1.1.1 Affective distortions of stimulus duration

A good deal of research has been concerned with the influence of emotionally salient stimuli on subjective duration judgements. Extensive evidence indicates that negative stimuli that elicit a defensive response are judged as lasting longer than neutral stimuli. In two different duration estimation paradigms, negative sounds were judged as lasting longer than neutral sounds (Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007). Similar results have been obtained from other paradigms, demonstrating overestimation of aversive scenes (Dirnberger et al., 2012; Grommet et al., 2011) and angry faces (Droit-Volet, Brunot, & Niedenthal, 2004).

The effects of positive stimuli on duration judgements are more mixed. Many studies report overestimations of the duration of positive stimuli. When asked to reproduce the duration of stimuli with a button press, or estimate them via verbal estimation, participants overestimated the duration of positive sounds, as compared to neutral sounds (Noulhiane et al., 2007); however, positive sounds were underestimated as compared to negative sounds. Similarly, when exposed to stimulus displays of 2, 4, or 6 seconds, and asked to reproduce these durations with a button press of equivalent duration, participants judged positive images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) as lasting longer than neutral images within the 4-second display condition (Lambrechts, Mella, Pouthas, & Noulhiane, 2011). Yet another study using IAPS images demonstrated overestimation of low arousal positive images as compared to low arousal negative images, but underestimation of high arousal positive images as compared to high arousal negative images (Angrilli, Cherubini, Pavese, & Mantredini, 1997). However, only comparisons of the relative difference between negative and positive stimuli were possible in this experiment, since no comparisons were made against a baseline neutral stimulus condition. Thus, it remains possible that the high arousal positive images, although underestimated as compared to negative images, could have been overestimated (or similar in subjective duration) as compared to neutral images, consistent with Lambrechts and colleagues (2011). More recent research into the specific effects of approach-motivation indicates that the duration of high-approach appetitive images (e.g. delicious desserts) are underestimated as compared to either neutral or high-withdrawal negative stimuli (Gable & Poole, 2012). Overall, the mixed results for positive stimuli highlight the need for a better understanding of the mechanisms underlying affective influences on subjective time perception.

1.1.2 Affective influences on visual perception

Emotionally salient stimuli have also been associated with altered experience of visual perception. A brief display of a fearful face has been linked to changes in spatial contrast sensitivity (Phelps, Ling, & Carrasco, 2006), where sensitivity shifts toward lower spatial frequencies (Bocanegra & Zeelenberg, 2009), which is consistent with the effects seen with aversive conditioned-stimulus elicited arousal (Lee, Baek, Lu, & Mather, 2014). Thus, there seems to be some evidence that emotional stimuli are able to modulate early vision to alter spatial perception. There is also evidence that temporal processing may be affected by emotional stimuli. In a temporal order judgment task, where two stimuli are displayed on either side of a computer screen with a varied temporal gap in between stimuli, both schematic images and realistic photos of angry faces are judged as appearing prior to a simultaneously presented neutral face, an effect known as “prior entry” (Fecica & Stolz, 2008; West, Anderson, Bedwell, & Pratt, 2010; West, Anderson, & Pratt, 2009).

A proposed explanation for the modulation of sensitivity to visual contrast and the prior entry effect is that the fearful faces facilitate processing via the magnocellular visual pathway (Bocanegra & Zeelenberg, 2009; West et al., 2010). The magnocellular pathway responds to higher temporal resolution visual input and is more tuned to lower spatial frequency than the other major visual pathway, the parvocellular visual pathway (Livingstone & Hubel, 1987). Thus, at least for fearful stimuli, perception may shift to respond to input at higher temporal resolutions. This shift could be partly responsible for the different subjective experience of ongoing perception during emotional events. If magnocellular pathway facilitation occurs in response to other aversive stimuli, then one would expect that these stimuli may lead to increased temporal sampling, and an improved ability to discriminate input displayed at high temporal frequencies.

1.1.3 A link between time keeping and visual perception?

Previous studies have employed a psychophysical magnitude estimation task to examine effects of emotional salience on perceptual experience, and found that viewing arousing emotional stimuli increased the subjective experience of perceptual vividness, or enhanced signal to noise ratio associated with relatively rapid perceptual processing (Todd et al., 2015; Todd, Talmi, Schmitz, Susskind, & Anderson, 2012). One potential explanation for this phenomenon is that it results from higher levels of temporal sampling for emotionally salient images. Models emerging from non-human animal research have linked effects of motivation to neurobiological mechanisms of time keeping (Matell & Meck, 2004; Meck, 1996). Such models posit that subjective time estimation is regulated by an internal pacemaker that operates via striatal timekeeping mechanisms, where pacemaker “pulses” are accumulated, and this sum indexes the amount of elapsed time (Gibbon, Church, & Meck, 1984). It has been suggested that emotional stimuli may speed this internal pacemaker, leading to a greater number of accumulated “pulses”, and thus overestimation of the duration of the stimulus (Droit-Volet & Meck, 2007). Thus, it may be that salient emotional stimuli such as those used by Todd and colleagues (2012, 2015) modulate subjective duration estimations due to their influence on the rate of this putative pacemaker. At the same time, the rate of this pacemaker may relate to ongoing visual processing, where an increased pacemaker rate may result in both an increased subjective duration as well as increased temporal resolution, the latter resulting in phenomenological changes in the visual experience.

1.2 The present investigation

In the present study I adopted a similar psychophysical magnitude estimation as Todd and colleagues (2012) to examine effects of valence on the moment-to-moment experience of visual perception within a framework proposed by pacemaker models. I created a novel paradigm in which stimuli faded to black over the course of two seconds, and detection of changes from frame to frame served to index perception during pacemaker “pulses.” Here, I make two assumptions: first, I assume that the images used in the study will result in differences in the clock speed of a neural pacemaker (Matell & Meck, 2004). Based on this premise, I further hypothesized that differences in pacemaker speed would result in differences in subjective perception of a continuous stimulus, such that increased pacemaker speed relates to increased temporal acuity. In the current paradigm, judgments of the smoothness or choppiness of a fading stimulus provide an index of subjective temporal acuity. Specifically, an increase in temporal acuity leads to subjective ratings of choppiness, since this indicates an increased ability to discern fine-grained changes across time in the stimulus fade. Conversely, a reduction in temporal acuity leads to subjective ratings of smoothness, since stimulus smoothness indicates a reduced ability to discern frame-to-frame changes in the stimulus. Thus I predicted that: (1) stimuli eliciting high approach motivation would result in the fade being experienced as smoother, consistent with reduced subjective acuity associated with a speeded sense of time; and (2) negative stimuli eliciting avoidance would result in the fade being experienced as choppier, indicating greater subjective acuity for temporal intervals consistent with an extended sense of time, and (3) trial by trial, stimuli rated as higher in approach would elicit greater estimations of smoothness. Moreover, I expected effects of approach motivation on subjective smoothness would reflect subjective influences on perceptual processing as reflected in the time course of ERP activity.

Chapter 2: Experiment 1

2.1 Method

2.1.1 Participants

Thirty-two university undergraduates participated (23 Female; Mean age = 20.2 years, SD = 2.22) with normal or corrected-to-normal vision participated for course credit. The experimental protocol was approved by the University of British Columbia Behavioural Research Ethics Board and was in accordance with the World Medical Association Declaration of Helsinki. The required number of participants was estimated from previous experiments using a magnitude estimation method to probe the subjective experience of affective stimuli (Todd et al., 2012). Data collection was stopped when the approximate targeted number of participants was collected. Four participants were excluded due to testing error and one participant was excluded due to software malfunction. An additional four participants were excluded for rating stimuli at 16 FPS (the objectively choppiest display) as more smooth on average than 48 FPS (the objectively smoothest display) among neutral stimuli, indicating that they had either flat or inverted response curves and did not properly perform the basic perceptual task of discriminating choppier from smoother fades. They could not be used in the inferential analyses since any influence of affect on smoothness ratings would be confounded by their inability to perform the task. Data from twenty-three participants (15 Female; Mean age = 20.3 years, SD = 2.39) were used.

2.1.2 Materials

An equal number of negative, neutral, and positive images formed three stimulus categories (75 images in total). Negative and neutral images were retrieved from the

International Affective Picture System (Lang et al., 2008) and positive images were retrieved from the internet. Negative stimuli depicted scenes of mutilation, death, and confrontation; neutral stimuli depicted commonplace scenes (e.g. grocery store, parking lot); positive stimuli were images of desserts selected to elicit approach motivation (Gable & Poole, 2012). Stimulus categories were matched in mean log luminance and contrast. Other objective stimulus characteristics were controlled for statistically. For each stimulus, a mosaic-like spatially scrambled version was created to act as the standard comparison for that stimulus. Both standards and targets were displayed at a visual angle of approximately 8.97° x 6.76°. All tasks were displayed on an LED monitor at a resolution of 1280x1024 at 144hz.

2.1.3 Procedure

In a magnitude estimation task, participants judged the relative smoothness of the presentation of a target stimulus fading to black, as compared to a standard in 225 trials (Figure 1). Trials began with a fixation cross lasting 1000 ms, followed by the standard presented for 2000 ms, fading to black at 24 frames per second (fps). Immediately following the standard, the target stimulus was displayed for 2000 ms, fading to black at one of three possible frame rates (16/24/48 fps). Participants then indicated their perceived fade smoothness of the target image as compared to the standard on a 21-point scale. The leftmost end of the scale was labeled as “A lot less smooth” (i.e. a “choppy” target fade presentation), the rightmost end was labeled as “A lot smoother” (i.e. a “smooth” target fade presentation), and the midpoint of the scale was labeled as “The same”. Trials were pseudorandomized and each target image was presented at each frame rate once. Six practice trials were completed prior to the experimental trials so that participants could become accustomed to the task.

