PLOS ONE

Categorical Perception of Emotion Expressions in Whole, Masked and Composite Faces.

--Manuscript Draft--

Manuscript Number:	
Article Type:	Research Article
Full Title:	Categorical Perception of Emotion Expressions in Whole, Masked and Composite Faces.
Short Title:	Categorical Perception of Emotions in Masked Faces.
Corresponding Author:	Martin Wegrzyn Universitat Bielefeld Bielefeld, GERMANY
Keywords:	faces; emotion; expression; categorical perception
Abstract:	Human observers are remarkably proficient at recognizing expressions of emotions and at readily grouping them into distinct categories. When morphing one facial expression into another, the linear changes in low-level features are insufficient to describe the changes in perception, which instead follow an s-shaped function. Important questions are, whether there are single diagnostic regions in the face that drive categorical perception, and how the information in those regions interacts when presented together. We report results from two experiments with morphed fear-anger expressions, where (a) half of the face was masked or (b) composite faces made up of different expressions were presented. When isolated upper and lower halves of faces were shown, the eyes were found to be almost as diagnostic as the whole face, with preserved categorical perception. In contrast, the mouth allowed for a substantially lesser amount of accuracy and nearly absent categorical perception. When a composite face consisting of mismatched upper and lower halves was used and observers were instructed to exclusively judge either the expression of mouth or eyes, the to-be-ignored part always influenced perception of the target region. In line with experiment 1, the eye region exerted a much stronger influence on mouth judgements than vice versa. Again, categorical perception was significantly more pronounced for upper halves of faces. The present study shows that identification of fear and anger in morphed faces relies heavily on information from the upper half, particularly the eye region. Categorical perception is possible when only the upper half is present, but compromised when only the lower part is shown. Moreover, observers nevertheless tend to integrate all available features, even when trying to focus on only one face part.
Order of Authors:	Martin Wegrzyn
	Isabelle Bruckhaus
	Johanna Kissler
Opposed Reviewers:	
Additional Information:	
Question	**Response**
Financial Disclosure Please describe all sources of funding that have supported your work. A complete funding statement should do the following:	Research was funded by the Deutsche Forschungsgemeinschaft (DFG; www.dfg.de), Cluster of Excellence 277 “Cognitive Interaction Technology”, in form of a scholarship awarded to MW. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Include **grant numbers and the URLs** of any funder's website. Use the full name, not acronyms, of funding institutions, and use initials to identify authors who received the funding. **Describe the role** of any sponsors or funders in the study design, data collection and analysis, decision to publish, or preparation of the manuscript. If they had no role in any of the above, include this sentence at the end of your statement: "*The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.*" If the study was **unfunded**, provide a statement that clearly indicates this, for example: "*The author(s) received no specific funding for this work.*" * typeset	
Competing Interests You are responsible for recognizing and disclosing on behalf of all authors any competing interest that could be perceived to bias their work, acknowledging all financial support and any other relevant financial or non-financial competing interests. Do any authors of this manuscript have competing interests (as described in the PLOS Policy on Declaration and Evaluation of Competing Interests)? **If yes**, please provide details about any and all competing interests in the box below. Your response should begin with this statement: *I have read the journal's policy and the authors of this manuscript have the following competing interests:* **If no** authors have any competing interests to declare, please enter this statement in the box: "*The authors have declared that no competing interests exist.*" * typeset	The authors have declared that no competing interests exist.