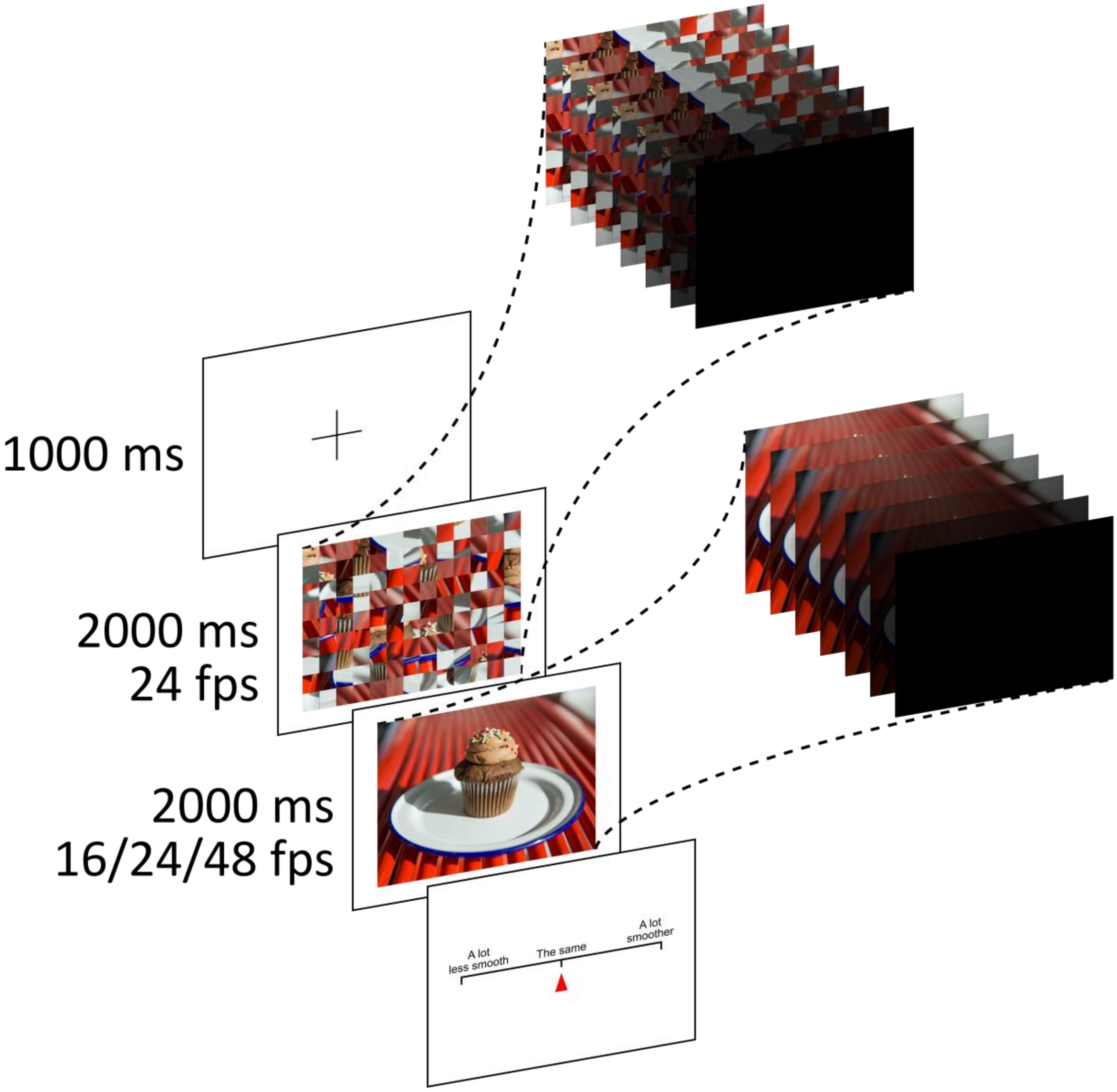

Figure 1. Magnitude estimation task employed in Experiment 1 and Experiment 2. In Experiment 3, the standard stimulus FPS was varied instead of the target stimulus, and a variable duration fixation cross was inserted in between the standard and the target.

Participants then rated each image for emotional arousal on a scale from 1 to 7, with 7 indicating high arousal (excited, jittery, or wide-awake) and 1 indicating low arousal (completely relaxed, calm, sluggish, or dull), noting that this was not a rating of pleasantness since arousal can be both positive (excitement) or negative (upset/anxious). On a separate 21-point scale, participants also rated to what degree the image elicited an “avoidance” or “approach” motivation to the subject or scene of the stimulus, with 1 indicating “high avoid” and 21 indicating “high approach”. During rating tasks, all images were presented for 2000 ms without fading to black. Finally, as an additional measure that may influence approach motivation toward the dessert stimuli, participants were asked how long it had been since they last ate. Both rating tasks had six practice trials prior to the experimental trials.

In order to assess and control for the effect of objective stimulus properties on perceived fade smoothness, I calculated the degree of edges, contrast, and saturation in each image using the Image Processing Toolbox packaged with MATLAB 8.3.0 (2014). Amount of edges was calculated using MATLAB’s edge function using a Canny filter with a threshold of 0.5. Contrast was calculated by finding the standard deviation of the grayscale pixel values. Saturation was calculated by extracting the mean value of each image’s saturation dimension after conversion to an HSV color map using MATLAB’s rgb2hsv function.

2.2 Results

For all analyses, reported values are Greenhouse-Geisser corrected when sphericity cannot be assumed, and pairwise comparisons are Bonferroni corrected.

2.2.1 Stimulus ratings

Arousal and approach/avoidance ratings of the stimuli (Table 1, Experiment 1) were submitted to one-way repeated-measures ANOVAs to verify differences between stimulus categories. For arousal ratings, there was a main effect of stimulus category, $F(2, 44) = 39.20$, $p < 0.001$, $\eta_p^2 = 0.64$. Pairwise comparisons revealed that negative stimuli were rated as significantly more arousing than neutral ($p < 0.001$) and positive stimuli ($p = 0.016$), and positive stimuli were rated as significantly more arousing than neutral stimuli ($p < 0.001$). For ratings of approach/avoidance there was again a main effect of stimulus category, $F(1.52, 33.53) = 64.33$, $p < 0.001$, $\eta_p^2 = 0.75$. Pairwise comparisons revealed a highly significant difference across all levels (ps < 0.001), with negative images rated as more avoid-motivating and positive stimuli as more approach-motivating as compared to neutral. Together, these results confirmed that the stimuli elicited the expected pattern of differential arousal and approach-motivation. Time since last eaten was not significantly correlated with arousal or approach/avoid ratings for positive stimuli, ps > 0.250.

2.2.2 Perceived fade smoothness

A 3 X 3 (Stimulus Frame Rate X Stimulus Category) repeated-measures ANOVA was performed on the perceived fade smoothness data (Figure 2a). There was a main effect of stimulus frame rate, $F(1.13, 24.90) = 35.16$, $p < 0.001$, $\eta_p^2 = 0.62$, observed power = 1.00. Pairwise comparisons revealed significantly different perceived fade smoothness across all levels (ps <= 0.001), with higher stimulus frame rate resulting in higher perceived fade smoothness. A main effect of stimulus category was also obtained, $F(1.32, 28.95) = 9.06$, $p = 0.003$, $\eta_p^2 = 0.29$, observed power = 0.892, with negative stimuli rated as least smooth and positive stimuli rated as smoothest (Table 2, Experiment 1). Pairwise comparisons reveal a significant difference between positive relative to neutral ($p = 0.007$), and negative stimuli ($p = 0.012$) and no significant difference between neutral and negative stimuli ($p = 0.242$) indicating that positive images were rated as smoother than negative and neutral pictures. There was also a significant interaction between the two factors, $F(4, 88) = 5.21$, $p = 0.001$, $\eta_p^2 = 0.19$. Simple main effects analyses for this interaction revealed a difference between positive images and neutral images at the 16 FPS ($p = 0.035$), a difference between positive and neutral and positive and negative at 24

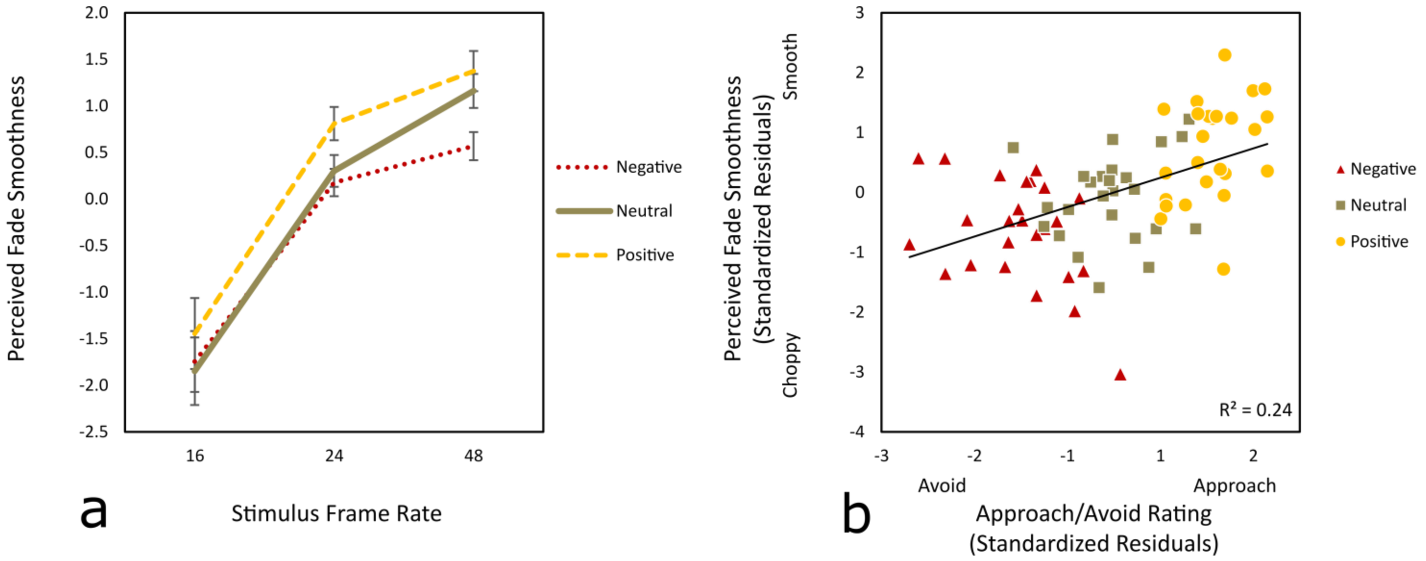

Figure 2. Affective influences on perceived fade smoothness in Experiment 1. (a) Effect of stimulus frame rate and stimulus category on perceived fade smoothness. Positive stimuli tend to be judged as most smooth, while negative stimuli appears choppier than neutral stimuli only at the highest frame rate. (b) Plot of standardized residuals of mean Approach/Avoid ratings and Perceived Fade Smoothness for each stimulus, across participants, after controlling for low-level objective stimulus properties. Overall, approach-motivation predicts a more smooth perception of the stimulus, while avoid-motivation predicts choppier perception.

FPS ($p = 0.009$, $p = 0.004$), and a difference between positive and negative and negative and neutral at 48 FPS ($p = 0.002$, $p = 0.001$), with all other comparisons non-significant (ps > 0.250). Thus, positive images were smoother than neutral but not negative at the lowest frame rate, smoother than neutral and negative at a medium frame rate, and only smoother than negative at the highest frame rate. Negative images were rated as choppier than neutral only at the highest frame rate. Thus, results showed that, while negative images were rated as choppiest and positive images as smoothest, suggesting reduced subjective temporal acuity for more positive stimuli, this pattern was most strongly driven by perceived fade smoothness for positive images.

2.2.3 Stimulus ratings predicting perceived fade smoothness

I employed a multi-level model using the lme4 package for R (Bates, Maechler, Bolker, & Walker, 2014; R Core Team, 2014) to look at the trial-by-trial within-subjects effect of image ratings on perceived fade smoothness after controlling for other potential influences (time since the participant last ate, degree of edges, contrast, and saturation in the target stimulus). Results showed that the mean number of edges in an image significantly influenced perceived fade smoothness, $\beta = -0.10$, $t = -3.56$, $p < 0.001$, such that more edges in an image result in a less smooth perception of the fade. Stimulus contrast also significantly influenced perceived fade smoothness, $\beta = -0.05$, $t = -2.01$, $p = 0.048$, with more contrast resulting in less smooth perception. As predicted, when controlling for the effect of all other variables in the model, approach/avoidance ratings were significantly related to perceived fade smoothness, $\beta = 0.15$, $t = 2.77$, $p = 0.012$, such that higher approach ratings result in a more smooth perception of stimulus fades (Figure 2b). This effect was also significant when arousal, time since last ate, and objective stimulus characteristics were not included in the model, $\beta = 0.15$, $t = 2.83$, $p = 0.009$. Perceived fade smoothness was not related to saturation, arousal ratings, or time since last eaten (ps > 0.250). Thus, for each image used in the task, the level of approach motivation elicited predicted greater smoothness, consistent with lower rates of sampling underlying speeded time perception.

Chapter 3: Experiment 2

3.1 Methods

The results from Experiment 1 indicate that the motivational relevance of images impacts the subjective moment-to-moment perceptual experience of stimuli. However, it is possible that the pattern of results obtained was due to the implicit affective connotation of the words used in the magnitude estimation task. The word “smooth” may have a positive connotation that was then transferred into a bias toward estimating positive images as more smooth and negative images as less smooth. Further, I described the opposing temporal perceptual experience as “choppy”, which may have a negative connotation, which could have further influenced participants to rate negative images as less smooth. In order to control for this confound, I performed a nearly identical experiment, with the only difference being that the word “continuous” was used to describe the perceptual experience of a smooth fade, and “discrete” was used to describe a choppy fade. Reflecting the new task instructions, the labels at the opposing ends of the rating scale in the magnitude estimation task were “A lot less continuous” and “A lot more continuous”.

3.1.1 Participants

Thirty-eight university undergraduates participated (21 Female; Mean age = 20.7 years, SD = 2.83) with normal or corrected-to-normal vision participated for course credit. The experimental protocol was approved by the University of British Columbia Behavioural Research Ethics Board and was in accordance with the World Medical Association Declaration of Helsinki. As in Experiment 1, the required number of participants was estimated from previous similar experiments (Todd et al., 2012). Data collection was stopped when the approximate targeted number of participants was collected. One participant withdrew from the experiment. An additional thirteen participants were excluded for rating stimuli at 16 FPS as more smooth on average than 48 FPS among neutral stimuli, indicating that they had either flat or inverted response curves and did not properly perform the basic perceptual task of discriminating choppier from smoother fades. Data from the remaining twenty-four participants (12 Female; Mean age = 20.7 years, SD = 3.31) were used.

3.1.2 Materials and procedure

The stimuli and display apparatus used were identical to Experiment 1. The procedure was identical to Experiment 1, except that the words “smooth” and “choppy” were substituted with “continuous” and “discrete”, respectively, in all oral and written instructions given to the participants.

3.2 Results

For all analyses, reported values are Greenhouse-Geisser corrected when sphericity cannot be assumed, and pairwise comparisons are Bonferroni corrected.

3.2.1 Stimulus ratings

Arousal and approach/avoidance ratings of the stimuli (Table 1, Experiment 2) were submitted to one-way repeated-measures ANOVAs which resulted in the same pattern of results as Experiment 1, Time since last eaten was not significantly correlated with arousal or approach/avoid ratings for positive stimuli, ps > 0.250.

3.2.2 Perceived fade smoothness

A 3 X 3 (Stimulus Frame Rate X Stimulus Category) repeated-measures ANOVA was performed on the perceived fade smoothness data (Figure 3a). There was a main effect of stimulus frame rate, $F(1.13, 25.90) = 16.71$, $p < 0.001$, $\eta_p^2 = 0.42$, observed power = 0.984. Pairwise comparisons revealed significantly different perceived fade smoothness between 16 FPS and both 24 FPS and 48 FPS (ps = 0.001), with higher stimulus frame rate resulting in higher perceived fade smoothness, but no significant difference between 24 FPS and 48 FPS ($p = 0.253$). A main effect of stimulus category was also obtained, $F(1.46, 33.67) = 10.26$, $p = 0.001$, $\eta_p^2 = 0.31$, observed power = 0.945, with negative stimuli rated as least smooth and positive stimuli rated as smoothest (Table 2, Experiment 2). Pairwise comparisons reveal a significant difference between positive relative to neutral ($p = 0.038$), and negative stimuli ($p = 0.005$) and a significant difference between neutral and negative stimuli ($p = 0.039$) indicating that positive stimuli were rated as smoother and negative stimuli as less smooth than neutral stimuli. There was no significant interaction between the two factors, $F(4, 92) = 1.91$, $p = 0.116$, $\eta_p^2 = 0.08$. Thus, results showed that, negative images were rated as choppiest and positive images as smoothest, suggesting reduced subjective temporal acuity for more positive stimuli and increased subjective temporal acuity for negative stimuli.

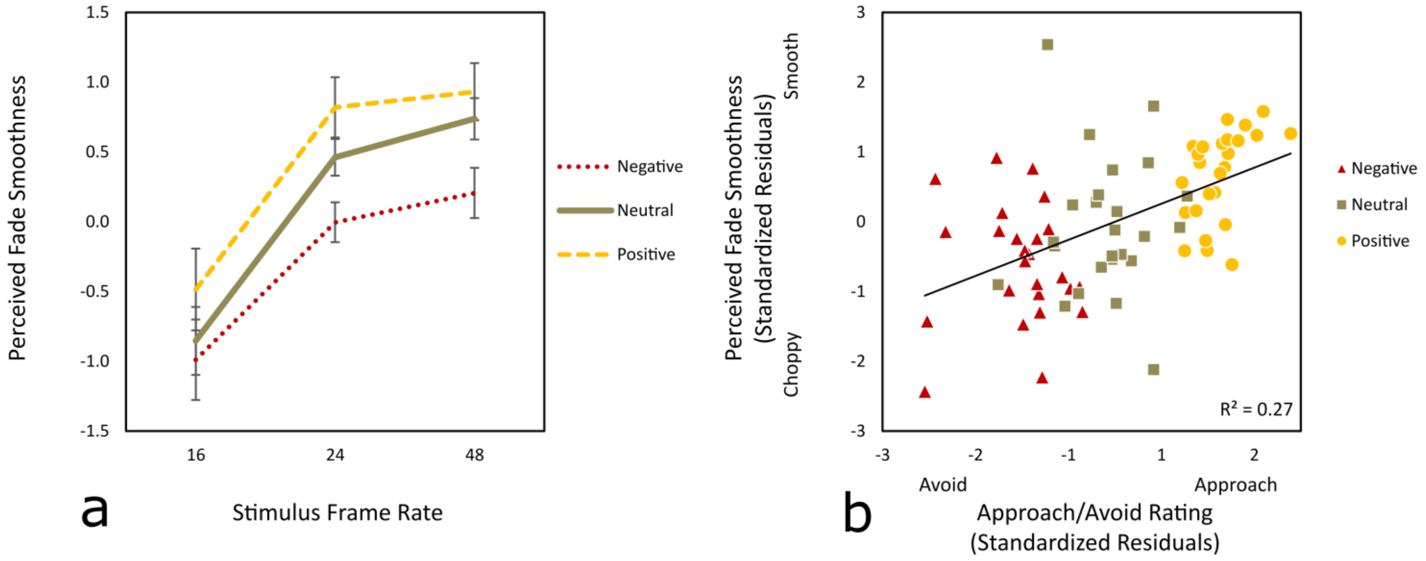

Figure 3. Affective influences on perceived fade smoothness in Experiment 2. (a) Effect of stimulus frame rate and stimulus category on perceived fade smoothness. There is a more clear differentiation between perceived fade smoothness among stimulus categories than was obtained in Experiment 1, with positive stimuli rated as most smooth and negative stimuli as least smooth overall. (b) Plot of standardized residuals of mean Approach/Avoid ratings and Perceived Fade Smoothness for each stimulus, across participants, after controlling for low-level objective stimulus properties. Overall, approach-motivation predicts a more smooth perception of the stimulus, while avoid-motivation predicts choppier perception.

3.2.3 Stimulus ratings predicting perceived fade smoothness

The same multi-level model as used in Experiment 1 was employed to investigate the effect of image ratings on perceived fade smoothness, controlling for time since the participant last ate and objective stimulus properties. Results showed that the stimulus contrast significantly influenced perceived fade smoothness, $\beta = -0.13$, $t = -4.38$, $p < 0.001$, such that higher contrast in an image results in a less smooth perception of the fade. As predicted, when controlling for the effect of all other variables in the model, approach/avoidance ratings were significantly related to perceived fade smoothness, $\beta = 0.08$, $t = 2.18$, $p = 0.043$, such that higher approach ratings result in a more smooth perception of stimulus fades (Figure 3b), though this effect was not significant when arousal, time since last ate, and objective stimulus characteristics were not included in the model, $\beta = 0.09$, $t = 1.94$, $p = 0.067$. Perceived fade smoothness was not related to amount of edges, saturation, arousal ratings, or time since last eaten (*p*s > 0.250). Thus, for each image used in the task, the level of approach motivation elicited predicted greater smoothness, consistent with lower rates of sampling underlying speeded time perception.

Chapter 4: Experiment 3

4.1 Methods

The results from Experiment 2 indicate that the results I obtained in Experiment 1 were not due to the implicit affective connotation of the words “smooth” and “choppy” used for the descriptions of the perceptual experience. Next, I employed electroencephalography (EEG) to further probe the observed effect in Experiments 1 and 2, which I term approach-motivated blurring (AMB), since the degree of approach-motivation toward a given stimulus influences subjective perceptual judgments of fade smoothness. Here I aimed to use event-related potentials (ERP) to probe differences in scalp potentials reflecting variation in perceived stimulus smoothness related to the influence of approach-motivation. Specifically, if early latency ERPs were parametrically modulated by subjective ratings reflecting AMB, it would provide evidence that the affective modulation of subjective smoothness ratings from the previous experiments reflects subjective enhancement of perceptual processing. Moreover, modulation of occipital late positive potential (LPP) activation would further contextualize the results within previous findings of enhanced sustained processing of emotionally and motivationally salient stimuli. The AMB effect indicates that subjective smoothness is highly associated with motivational picture content, and the LPP is modulated by affective picture content (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). Thus, the LPP should be modulated by AMB, which reflects approach motivation. However, because valence-related effects diverge for different categories of positive stimuli, I could not predict the direction of AMB-related ERP modulation based on previous research.

4.1.1 Participants

Thirty-one university undergraduates participated (25 Female; Mean age = 21.6 years, SD = 2.87) with normal or corrected-to-normal vision participated for course credit. The experimental protocol was approved by the University of British Columbia Behavioural Research Ethics Board and was in accordance with the World Medical Association Declaration of Helsinki. The required number of participants was estimated from a previous similar experiment investigating ERP responses to affective stimuli (Todd et al., 2012). Data collection was stopped when the approximate targeted number of participants was collected. Six participants were excluded for rating stimuli at 16 FPS as more smooth on average than 48 FPS across all stimulus categories, indicating that they had either flat or inverted response curves and did not properly perform the basic perceptual task of discriminating choppier from smoother fades. A further 6 participants were excluded from analyses for having too few trials remaining after the EEG artifact rejection procedure. Data from the remaining nineteen participants (18 Female; Mean age = 21.8 years, SD = 3.30) were used. One participant had missing data for time since last ate and was excluded only for analyses that required this variable.

4.1.2 Materials and procedure

The stimuli and display apparatus used were identical to Experiment 1. The procedure was similar to Experiment 1, with a slight alteration to the magnitude estimation task. Instead of varying the frame rate of the target, in this experiment I varied the frame rate of the standard image. This was done to ensure that the main ERP of interest (the response to the target image) reflected perceived rather than actual differences in the smoothness of the target stimulus. After the standard was displayed, a variable duration fixation cross was presented (500-900 ms, uniformly randomized), immediately followed by the target image display for 2000 ms at 24 FPS.

4.1.3 EEG recording and analysis

Scalp potentials were recorded continuously at a sampling rate of 512 Hz from 64 Ag/AgCl electrodes inserted into a mesh cap. Horizontal electrooculogram (HEOG) recordings were obtained from flat electrodes placed at the outer canthi of the eyes. A single flat electrode was placed below the participant's right eye to record vertical electrooculogram (VEOG). Electrode measurements were amplified using an ActiveTwo amplifier (Biosemi, Amsterdam, The Netherlands).

Pre-processing of continuous EEG was done using EEGLAB (Delorme & Makeig, 2004) and artifact rejection, epoching and extraction were performed using ERPLAB (Lopez-Calderon & Luck, 2014). Continuous EEG was referenced to left and right mastoids, down-sampled to 256 Hz, and bandpass filtered to 0.1-40 Hz. Note that this commonly-employed high-pass frequency has been previously determined to be acceptable for slower ERP components such as the LPP (e.g. Hajcak, Weinberg, MacNamara, & Foti, 2012). Epochs were extracted from 150 ms before to 2000 ms after standard and target displays. Trials with eye blinks and major eye movements were rejected using ERPLAB's moving-window peak-to-peak algorithm to detect extreme voltage deflections in the three oculogram channels (voltage threshold = 60 μV, window width = 200 ms, window step = 50 ms). Trials with extreme voltage deflections in midline electrodes (Oz, POz, Pz, CPz, Cz, FCz, Fz, AFz, Fpz) were rejected using a separate moving-window peak-to-peak procedure (voltage threshold = 70 μV, window width = 200 ms, window step = 50 ms).