Ethics Statement You must provide an ethics statement if your study involved human participants, specimens or tissue samples, or vertebrate animals, embryos or tissues. All information entered here should **also be included in the Methods section** of your manuscript. Please write "N/A" if your study does not require an ethics statement. **Human Subject Research (involved human participants and/or tissue)** All research involving human participants must have been approved by the authors' Institutional Review Board (IRB) or an equivalent committee, and all clinical investigation must have been conducted according to the principles expressed in the Declaration of Helsinki. Informed consent, written or oral, should also have been obtained from the participants. If no consent was given, the reason must be explained (e.g. the data were analyzed anonymously) and reported. The form of consent (written/oral), or reason for lack of consent, should be indicated in the Methods section of your manuscript. Please enter the name of the IRB or Ethics Committee that approved this study in the space below. Include the approval number and/or a statement indicating approval of this research. **Animal Research (involved vertebrate animals, embryos or tissues)** All animal work must have been conducted according to relevant national and international guidelines. If your study involved non-human primates, you must provide details regarding animal welfare and steps taken to ameliorate suffering; this is in accordance with the recommendations of the Weatherall report, "The use of non-human primates in research." The relevant guidelines followed and the committee that approved the study should be identified in the ethics statement. If anesthesia, euthanasia or any kind of	The study was approved by the ethics board of Bielefeld University (Ethic Statement Nr. 2014-010). All participants gave oral informed consent before taking part in the experiments. The ethics board of Bielefeld University advises researchers to use oral informed consent so that full anonymity can be ensured (cf. http://www.uni-bielefeld.de/Universitaet/Ueberblick/Organisation/Organisationseinheiten/Kommissionen/Ethikkommission/Antrag/Handreichung-28-11-2014.pdf (document in German language))

animal sacrifice is part of the study, please include briefly in your statement which substances and/or methods were applied. Please enter the name of your Institutional Animal Care and Use Committee (IACUC) or other relevant ethics board, and indicate whether they approved this research or granted a formal waiver of ethical approval. Also include an approval number if one was obtained. **Field Permit** Please indicate the name of the institution or the relevant body that granted permission.	
Data Availability PLOS journals require authors to make all data underlying the findings described in their manuscript fully available, without restriction and from the time of publication, with only rare exceptions to address legal and ethical concerns (see the PLOS Data Policy and FAQ for further details). When submitting a manuscript, authors must provide a Data Availability Statement that describes where the data underlying their manuscript can be found. Your answers to the following constitute your statement about data availability and will be included with the article in the event of publication. **Please note that simply stating 'data available on request from the author' is not acceptable.** ***If, however, your data are only available upon request from the author(s), you must answer "No" to the first question below, and explain your exceptional situation in the text box provided.*** Do the authors confirm that all data underlying the findings described in their manuscript are fully available without restriction?	Yes - all data are fully available without restriction
Please describe where your data may be found, writing in full sentences. **Your answers should be entered into the box below and will be published in the form you provide them, if your manuscript is accepted.** If you are copying our sample text below, please ensure you replace any instances of XXX with the appropriate details.	All relevant data are within the paper and its Supporting Information files.

If your data are all contained within the paper and/or Supporting Information files, please state this in your answer below. For example, “All relevant data are within the paper and its Supporting Information files.” If your data are held or will be held in a public repository, include URLs, accession numbers or DOIs. For example, “All XXX files are available from the XXX database (accession number(s) XXX, XXX)." If this information will only be available after acceptance, please indicate this by ticking the box below. If neither of these applies but you are able to provide details of access elsewhere, with or without limitations, please do so in the box below. For example: “Data are available from the XXX Institutional Data Access / Ethics Committee for researchers who meet the criteria for access to confidential data.” “Data are from the XXX study whose authors may be contacted at XXX.” * typeset	
Additional data availability information:	

Universität Bielefeld **Department of Psychology**

University of Bielefeld | P.O. Box 10 01 31 | 33501 Bielefeld

Martin Wegrzyn

Room: T5-213
Tel.: ++49 521-106-4527
Fax: ++49 521.106-6422
martin.wegrzyn@uni-bielefeld.de
www.uni-bielefeld.de/psychologie/ae/AE02/

PLOS ONE

Editiorial Board

United Kingdom

Bielefeld, 3 March 2015

Manuscript submission for publication in PLOS ONE.

Dear Editor,

enclosed please find our manuscript entitled *"Categorical Perception of Emotion Expressions in Whole, Masked and Composite Faces"*, which we would like to submit for publication in *PLOS ONE* as a research article.

Investigating how humans recognize emotional expressions in faces is an important aim of psychological science. While we know that humans are remarkably proficient in grouping facial expressions into distinct categories, we do not know what information in the face needs to be present for this categorical perception to occur. To our knowledge, we present the first study describing categorical perception in masked faces, when only partial information is available to the observer.