In order to obtain ERPs reflecting differences in subjective smoothness, I calculated the mean smoothness ratings for each trial across participants. A linear regression predicting mean smoothness from ordinalized standard frame rate was then performed to obtain standardized residuals, which reflect the variability in participants' smoothness ratings that could not be predicted from objective smoothness. The standardized residuals, which served as a behavioural measure of the AMB effect, were then used to group the trials into three categories of subjective smoothness (low/medium/high). Because the AMB effect is responsive to differences in picture content, there is considerable overlap between low/medium/high smoothness bins and negative/neutral/positive images respectively, where the low smoothness bin consists predominantly of negative images, the high smoothness bin consists predominantly of positive image trials, and the medium smoothness bin consists predominantly of neutral images (Table 3). ERPs were baseline corrected using the 150 ms preceding stimulus onset and extracted for target displays at each level of subjective smoothness ratings. Artifact rejection resulted in mean rejection rate of 22.4% of the binned epochs.

4.2 Results

For all analyses, reported values are Greenhouse-Geisser corrected when sphericity cannot be assumed, and pairwise comparisons are Bonferroni corrected.

4.2.1 Behavioural results

4.2.1.1 Stimulus ratings

Arousal and approach/avoidance ratings of the stimuli (Table 1, Experiment 3) were submitted to one-way repeated-measures ANOVAs which resulted in the same pattern of results as the previous two experiments. Time since last eaten was not significantly correlated with arousal or approach/avoid ratings for positive stimuli ($p = 0.193$, $p > 0.250$, respectively).

4.2.1.2 Perceived fade smoothness

A 3 X 3 (Stimulus Frame Rate X Stimulus Category) repeated-measures ANOVA was performed on the perceived fade smoothness data (Figure 4a). There was a main effect of stimulus frame rate, $F(1.04, 18.66) = 17.65$, $p < 0.001$, $\eta_p^2 = 0.50$ observed power = 0.981. Pairwise comparisons revealed significant differences in perceived fade smoothness between 16 FPS and both 24 FPS and 48 FPS ($p = 0.002$, $p = 0.001$, respectively), and a significant difference between 24 FPS and 48 FPS ($p = 0.012$), with lower standard frame rate resulting in smoother ratings of the target. A main effect of stimulus category was also obtained, $F(2, 36) = 6.31$, $p = 0.004$, $\eta_p^2 = 0.26$, observed power = 0.871, with negative stimuli rated as least smooth and positive stimuli rated as smoothest (Table 2, Experiment 3). Pairwise comparisons reveal a significant difference between positive relative to negative ($p = 0.028$), a near significant difference relative to neutral stimuli ($p = 0.056$) and no significant difference between neutral and negative stimuli ($p = 0.794$) with the overall trend being that positive stimuli were rated as smoother and negative stimuli as less smooth than neutral stimuli. There was no significant interaction between the two factors, $F(2.56, 46.07) = 0.208$, $p = 0.862$, $\eta_p^2 = 0.01$. Thus, results showed that, negative images were rated as choppiest and positive images as smoothest, suggesting reduced subjective temporal acuity for more positive stimuli and increased subjective temporal acuity for negative stimuli.

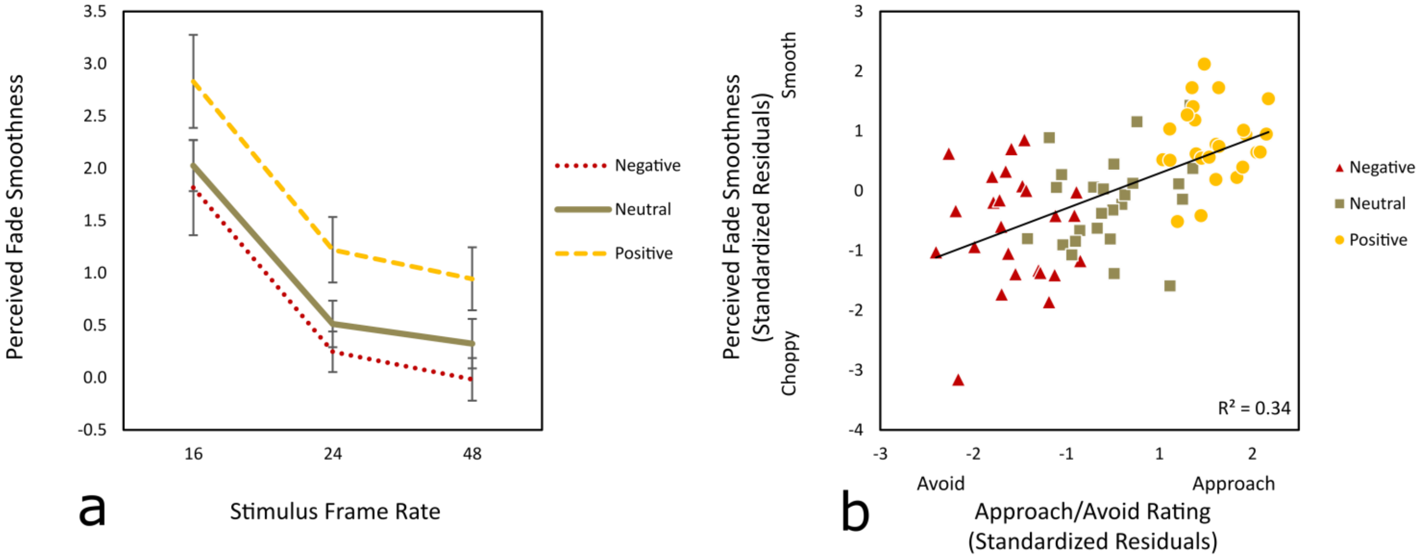

Figure 4. Affective influences on perceived fade smoothness in Experiment 3. (a) Effect of stimulus frame rate and stimulus category on perceived fade smoothness. Note that the trend in these results is the reverse of the previous experiments, since the standard's frame rate was varied rather than the target. Positive stimuli were rated as most smooth and negative stimuli as least smooth overall, with little difference between neutral and negative images. (b) Plot of standardized residuals of mean Approach/Avoid ratings and Perceived Fade Smoothness for each stimulus, across participants, after controlling for low-level objective stimulus properties. Overall, approach-motivation predicts a more smooth perception of the stimulus, while avoid-motivation predicts choppier perception.

4.2.1.3 Stimulus ratings predicting perceived fade smoothness

The same multi-level model used in Experiment 1 and 2 was employed to investigate the effect of image ratings on perceived fade smoothness, controlling for the amount of time since the participant last ate and objective stimulus properties. Results showed that the number of edges in the stimulus significantly influenced perceived fade smoothness, $\beta = -0.06$, $t = -2.01$, $p = 0.049$, such that more edges results in a less smooth perception of the fade. When controlling for the effect of all other variables in the model, approach/avoidance ratings related to perceived fade smoothness at the level of a trend, $\beta = 0.15$, $t = 1.99$, $p = 0.06$, such that higher approach ratings result in a more smooth perception of stimulus fades (Figure 4b), though this effect was not significant when arousal, time since last ate, and objective stimulus characteristics were not included in the model, $\beta = 0.12$, $t = 1.77$, $p = 0.091$. Perceived fade smoothness was not related to amount of contrast, saturation, arousal ratings, or time since last eaten (*p*s > 0.250). Thus, for each image used in the task, as in previous studies the overall pattern of results was that higher levels of approach motivation elicited predicted greater smoothness, consistent with lower rates of sampling underlying speeded time perception. However, in this experiment the effect did not reach the conventional level of significance.

4.2.2 Event-related potentials

4.2.2.1 Early ERPs for subjective smoothness levels

Our primary question focused on whether behavioural findings of AMB reflected perceptual (rather than merely conceptual) processes, and the goal was to determine when and where on the scalp cortical modulation by AMB could be first observed. Consistent with connectivity between visual cortex and motivation circuits (Amaral, Behniea, & Kelly, 2003), I expected behavioral effects to be associated with ERPs linked to higher-order perceptual processes. First, to systematically examine modulation of ERP activity by AMB in a principled and conservative data-driven manner, I employed the Mass Univariate ERP Toolbox (Groppe, Urbach, & Kutas, 2011). Using this toolbox, reliable differences between conditions are revealed by creating a difference wave, and then performing a series of one-sample *t*-tests across the desired time window while correcting for multiple comparisons.

In the present study, three difference waves were created to compare high/medium, high/low, and medium/low subjective smoothness bins. In each case, the lower smoothness bin was always subtracted from the higher smoothness bin. A separate mass univariate analysis was performed for each of these difference waves, using repeated measures, two-tailed *t*-tests at every time point between 100 and 400 ms (77 time points) at all 64 scalp electrodes, resulting in 4928 comparisons in total. The Benjamini, Krieger, & Yekutieli, (2006) procedure for controlling false discovery rate (FDR) was used, with family-wise alpha set to 0.0167 to correct for multiple comparisons. This particular analysis is recommended by Groppe and colleagues (2011) for both focal and distributed effects, when it is important to avoid making Type II errors, and when it is likely that a relatively large number of individual inferential tests will fail to reject the null hypothesis.

Significant differences emerged in the high-low (Figure 5a) and high-medium (Figure 5b), but not the medium-low, comparisons. High subjective smoothness trials resulted in 354 significant differences from low smoothness trials that were beyond the critical *t*-score of ±3.82 (corresponding to a test-wise alpha of 0.001), with an estimated upper bound of 6.9 false discoveries. Two clusters of differences can be observed (Figure 5a): first, a negative difference at occipital electrodes starting at 129 ms and ending at 258 ms; second, a positive cluster at frontal and central electrodes starting at 218 ms and ending at about 352 ms, with most differences present in the left hemisphere. The comparison between high and medium smoothness trials resulted in qualitatively similar results with reduced magnitude in differences. 224 significant differences from were beyond the critical *t*-score of ±4.03 (corresponding to a test-wise alpha of < 0.001), with an estimated upper bound of 3.7 false discoveries. Similar clusters of results are apparent (Figure 5b): first, a negative difference at occipital electrodes starting at 137 ms and ending at 152 ms; second, a positive cluster at frontal and central

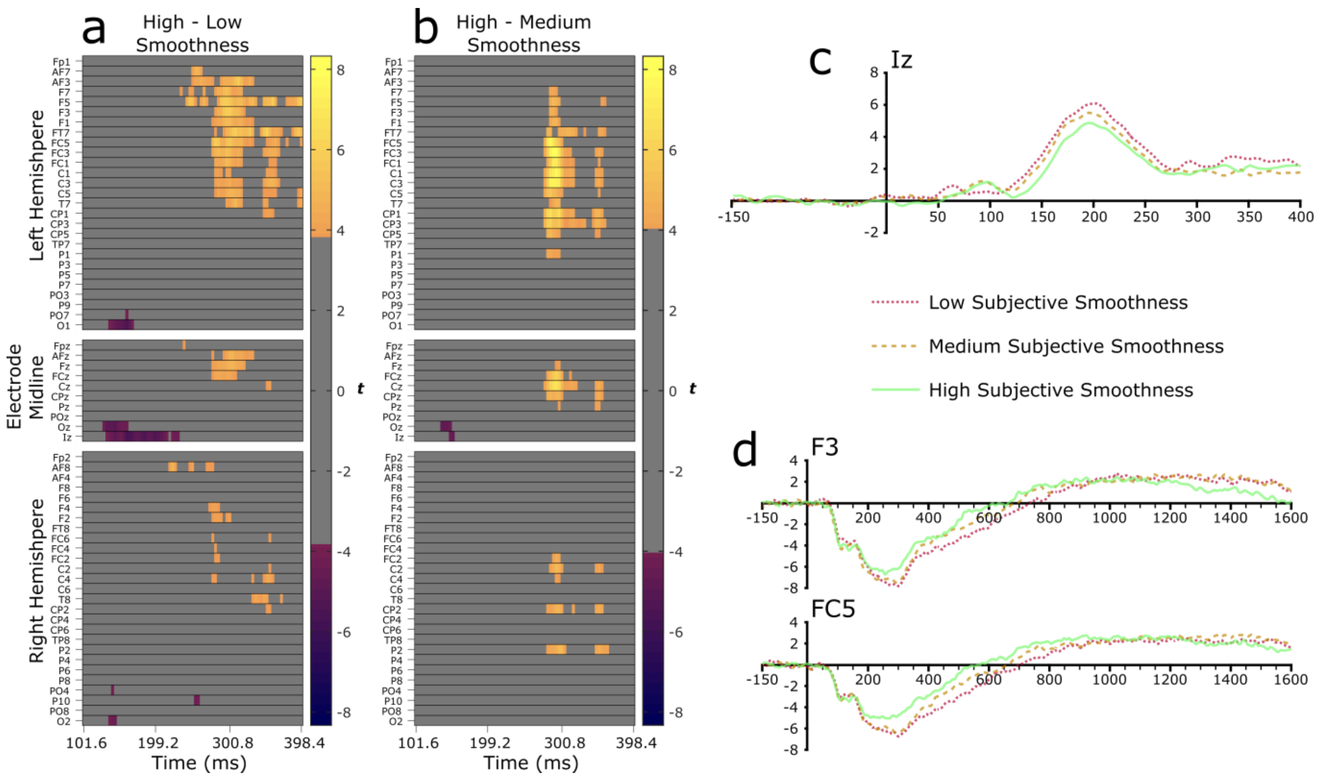

Figure 5. Mass univariate analyses for the early ERP time window. (a) Results of t-tests for high minus low subjective smoothness bins for each time point and scalp electrode. Non-significant comparisons are represented by grey cells. A focal negative cluster of significant t-tests is apparent at an early latency (around 150 ms) at occipital electrode sites represented by dark blue-purple cells. A widespread positive cluster of significant t-tests is apparent later (~300 ms) at fronto-central left-lateralized electrode sites, is represented by light yellow-orange cells. (b) Results of *t*-tests for high minus medium subjective smoothness. Similar clusters of significant t-tests as plot (a) in this figure, reveal a less widespread time course for each cluster. (c) ERP plot to illustrate early cluster of significant *t*-tests from mass univariate analysis. The high subjective smoothness bin has a reduced positive peak appearing at occipital sites at ~200 ms as compared to medium or low smoothness. (d) ERP plot to illustrate late cluster of significant t-tests from mass univariate analysis. The high subjective smoothness bin has a less negative peak around 300 ms as compared to medium or low smoothness.

electrodes starting at 277 ms and ending at about 363 ms, with most differences present in the left hemisphere.

ERPs for smoothness bins were plotted to illustrate the observed differences. A plot of representative electrode (Iz) to illustrate the early negative difference (Figure 5c) reveals a less positive peak for high subjective smoothness at 200 ms as compared to medium or low smoothness. This difference corresponds to an amplitude modulation at the time period of the post sensory P2, an early-to-mid- latency positive ERP peak measured at occipitoparietal electrodes (Hackley, Woldorff, & Hillyard, 1990; Qian, Al-Aidroos, West, Abrams, & Pratt, 2012) by subjective smoothness, such that reporting high smoothness was associated with a reduced amplitude. The visual P2 component has been associated with object discrimination (Rousselet, Husk, Bennett, & Sekuler, 2008) and affective salience (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004; Todd et al., 2012). Thus, this component has been found to be sensitive to subjective modulation of visual perception associated with extraction of information about the meaning of a visual stimulus (Todd et al., 2012). The current findings of smaller amplitude for higher levels of AMB at the time period of the P2 suggest that AMB reflects altered perceptual processing of approach-motivating stimuli that occurs following stimulus identification.

To illustrate the positive difference later in the ERP, plots of two representative electrodes (FC5 and F3) were created (Figure 5d), indicating that high smoothness trials have a less negative deflection at 300 ms as compared to medium or low smoothness. The plots indicate that the difference arises at the beginning of the LPP in frontal and central electrodes. Thus, this result is consistent with a modulation of the LPP onset or amplitude near its onset, with higher smoothness associated with a greater initial LPP amplitude at medial and left-lateralized frontal and central electrode sites.

4.2.2.2 LPP **component for subjective smoothness levels**

Because the LPP is canonically sensitive to emotional/motivational salience, I wished to examine its modulation by AMB. I employed the Mass Univariate Approach to investigate differences in LPP modulation in order to remain consistent with the analytic approach to the early ERP differences and to provide more precise timing and scalp distribution information for the behavioural effect. The same difference waves and analysis parameters were used for the present analysis as the early ERP analysis, with the exception that I are now comparing the subjective smoothness bins at every time point between 400 and 1600 ms (309 time points) at all 64 scalp electrodes, resulting in 19776 comparisons in total.

Significant differences emerged in the high-low (a), but not the high-medium or medium-low comparisons. High subjective smoothness trials resulted in 2664 significant differences from low smoothness trials that were beyond the critical *t*-score of ±3.51 (corresponding to a test-wise alpha of 0.003), with an estimated upper bound of 44.5 false discoveries. Two clusters of differences can be observed (Figure 6a): first, positive differences showing higher amplitudes for images perceived as smoother, are present at frontal and central electrodes at 400 ms, ending at about 914 ms post-stimulus, and are predominantly observed in the left hemisphere. Second, a cluster of negative differences, indicating lower amplitudes for images perceived as smoother, is observed among occipital sites. This difference spreads to parietal and central electrode sites beginning at about 594 ms and continuing until the end of the analyzed period.

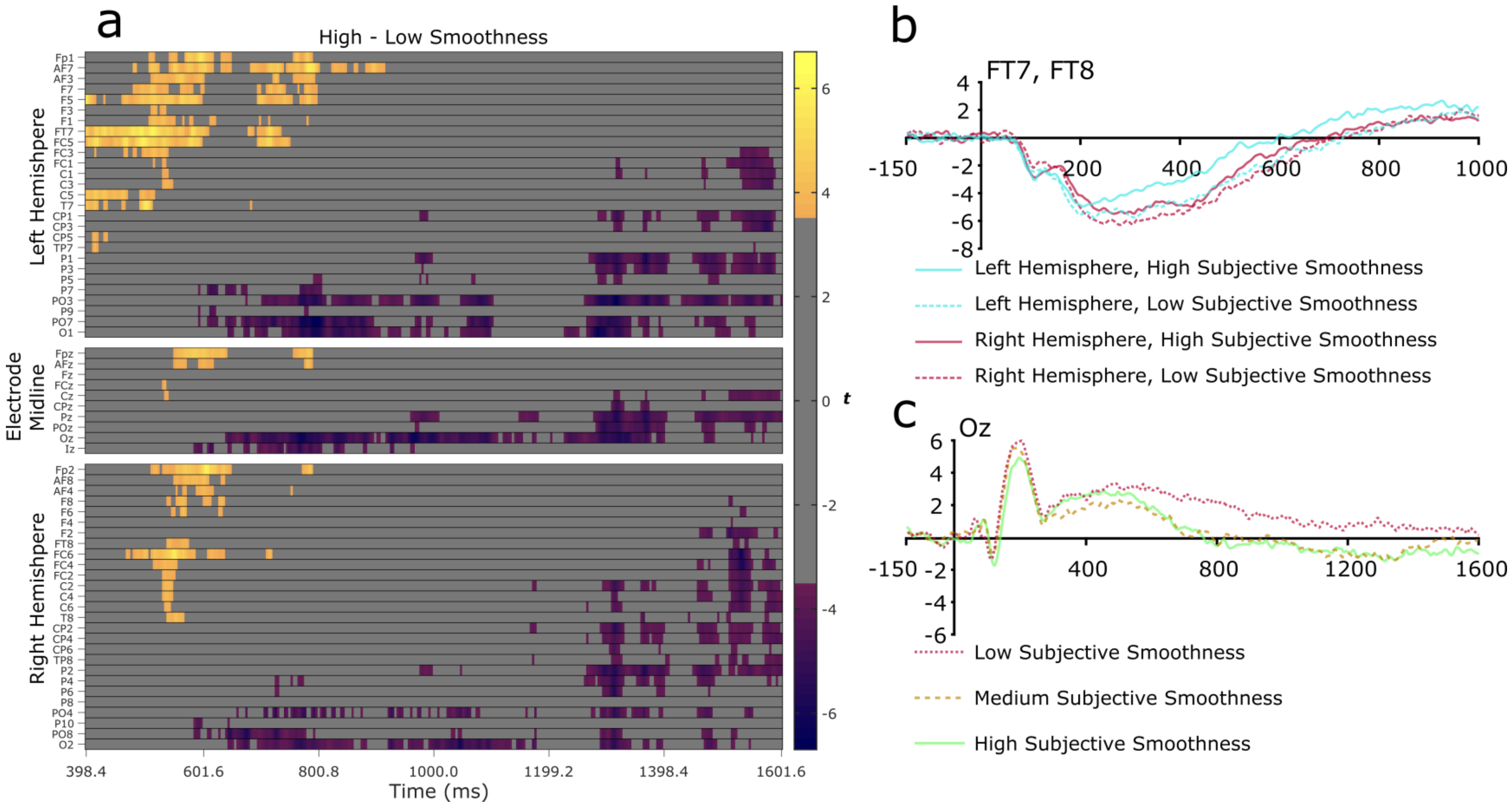

Figure 6. Mass univariate analysis for late in the ERP. (a) Results of t-tests for high minus low subjective smoothness bins for each time point and scalp electrode. Non-significant comparisons are represented by grey cells. A widespread positive cluster of significant *t*-tests is apparent at an early latency (400-900 ms) at fronto-central left-lateralized electrode sites, represented by light yellow-orange cells. A widespread negative cluster of significant *t*-tests is apparent later (~600 ms-1600ms) primarily at occipital and other posterior sites, represented by dark blue-purple cells. (b) ERP plot to illustrate early cluster of significant *t*-tests from mass univariate analysis. The high subjective smoothness bin has an increased amplitude as compared to the low smoothness bin. The more widespread differences observed for left-lateralized electrode sites is due to an increased amplitude in the high smoothness bin for left hemisphere sites as compared to right hemisphere sites. (c) ERP plot to illustrate late cluster of significant *t*-tests from mass univariate analysis. The low subjective smoothness bin has a higher amplitude throughout the examined period as compared to medium or low smoothness.

Plots of fronto-temporal electrodes illustrate the slight lateralization evident in the positive differences (Figure 6b). The plots indicate that the more pronounced differences in the left hemisphere as compared to the right hemisphere are due to an increased LPP amplitude in the high smoothness bin for left hemisphere sites rather than a reduced LPP amplitude in low smoothness bin at left hemisphere sites. Thus, this result is consistent with a slightly lateralized modulation of the LPP, with higher smoothness associated with a larger left-lateralized LPP amplitude.

Plot of a midline posterior electrode (Oz) illustrates the negative differences found in the inferential analysis (Figure 6c). The negative differences observed are due to a lower amplitude for high smoothness at posterior sites as compared to low smoothness trials. Thus, this result is indicative of modulation of late ERP activity at occipital and parietal electrode sites by subjective smoothness. In summary, subjective smoothness ratings were associated with modulation of a left-lateralized LPP, consistent with previous research on appetitive stimuli and the LPP (Gable & Harmon-Jones, 2010). Further, subjective smoothness ratings were associated with differential LPP activity over occipital regions during stimulus presentation, suggesting extended subjective enhancement of visual cortex activity, thought to reflect re-entrant processes, is associated with the effects of approach motivation on experience of seeing. Together, the ERP findings shed light on the behavioural phenomenon of AMB identified by this study, indicating that AMB is associated with modulation of relatively rapid high-level visual processing driven by meaning extraction as well as later sustained elaboration. As a supplemental analysis to confirm canonical patterns of LPP evoked by emotion category elicited by the task, I performed the same analysis on difference waves created for positive-neutral, negative-neutral and positive-negative stimuli (See Supplemental Material). Overall, positive images were associated with modulation of a left-lateralized LPP, consistent with previous research on appetitive stimuli (Gable & Harmon-Jones, 2010), and evoked greatest activation in an early time window (400-650 ms); negative images evoked a large and sustained response both early and late in the LPP time window.