In our study**,** participants viewed morphed fearful and angry faces and had to identify the expressed emotion. Observers were presented with either masked faces, showing only partial information, or with composite faces, where conflicting information was visible in the face. By this, we were able to investigate which information in the face is most diagnostic in isolation and how face parts of different diagnostic value influence each other when presented together. Our results clearly demonstrate that the eyes and upper face half allow for categorical perception on a very high level, while the mouth and lower face half do not. Also, we demonstrate a strong interference from the eyes when trying to judge the expression of the lower face half. Hence, participants seemed unable to ignore a highly diagnostic face part, even if actively trying to do so. Therefore, we believe that our findings will highly appeal to the readership of *PLOS ONE*. We would like to suggest Chris I. Baker, Kun Guo, Marco Tamietto and Andreas Keil as possible Academic Editors to handle the manuscript.

The manuscript and the data have not been published previously and they are not under consideration for publication elsewhere. All listed authors have contributed significantly to the manuscript and have agreed to publish it in *PLOS ONE* in its present form. We would appreciate a positive review and are looking forward to your reply.

Sincerely for the authors,

M. Wegrzyn

Martin Wegrzyn

Categorical Perception of Emotion Expressions in Whole, Masked and Composite Faces.

Martin Wegrzyn[1,2,*], Isabelle Bruckhaus[1] & Johanna Kissler[1,2]

[1]Department of Psychology, Bielefeld University, Bielefeld, Germany

[2]Center of Excellence Cognitive Interaction Technology (CITEC), Bielefeld University, Bielefeld, Germany

Manuscript Requirements:

Title: 83 Characters

Abstract: 277 Words

Text: 5004 Words

References: 34

Tables: 0

Figures: 7

***Corresponding Author:**

Martin Wegrzyn

Bielefeld University

Department of Psychology

Postfach 10 01 31

33501 Bielefeld

Tel. +49 521-106-4527

Fax. +49 521-106-154454

martin.wegrzyn@uni-bielefeld.de

ABSTRACT

Human observers are remarkably proficient at recognizing expressions of emotions and at readily grouping them into distinct categories. When morphing one facial expression into another, the linear changes in low-level features are insufficient to describe the changes in perception, which instead follow an s-shaped function.

Important questions are, whether there are single diagnostic regions in the face that drive categorical perception, and how the information in those regions interacts when presented together.

We report results from two experiments with morphed fear-anger expressions, where (a) half of the face was masked or (b) composite faces made up of different expressions were presented.

When isolated upper and lower halves of faces were shown, the eyes were found to be almost as diagnostic as the whole face, with preserved categorical perception. In contrast, the mouth allowed for a substantially lesser amount of accuracy and nearly absent categorical perception.

When a composite face consisting of mismatched upper and lower halves was used and observers were instructed to exclusively judge either the expression of mouth or eyes, the to-be-ignored part always influenced perception of the target region. In line with experiment 1, the eye region exerted a much stronger influence on mouth judgements than vice versa. Again, categorical perception was significantly more pronounced for upper halves of faces.

The present study shows that identification of fear and anger in morphed faces relies heavily on information from the upper half, particularly the eye region. Categorical perception is possible when only the upper half is present, but compromised when only the

lower part is shown. Moreover, observers nevertheless tend to integrate all available features, even when trying to focus on only one face part.

1. INTRODUCTION

Facial expressions are a powerful means of conveying information about the emotional state of an individual. Recognizing and correctly interpreting these non-verbal signs is of vital importance for successful social interaction [1].

Faces are not only complex stimuli, but their expressions can often be subtle and ambiguous. Despite this, human observers can readily recognize expressions of emotions and assign them distinct labels. A large body of research suggests that there are a number of basic emotions which are correctly recognized by almost any observer [2], although their exact number is under debate [3]. Even when the expression's intensity varies continuously, as in manipulated faces where one expression is gradually morphed into another, human observers readily group them into distinct categories with a high level of confidence [4].

This is demonstrated by identification tasks where linear changes in low-level features lead to non-linear changes in perception, best described by a sigmoid function with a steep category boundary. Categorical perception of facial expressions has been demonstrated in a number of seminal studies [5–7]. In general, categorical perception refers to the phenomenon that objects from the same category will be perceived as more similar than objects from different categories [8], despite being equally far apart from each other on a given physical dimension. One example is human colour perception, where two different wavelengths will only be perceived as two different colours when a category boundary is crossed [9].

Faces are inherently multidimensional stimuli, and in face processing categorical perception can relate to different dimensions (identity, age, attractiveness, gender, emotion), which in turn may depend on different facial features. Regarding emotion, each expression of a basic emotion can be described in terms of a number of muscle groups that are active when a person shows that particular emotion [10]. For example, fear will most frequently be expressed in the face by the brows raised and drawn together, the upper eyelids raised, the lower eyelids tensed, the lips stretched back and, in some cases, the mouth opened [11,12]. Furthermore, masking studies have demonstrated that each basic emotion is recognized through different diagnostic areas of the face [13]. For example, fear can be best recognized when the eyes are visible, while happiness is best inferred from the mouth region. On the other hand, eye tracking studies have shown that for all six basic expressions, including ones of low intensity, people focus primarily on the eyes [14]. While eye tracking studies shed light on how observers usually inspect faces, masking studies help to understand what information is indispensable in order to make a correct decision. Therefore a masking approach helps to make causal inferences about the diagnostic value of each facial feature.

To understand categorical perception of facial expressions, it is essential to know which information in the face is used to make a categorical decision and how facial features are integrated into a perceptive whole, so that successful categorization can occur.

It is known that faces are preferentially processed as a whole, in what is referred to as holistic processing [15–17]. For example, in the composite face illusion complementary upper and lower face halves are combined into a whole face. This renders it considerably more difficult to make a decision about the properties of either half, compared to judging each part in isolation [18]. It may be more difficult to recognize a person's identity from a lower face half when it has been combined with the upper face half of another person, while the same task is easy when each half is presented in isolation [18]. The composite face illusion has also been used to investigate facial expressions: Using happy and angry faces, interference from composites with mis-matching expressions have been found reflected in slower reaction times [19,20].

So far, both masking studies [13] and composite face paradigms [20] used full-blown facial expressions instead of gradually morphed faces. Chen and Chen [21] have used morphed happy-sad expressions in a composite face, but always asked to judge the whole face and not its parts, therefore making it difficult to draw inferences on how the perception of one facial feature is influenced by another one.

Masking or composite face studies with morphed faces however allow to better describe human behaviour in psychophysical terms, as the subjective perception dissociates from the changes in low-level features. They also allow to better understand how we process subtle and ambiguous expressions, which are arguably most relevant in daily life. Therefore, it is useful to investigate the relationship of categorical perception and featural (i.e. focusing on single parts) or configural (i.e. integrating parts into a whole) face processing. Main questions are, whether there are diagnostic regions in the face that are sufficient to allow for categorical perception, and whether multiple features need to be integrated when making categorical judgements. Therefore, to better understand mechanisms of categorical perception of facial expressions, a promising approach is to break down the face into its features and understand how each contributes to identifying a certain expression. In a second step, the features can be re-assembled into a whole and one can investigate how they are integrated to infer an expression from a whole face.

To address these questions, two experiments with faces morphed from fear to anger were performed. Masking studies show that both expressions are mainly recognized from the eye region [13] and studies with neurological patients also point to a special role of the eyes for recognizing fear [22]. Beginning with the seminal work by Etcoff and Magee [7], fear-anger pairings have been frequently used in investigating categorical perception (e.g. [5,6] ; cf. [8]).

In the present study, the first experiment was carried out to investigate how observers make categorical decisions from morphed faces when only a limited amount of features is present. In this experiment, an upper face half, a lower face half, or an intact face was shown and observers were asked to rate each morph as being either angry or fearful. The second experiment investigated how this relates to performance in a composite face task, when participants have to ignore one half of the face to make an optimal decision. In this experiment, a face assembled of an upper and lower half was presented. The observers had to judge only one half at a time, while the distractor half was showing either full-blown anger of fear. Together, these experiments aim to elucidate the psychophysics of perception of facial expression.

2. EXPERIMENT 1

2.1 Participants

30 participants took part in the experiment (22 female). Mean age of participants was 25 years (range: 18-32). Participants received course credit or 5 EUR for participation. Participants reported no history of neurological or psychiatric illness and had normal or corrected-to-normal vision. The study was approved by the ethics board of Bielefeld University. All participants gave oral informed consent before taking part in the experiment.