Chapter 5: Cross-experiment Behavioural Analysis

5.1 Methods

Because the sample size was determined based on power to find main effects as observed in the previous studies, I next combined the data from all three experiments for examination of potential interactions and further inferential analysis. Some data recategorization was necessary: in Experiment 3, I varied the standard frame rate rather than the target frame rate, while still asking the participant to indicate how much more or less smooth the target was as compared to the standard. This resulted in a reversed pattern of smoothness ratings across the varied stimulus frame rate as compared to the previous two experiments. In order to correct for this task difference for the combined analysis, the data have been reorganized so that so that the independent variable now corresponds to the objective smoothness of the target as compared to standard (choppier, same, and smoother) rather than the variable stimulus' frame rate.

5.1.1 Participants

Across all experiments, a total of 99 participants had complete smoothness rating data (68 Female; Mean age = 20.8, SD = 2.72). 4 participants were removed due to testing error. A further 20 participants were excluded for rating stimuli at 16 FPS as more smooth on average than 48 FPS among neutral stimuli, leaving 75 participants (52 Female; Mean age = 21.0, SD = 2.94) with acceptable data for analysis. Of these participants, one had missing data for time since last ate and was excluded only for analyses that required this variable.

5.2 Results

5.2.1 Stimulus ratings

Arousal and approach/avoidance ratings of the stimuli (Table 1, Experiment 2) were submitted to two separate mixed ANOVAs to verify differences between stimulus categories across the three experiments. For arousal ratings, there was a main effect of stimulus category, $F(1.65, 118.94) = 162.99$, $p < 0.001$, $\eta_p^2 = 0.69$. Pairwise comparisons revealed a significant difference between all stimulus categories (ps < 0.001), with neutral images rated as least arousing and negative images as most arousing. For ratings of approach/avoidance there was again a main effect of stimulus category, $F(1.56, 112.41) = 230.49$, $p < 0.001$, $\eta_p^2 = 0.76$. Pairwise comparisons revealed a highly significant difference across all levels (ps < 0.001), with negative images rated as more avoid-motivating and positive stimuli as more approach-motivating as compared to neutral. Together, these results confirmed that the stimuli elicited the expected pattern of differential arousal and approach-motivation. Time since last eaten was not significantly correlated with arousal or approach/avoid ratings for positive stimuli, ps > 0.250. There was no effect of experiment on either arousal or approach/avoidance (ps > 0.250) and there was no significant interaction between experiment and arousal ($p = 0.115$) or experiment and approach/avoidance ($p = 0.070$).

5.2.2 Perceived fade smoothness

A 3 X 3 X 3 (Objective Smoothness X Stimulus Category X Experiment) mixed ANOVA was performed on the perceived fade smoothness data (Figure 7a). There was a main effect of objective smoothness, $F(1.39, 100.35) = 64.33$, $p < 0.001$, $\eta_p^2 = 0.47$, observed power = 1.00. All pairwise comparisons between objective smoothness levels were significant (ps < 0.001), with higher objective smoothness resulting in higher smoothness ratings. There was a main effect of stimulus category, $F(1.59, 114.54) = 21.77$, $p < 0.001$, $\eta_p^2 = 0.23$, observed power = 1.00. Pairwise comparisons reveal a significant difference between negative and neutral stimuli ($p = 0.013$) and significant differences between positive and both neutral and negative stimuli (ps < 0.001), where negative was rated as least smooth and positive images as most smooth. There was also an interaction between objective smoothness and stimulus category, $F(4, 288) = 3.81$, $p = 0.005$, $\eta_p^2 = 0.05$, observed power = 0.891. Pairwise comparisons revealed that negative and neutral images were not significantly different from one another at the choppiest objective smoothness ($p > 0.250$) and at the same objective smoothness ($p = 0.124$), while all other comparisons of stimulus category and objective smoothness were significant (ps < 0.004). Thus, positive stimuli were reliably rated as more smooth than neutral across all levels of objective smoothness and negative stimuli were only significantly less smooth than neutral at the highest objective smoothness level. In sum, across experiments, positive images were rated as more smooth and negative images as less smooth than neutral, but the difference between negative and neutral is only reliable at the highest objective smoothness. Overall, positive stimuli more reliably modulate subjective smoothness as compared to negative stimuli (Table 4).

There was also a main effect of experiment $F(2, 72) = 22.31$, $p < 0.001$, $\eta_p^2 = 0.38$. Pairwise comparisons revealed that experiment 1 and 2 did not differ in overall smoothness ratings ($p > 0.250$), while experiment 3 had significantly higher smoothness ratings than experiment 1 and 2 (ps < 0.001). There was no interaction between experiment and emotion ($p > 0.250$), but there was a significant interaction between experiment and objective smoothness, $F(4, 144) = 7.56$, $p < 0.001$, $\eta_p^2 = 0.17$. Simple main effects analyses reveal that at the choppiest objective smoothness, experiment 3 had a significantly higher smoothness rating than experiment

2 ($p = 0.002$) and experiment 1 ($p < 0.001$), and that experiment 1 and 2 were not significantly different ($p = 0.062$). Similarly, at the smoothest objective smoothness, experiment 3 had higher subjective smoothness ratings than experiment 1 ($p = 0.007$) and experiment 2 ($p < 0.001$), and experiment 1 and 2 did not differ significantly ($p > 0.250$). The experiments did not differ in their ratings at the same objective smoothness ($p > 0.250$). The 3-way interaction between stimulus category, objective smoothness, and experiment was not significant ($p = 0.096$). These differences between Experiment 3 and the other two experiments likely reflect the fact that in experiments 1 and 2 frame rate was manipulated on the targets and in experiment 3 it was manipulated in the standard. Yet despite shifts in perceptions of overall smoothness, the effect of approach motivation on relative smoothness ratings remained consistent across experiments.

5.2.3 Stimulus ratings predicting perceived fade smoothness

The same multi-level model as used in Experiment 1, 2, and 3 was employed to investigate the effect of image ratings on perceived fade smoothness, controlling for time since the participant last ate and objective stimulus properties, with experiment modeled as a random effect. Perceived fade smoothness was significantly influenced by stimulus contrast ($\beta = -0.07$, $t = -3.22$, $p = 0.002$) and number of edges ($\beta = -0.05$, $t = -2.20$, $p = 0.031$), such that higher contrast and more edges predict reduced perceived smoothness. With the higher power across experiments, the data also revealed that time since participants last ate also predicted fade smoothness, $\beta = 0.05$, $t = 2.65$, $p = 0.008$, where more time since eating resulted in higher smoothness ratings. As predicted, approach/avoidance ratings were significantly related to perceived fade smoothness, $\beta = 0.08$, $t = 2.96$, $p = 0.005$, such that higher approach ratings result in a more smooth perception of stimulus fades (Figure 7b). This effect was also significant when

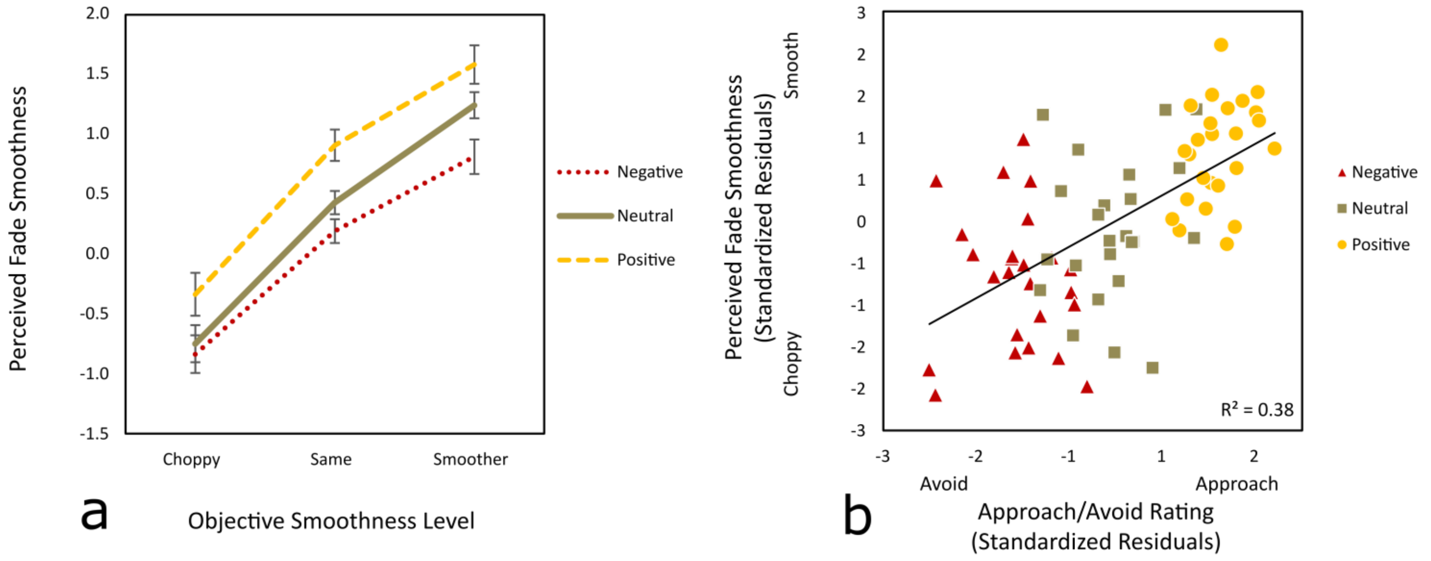

Figure 7. Affective influences on perceived fade smoothness across all three experiments. (a) Effect of stimulus frame rate and stimulus category on perceived fade smoothness. Positive stimuli have a strong effect on smoothness judgments across all objective smoothness levels, while negative images only significantly influence judgements at when the target is smoother than the standard. (b) Plot of standardized residuals of mean Approach/Avoid ratings and Perceived Fade Smoothness for each stimulus, across participants, after controlling for low-level objective stimulus properties. Overall, approach-motivation predicts a more smooth perception of the stimulus, while avoid-motivation predicts choppier perception.

arousal, time since last ate, and objective stimulus characteristics were not included in the model, $\beta = 0.07$, $t = 2.55$, $p = 0.013$. Perceived fade smoothness was not related to saturation ($p > 0.250$) or arousal ratings ($p = 0.174$). Thus, for each image used in the task, the level of approach motivation elicited predicted greater smoothness, consistent with lower rates of sampling underlying speeded time perception.

Chapter 6: Conclusion

6.1 Summary of findings

In the present study I employed a novel psychophysical experimental design to examine the subjective experience of the temporal resolution of emotionally relevant stimuli. I demonstrate that the often noted experience that time flies when you're having fun is embodied in a literal blurring of perceptual experience, or AMB, and its perceptual cortical expression. Together, these experiments demonstrated distinct differences between the subjective moment-to-moment perceptual experience of positive high approach, negative, and neutral stimuli. Although participants were accurate at differentiating between different stimulus frame rates overall, at each individual frame rate approach-motivation resulted in a smoother percept, a phenomenon I refer to as approach-motivated blurring (AMB). In Experiment 2 I replicated the findings after altering the wording of the task to control for potential associations between positive and negative affect and the words "smooth" and "choppy". In Experiment 3 I found AMB modulation of ERP components associated with altered perceptual processing and reentrant processing of the stimulus as the fade unfolded. Experiments 2 and 3 provide convergent evidence suggesting these behavioural results are due to altered experience of seeing rather than demand characteristics. Such AMB is consistent with models positing a mechanism of altered temporal sampling for affectively salient events.

6.2 Relation to previous research

6.2.1 Time-keeping, visual perception, and attentional accounts

Altered experience of duration is often explained in terms of increased or decreased speed of an internal pacemaker (e.g. Burle & Casini, 2001; Droit-Volet et al., 2004; Wearden, Philpott, & Win, 1999). The experiment was designed to probe whether putative changes in pacemaker speed influence moment-to-moment temporal experience, with greater stimulus choppiness reflecting enhanced subjective temporal acuity consistent with slowed time and vice versa. Previous studies have shown that negative stimuli tend to be judged as longer in duration than neutral stimuli (Dirnberger et al., 2012; Droit-Volet et al., 2004), which should result in a longer subjective duration for each frame of the fading stimulus. Similarly, there is evidence that high approach positive stimuli are judged as shorter in duration than neutral items (Gable & Poole, 2012). This would result in shorter perceived time for each frame in the stimulus fade, and thus less ease of distinguishing frames and a "smoother" temporal percept. The results are consistent with these predictions, and support a view of opposing patterns of temporal sampling for high approach and high avoidance stimuli, with decreased temporal sampling for high approach stimuli. In turn, the findings have implications for interpretation of several models.

The Striatal Beat Frequency model (Matell & Meck, 2004) is a recent model that links behavioural findings of temporal duration to neurobiological substrates mediating interval timing. In this model, cortical and thalamic oscillating neuron ensembles code for subjective temporal duration, so that speeded neural oscillations are analogous to an increased clock speed of the pacemaker. This model proposes that dopamine modulates clock speed, such that an increase in dopamine results in a slowed subjective sense of time (Meck, Penney, & Pouthas, 2008). Dopamine's role in reward prediction and expectation is well-established (Berridge & Robinson, 1998), and thus it is expected to play a role in AMB; however, the results suggest the relationship is likely more complex than straightforward increases in sampling with higher levels of dopamine. Future research can employ pharmacological manipulations to examine dopaminergic influences on patterns of neural activation associated with AMB.

One assumption that I made in the design of the experiment was that the pulses of the putative pacemaker used for duration timing relates to differences in visual perception. While the results seem to be consistent with this, this assumption was not directly tested; it remains unclear exactly how the cognitive pacemaker relates to the rate of visual sampling from the environment. One possibility is that increased temporal sampling due to magnocellular pathway facilitation may relate to the speed of the putative pacemaker responsible for time-keeping. If this is true, then the increased temporal resolution of the magnocellular pathway may be partly responsible for the reduced temporal smoothness of the fading stimuli. However, to fully account for the observed AMB effect, positive stimuli must facilitate the parvocellular pathway (or inhibit the magnocellular pathway) thus leading to processing stimuli at a lower temporal frequency. To my knowledge, no such relationship exists, so this seems to be an unlikely mechanism to describe AMB. However, differences in magnocellular processing may still be partly responsible for effects seen in aversive stimuli.

Previous research has noted the crucial importance of attention in evaluations of temporal duration (Buhusi & Meck, 2009). Some evidence suggests that subjective temporal distortions are at least partly due to encoding efficiency, such that mundane stimuli are judged as shorter, while novel stimuli are judged as longer (Eagleman & Pariyadath, 2009). This line of research does not offer an adequate explanation for the data, since both the negative and positive stimuli used in this study are likely engaging more attentional resources than the neutral images (see Vuilleumier, 2005), and yet they have opposing effects on perceived stimulus smoothness. The results are more consistent with evidence that greater attentional deployment to tracking the passage of time results in longer perceived duration (Brown, 1997; Burle & Casini, 2001). Here negative/avoidance-motivating stimuli may result in increased attention to the passage of time;

duration becomes more salient when one is anxious to remove oneself from the current situation. In contrast, positive/approach-motivating stimuli may serve as a distraction from time-keeping as attention may become focused on reward acquisition (Gable & Harmon-Jones, 2008), resulting in less attentional deployment to fine-grained temporal perceptual information.

6.2.2 Event-related potentials

Our electrophysiological examinations revealed early (at ~200 ms) ERP amplitude modulation at occipital electrode sites and a slightly left-lateralized fronto-central LPP as well as a later occipital LPP by AMB. The early occipital modulation is consistent with that of a visual P2, which has been associated with object discrimination (Rousselet et al., 2008). In the experiment, high subjective smoothness was associated with a reduced positive deflection at this time period and spatial distribution, which may indicate modulation of high-level perceptual processes by AMB. Previous research has revealed modulation of a posterior P2 by emotional salience and perceptual vividness (Todd et al., 2012). Such findings are consistent with modulation of visual processing by subjective salience at a latency sufficient to allow extraction of meaning. This pattern of response is also consistent with previously observed amplitude attenuation of the posterior P2 due to attentional processing of visual stimuli (Hackley et al., 1990).

The association between subjective smoothness and the LPP contextualizes the findings within previous studies of ERP effects of affective salience. The LPP is modulated by affective picture content (Cuthbert et al., 2000), and the AMB effect I report here indicates that subjective smoothness is highly associated with affective picture content. Beyond this observation, the LPP results indicate that AMB reflects more than an early "flash" of altered perceptual processing, but also more sustained visual processing likely driven by re-entrant processes. The frontal negativity observed just prior to the LPP may reflect frontal cortical contributions to such re-entrant processes, though future studies will be required to precisely localize such effects.

At left-lateralized frontal and central sites, I also observed increased positive activation for high smoothness images relative to low smoothness images. The left-lateralization is consistent with previous findings showing positively valenced content is associated with a left-lateralized LPP (Cunningham, Espinet, Deyoung, & Zelazo, 2005; van de Laar, Licht, Franken, & Hendriks, 2004). This component has previously been associated with a local spatial attentional bias that can be caused by approach-motivating images (Gable & Harmon-Jones, 2010). Recent research has established robust attentional prioritization of stimuli associated with reward (Chelazzi, Perlato, Santandrea, & Della Libera, 2013). Thus, one interpretation is that greater smoothness is perceived when local attentional processing is induced by approach-motivating stimuli. Future investigations involving independent manipulations of attentional focus may pursue this possibility.

At later latencies at occipital sites, I observed the reverse pattern of higher LPP amplitudes in response to low subjective smoothness. Both emotional arousal and sustained attentional engagement modulate LPP amplitude (Gable & Adams, 2013). Here, as the present study did not manipulate sustained attention, it is not possible to tease apart the two. Future studies can disentangle attentional and affective influences on the late LPP in this task. Nevertheless, it is important to note that this is a daunting task as the LPP is a late ERP deflection reflecting activity of large-scale networks in a highly context dependent fashion. Thus, the direction of differences in amplitude is difficult to interpret as reflecting the degree of activation in underlying brain regions. I prefer a more conservative interpretation of LPP differences as simply reflecting neural discrimination between conditions. In this light, the importance of the LPP findings is that they reflect ongoing neural processing reflecting the behavioural effect of approach motivated blurring in real time during perception of the stimulus. Note that though there was a very evident LPP present in the ERPs, a slight attenuation to the LPP may have occurred due to the 0.1 Hz high-pass filter (Hajcak et al., 2012).

6.3 Limitations and future directions

One limitation to this study is that the affective stimuli varied on multiple dimensions. They differed in valence, arousal, and approach-motivation tendency. The influence of arousal for this effect may not be trivial, since this dimension has been shown to interact with valence in duration estimation (Angrilli et al., 1997), and may influence temporal processing in a non-monotonic fashion (Lambrechts et al., 2011; Noulhiane et al., 2007). Among positive stimuli, more approach-motivating stimuli influence temporal duration comparisons while low-approach positive stimuli do not (Gable & Poole, 2012). In this experiment I was able to look at the influences of these variables on judgements of temporal smoothness, but a more systematic investigation of these dimensions within each valence may provide further insight into the specific relationships between these variables and ongoing temporal experience.

This study employed a purely subjective measure of moment-to-moment visual temporal experience. It is possible that temporal sampling of the environment does increase, either through magnocellular facilitation, or perhaps through modulation of the peak occipital alpha frequency, both of which relate to the temporal resolution of vision (Livingstone & Hubel, 1987; Samaha & Postle, 2015). If either of these mechanisms is at play in AMB, one would expect affective modulation of behavioural performance in a task where the temporal resolution of vision is the primary determining factor on participant performance. Future research can investigate affective influences on performance in a task that evaluates the temporal resolution of vision, while evaluating differences in peak alpha and manipulating magnocellular pathway activity (e.g. via a pulsed pedestal; Chan, Igochine, Hasher, & Pratt, 2016).

References

Amaral, D. ., Behniea, H., & Kelly, J. . (2003). Topographic organization of projections from the amygdala to the visual cortex in the macaque monkey. *Neuroscience*, *118*(4), 1099–1120. http://doi.org/10.1016/S0306-4522(02)01001-1

Angrilli, a, Cherubini, P., Pavese, a, & Mantredini, S. (1997). The influence of affective factors on time perception. *Perception And Psychophysics*, *59*(6), 972–982.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4 [Computer Software].

Benjamini, Y., Krieger, A. M., & Yekutieli, D. (2006). Adaptive linear step-up procedures that control the false discovery rate. *Biometrika*, *93*(3), 491–507. http://doi.org/10.1093/biomet/93.3.491

Berridge, K. C., & Robinson, T. E. (1998). What is the role of dopamine in reward: Hedonic impact, reward learning, or incentive salience? *Brain Research Reviews*, *28*(3), 309–369. http://doi.org/10.1016/S0165-0173(98)00019-8

Bocanegra, B. R., & Zeelenberg, R. (2009). Emotion improves and impairs early vision. *Psychological Science*, *20*(6), 707–713. http://doi.org/10.1111/j.1467-9280.2009.02354.x

Brown, S. W. (1997). Attentional resources in timing: interference effects in concurrent temporal and nontemporal working memory tasks. *Perception & Psychophysics*, *59*(7), 1118–1140. http://doi.org/10.3758/BF03205526

Buhusi, C. V, & Meck, W. H. (2009). Relative time sharing: new findings and an extension of the resource allocation model of temporal processing. *Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences*, *364*(1525), 1875–1885. http://doi.org/10.1098/rstb.2009.0022

Burle, B., & Casini, L. (2001). Dissociation between activation and attention effects in time estimation: Implications for internal clock models. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(1), 195–205. http://doi.org/10.1037/0096-1523.27.1.195

Carretié, L., Hinojosa, J. a, Martín-Loeches, M., Mercado, F., & Tapia, M. (2004). Automatic attention to emotional stimuli: neural correlates. *Human Brain Mapping*, *22*(4), 290–9. http://doi.org/10.1002/hbm.20037

Chan, D., Igochine, L., Hasher, L., & Pratt, J. (2016). Turn up the noise: Increased visual noise in the M-pathway in older adults. *Journal of Vision*, *16*(12), 784. http://doi.org/10.1167/16.12.784

Chelazzi, L., Perlato, A., Santandrea, E., & Della Libera, C. (2013). Rewards teach visual selective attention. *Vision Research*, *85*, 58–72. http://doi.org/10.1016/j.visres.2012.12.005

Cunningham, W. A., Espinet, S. D., Deyoung, C. G., & Zelazo, P. D. (2005). Attitudes to the right- and left: Frontal ERP asymmetries associated with stimulus valence and processing goals. *NeuroImage*, *28*(4), 827–834. http://doi.org/10.1016/j.neuroimage.2005.04.044

Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biological Psychology*, *52*(2), 95–111. http://doi.org/10.1016/S0301-0511(99)00044-7

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. http://doi.org/10.1016/j.jneumeth.2003.10.009

Dirnberger, G., Hesselmann, G., Roiser, J. P., Preminger, S., Jahanshahi, M., & Paz, R. (2012).

Give it time: Neural evidence for distorted time perception and enhanced memory encoding in emotional situations. *NeuroImage*, *63*(1), 591–599. http://doi.org/10.1016/j.neuroimage.2012.06.041

Droit-Volet, S., Brunot, S., & Niedenthal, P. (2004). Perception of the duration of emotional events. *Cognition & Emotion*, *18*(6), 849–858. http://doi.org/10.1080/02699930341000194

Droit-Volet, S., & Meck, W. H. (2007). How emotions colour our perception of time. *Trends in Cognitive Sciences*, *11*(12), 504–513. http://doi.org/10.1016/j.tics.2007.09.008

Eagleman, D. M., & Pariyadath, V. (2009). Is subjective duration a signature of coding efficiency? *Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences*, *364*(1525), 1841–1851. http://doi.org/10.1098/rstb.2009.0026

Fecica, A. M., & Stolz, J. A. (2008). Facial Affect and Temporal Order Judgments. *Experimental Psychology*, *55*(1), 3–8. http://doi.org/10.1027/1618-3169.55.1.3

Gable, P. A., & Adams, D. L. (2013). Nonaffective motivation modulates the sustained LPP (1,000-2,000ms). *Psychophysiology*, *50*(12), 1251–1254. http://doi.org/10.1111/psyp.12135

Gable, P. A., & Harmon-Jones, E. (2008). Approach-Motivated Positive Affect Reduces Breadth of Attention. *Psychological Science*, *19*(5), 476–482. http://doi.org/10.1111/j.1467-9280.2008.02112.x

Gable, P. A., & Harmon-Jones, E. (2010). Late positive potential to appetitive stimuli and local attentional bias. *Emotion*, *10*(3), 441–446. http://doi.org/10.1037/a0018425

Gable, P. A., & Poole, B. D. (2012). Time Flies When You’re Having Approach-Motivated Fun: Effects of Motivational Intensity on Time Perception. *Psychological Science*, *23*(8), 879–886. http://doi.org/10.1177/0956797611435817

Gibbon, J., Church, R. M., & Meck, W. H. (1984). Scalar timing in memory. *Annals of the New*

York Academy of Sciences, *423*, 52–77. http://doi.org/10.1111/j.1749-6632.1984.tb23417.x

Grommet, E. K., Droit-Volet, S., Gil, S., Hemmes, N. S., Baker, a H., & Brown, B. L. (2011). Time estimation of fear cues in human observers. *Behavioural Processes*, *86*(1), 88–93. http://doi.org/10.1016/j.beproc.2010.10.003

Groppe, D. M., Urbach, T. P., & Kutas, M. (2011). Mass univariate analysis of event-related brain potentials/fields I: A critical tutorial review. *Psychophysiology*, *48*(12), 1711–1725. http://doi.org/10.1111/j.1469-8986.2011.01273.x

Hackley, S. A., Woldorff, M., & Hillyard, S. A. (1990). Cross-Modal Selective Attention Effects on Retinal, Myogenic, Brainstem, and Cerebral Evoked Potentials. *Psychophysiology*, *27*(2), 195–208. http://doi.org/10.1111/j.1469-8986.1990.tb00370.x

Hajcak, G., Weinberg, A., MacNamara, A., & Foti, D. (2012). ERPs and the Study of Emotion. In *The Oxford Handbook of Event-Related Potential Components* (pp. 441–472). Oxford University Press. http://doi.org/10.1093/oxfordhb/9780195374148.013.0222

Hancock, P. A., & Weaver, J. L. (2005). On time distortion under stress. *Theoretical Issues in Ergonomics Science*, *6*(2), 193–211. http://doi.org/10.1080/14639220512331325747

Lambrechts, A., Mella, N., Pouthas, V., & Noulhiane, M. (2011). Subjectivity of Time Perception: A Visual Emotional Orchestration. *Frontiers in Integrative Neuroscience*, *5*(November), 1–6. http://doi.org/10.3389/fnint.2011.00073

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8.* University of Florida, Gainesville, FL.

Lee, T. H., Baek, J., Lu, Z. L., & Mather, M. (2014). How Arousal Modulates the Visual Contrast Sensitivity Function. *Emotion*, *14*(5), 978–984. http://doi.org/10.1037/a0037047

Livingstone, M. S., & Hubel, D. H. (1987). Psychophysical evidence for separate channels for the perception of form, color, movement, and depth. *Journal of Neuroscience*, *7*(11), 3416–3468.

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience, 8*(April), 1–14. http://doi.org/10.3389/fnhum.2014.00213

Matell, M. S., & Meck, W. H. (2004). Cortico-striatal circuits and interval timing: Coincidence detection of oscillatory processes. *Cognitive Brain Research*, *21*(2), 139–170. http://doi.org/10.1016/j.cogbrainres.2004.06.012

Meck, W. H. (1996). Neuropharmacology of timing and time perception. *Cognitive Brain Research*, *3*(3–4), 227–242. http://doi.org/10.1016/0926-6410(96)00009-2

Meck, W. H., Penney, T. B., & Pouthas, V. (2008). Cortico-striatal representation of time in animals and humans. *Current Opinion in Neurobiology*, *18*(2), 145–52. http://doi.org/10.1016/j.conb.2008.08.002

Noulhiane, M., Mella, N., Samson, S., Ragot, R., & Pouthas, V. (2007). How emotional auditory stimuli modulate time perception. *Emotion*, *7*(4), 697–704. http://doi.org/10.1037/1528-3542.7.4.697

Phelps, E. a, Ling, S., & Carrasco, M. (2006). Emotion facilitates perception and potentiates the perceptual benefits of attention. *Psychological Science, 17*(4), 292–9. http://doi.org/10.1111/j.1467-9280.2006.01701.x

Qian, C., Al-Aidroos, N., West, G., Abrams, R. A., & Pratt, J. (2012). The visual P2 is attenuated for attended objects near the hands. *Cognitive Neuroscience, 3*(2), 98–104. http://doi.org/10.1080/17588928.2012.658363

R Core Team. (2014). R: A Language and Environment for Statistical Computing [Computer Software].

Rousselet, G. A., Husk, J. S., Bennett, P. J., & Sekuler, A. B. (2008). Time course and robustness of ERP object and face differences. *Journal of Vision*, *8*(2008), 3.1-18. http://doi.org/10.1167/8.12.3

Samaha, J., & Postle, B. R. (2015). The Speed of Alpha-Band Oscillations Predicts the Temporal Resolution of Visual Perception. *Current Biology*, *25*(22), 2985–2990. http://doi.org/10.1016/j.cub.2015.10.007

Todd, R. M., Ehlers, M. R., Müller, D. J., Robertson, A., Palombo, D. J., Freeman, N., … Anderson, A. K. (2015). Neurogenetic Variations in Norepinephrine Availability Enhance Perceptual Vividness. *Journal of Neuroscience*, *35*(16), 6506–6516. http://doi.org/10.1523/JNEUROSCI.4489-14.2015

Todd, R. M., Talmi, D., Schmitz, T. W., Susskind, J., & Anderson, A. K. (2012). Psychophysical and Neural Evidence for Emotion-Enhanced Perceptual Vividness. *Journal of Neuroscience*, *32*(33), 11201–11212. http://doi.org/10.1523/JNEUROSCI.0155-12.2012

van de Laar, M. C., Licht, R., Franken, I. H. a, & Hendriks, V. M. (2004). Event-related potentials indicate motivational relevance of cocaine cues in abstinent cocaine addicts. *Psychopharmacology*, *177*(1–2), 121–129. http://doi.org/10.1007/s00213-004-1928-1

Vuilleumier, P. (2005). How brains beware: neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, *9*(12), 585–94. http://doi.org/10.1016/j.tics.2005.10.011

Wearden, J. H., Philpott, K., & Win, T. (1999). Speeding up and (...relatively...) slowing down an internal clock in humans. *Behavioural Processes*, *46*(1), 63–73. http://doi.org/10.1016/S0376-6357(99)00004-2

West, G. L., Anderson, A. K., Bedwell, J. S., & Pratt, J. (2010). Red diffuse light suppresses the accelerated perception of fear. *Psychological Science*, *21*(7), 992–9. http://doi.org/10.1177/0956797610371966

West, G. L., Anderson, A. K., & Pratt, J. (2009). Motivationally significant stimuli show visual prior entry: evidence for attentional capture. *Journal of Experimental Psychology*. *Human Perception and Performance*, *35*(4), 1032–42. http://doi.org/10.1037/a0014493

Appendices

Appendix A : Tables

Variable	Mean (SD)		
	Experiment 1	Experiment 2	Experiment 3
Negative Approach/Avoid	6.74 (2.74)	6.56 (3.11)	5.16 (2.94)
Neutral Approach/Avoid	10.74 (0.73)	10.54 (1.44)	10.91 (1.02)
Positive Approach/Avoid	13.8 (2.13)	14.35 (2.66)	15.12 (2.51)
Negative Arousal	4.71 (1.28)	5.03 (1.6)	5.67 (1.00)
Neutral Arousal	1.84 (0.65)	2.11 (0.66)	1.84 (0.51)
Positive Arousal	3.49 (1.47)	3.98 (1.63)	3.43 (1.33)
Time since last eaten (minutes)	195.74 (271.32)	290.58 (263.65)	259.94 (304.80)

Table 1. Image ratings and minutes since participant last ate.

	Stimulus Frame Rate					
	16 fps		24 fps		48 fps	
Stimulus Category	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI
Experiment 1						
Negative	-1.74 (1.57)	[-2.42, -1.07]	0.18 (0.71)	[-0.13, 0.48]	0.57 (0.72)	[0.26, 0.88]
Neutral	-1.85 (1.74)	[-2.6, -1.09]	0.30 (0.81)	[-0.05, 0.65]	1.16 (0.87)	[0.78, 1.54]
Positive	-1.44 (1.83)	[-2.23, -0.65]	0.81 (0.86)	[0.44, 1.18]	1.37 (1.04)	[0.93, 1.82]
Experiment 2						
Negative	-0.99 (1.41)	[-1.59, -0.39]	0.00 (0.70)	[-0.30, 0.29]	0.21 (0.88)	[-0.17, 0.58]
Neutral	-0.85 (1.19)	[-1.36, -0.35]	0.46 (0.64)	[0.19, 0.73]	0.74 (0.72)	[0.43, 1.04]
Positive	-0.49 (1.44)	[-1.09, 0.12]	0.82 (1.06)	[0.37, 1.27]	0.93 (1.00)	[0.51, 1.35]
Experiment 3						
Negative	1.82 (1.99)	[0.86, 2.78]	0.25 (0.85)	[-0.16, 0.66]	-0.02 (0.88)	[-0.44, 0.41]
Neutral	2.03 (1.06)	[1.52, 2.54]	0.51 (0.97)	[0.05, 0.98]	0.33 (1.03)	[-0.17, 0.82]
Positive	2.83 (1.94)	[1.90, 3.76]	1.22 (1.36)	[0.57, 1.88]	0.95 (1.31)	[0.31, 1.58]

Table 2. Perceived fade smoothness across stimulus category and stimulus frame rate.

	Image count		
Smoothness Bin	Negative	Neutral	Positive
Low	41	28	6
Medium	21	30	24
High	13	17	45

Table 3. Frequency of image type in ERP smoothness bins.

	p-value		
Experiment	Positive vs. Negative	Positive vs. Neutral	Neutral vs. Negative
1	0.012 *	0.007 **	0.242
2	0.005 **	0.038 *	0.039 *
3	0.028 **	0.056	0.794
Combined	< 0.001 ***	< 0.001 ***	0.013**

Table 4. Pairwise comparisons of stimulus category smoothness ratings. One, two or three asterisks indicate *p* < .05, .01, .001, respectively.