Two participants showed performance close to guessing for all conditions combined with exceptionally fast reaction times, indicative of non-compliance. Their data were excluded, leaving 28 participants for further analysis.

2.2 Material

Anger and fear pictures of 20 identities (10 male, 10 female) were selected from the KDEF [23] and NimStim [24] databases. The pictures were used to generate morphs in 9 steps with Gimp 2.6 (www.gimp.org) and the GAP toolbox, resulting in 11 morphing grades including the original images. Faces were divided into an upper and lower half, with the border defined as being above the nostrils at the bridge of the nose of the middle morph. This border was defined for each face identity and subsequently applied to all of its morphs.

In Experiment 1 there were three visibility conditions (whole face, upper half, lower half).

The half of no interest was blurred with a very broad Gaussian filter, preserving only a rough outline of the face, thereby conveying a feeling of wholeness, while rendering the masked features invisible (cf. Fig. 1).

[Figure 1. Design of Experiment 1. Illustration of a face morphed from the original fearful (outer left) to the original angry expression (outer right) in 9 intermediary steps, resulting in a total of 11 face morphs; a, whole face; b, upper half intact ('eyes' condition); c, lower half intact ('mouth' condition); due to copyright restrictions, the depicted example is an in-house generated face which was not used in the present experiment.]

2.3 Design

A two-alternatives forced choice identification task was used, in which participants had to decide for each face whether its expression was 'angry' or 'fearful'. Each of the 20 identities was presented in 11 morphing grades. The experiment consisted of two runs with a total of 40 trials per cell, resulting in a resolution of 2.5% for identification performance. The first run was repeated after a short break, to allow for analyses of intra-subject stability. This resulted in a total of 440 trials per masking condition (11 morphs x 20 identities x 2 runs). Pictures were shown with no time limit until a response was given, after which the next stimulus was shown directly, to allow for smooth work-flow. Participants were able to monitor their progress on a status bar presented at the bottom of the screen. Order of stimuli was randomized, the only constraint being that two subsequent trials never contained the same face identity.

Participants had to press the left or right mouse button to indicate whether the target face part showed an angry or fearful expression (button assignment counterbalanced between participants). Experiments were performed using Presentation software (Version 17.1, www.neurobs.com). All experiment files, including raw data, can be found in the online supplement.

2.4 Analysis

Data analysis was performed with Python 2.7.5 (www.python.org) using NumPy, SciPy, Pandas, Matplotlib and the IPython Notebook, all as provided with Anaconda 1.8.0 (Continuum Analytics; docs.continuum.io/anaconda). Full code and output for all analyses can be found in the online supplement. Refer to S1 and S2 for data import and restructuring; S3 for main data analysis; S4 for fitting psychometric functions and cross-validation; and to S5 for analyses of single face identities.

To characterise the participants' performance, linear and logistic functions were fitted to their data. The linear function ($F_{linear}(x;\alpha,\beta)=\beta*x+\alpha$) should correspond best to changes in low-level features and would be a good fit if observers' performance closely followed the basic image properties. The logistic function ($F_{logistic}(x;\alpha,\beta)=1/[\ 1+\exp(-\beta(x-\alpha))\ ]$) is well-suited to describe observers' performance in psychometric terms [25, p. 82] and should provide an optimal fit if the observers engage in categorical perception. It also provides slope information (β parameter), to quantify how steep the category boundary is for a certain condition.

Furthermore, for cross-validation, data from one half of the experiment were used to predict the other half of the data. Since each participant performed every trial twice, data from the first half of the experiment were used to predict the data from the second half (and vice versa). This allowed assessing whether the model that can best describe the data is also best in predicting new measurements. That is, whether one is able to predict what condition a participant was in, given the responses made in a previous run and the function fitted to that data. In all cases, goodness of fit was assessed by computing sums of squared errors (ss^2). The more similar two conditions are, or the more similar a fitted function is to left-out data, the smaller the ss^2 should be. Using sums of squared errors has the advantages of being an intuitive measure of similarity and being virtually assumption-free [26, p. 106].

2.5 Results

2.5.1 Comparison of response curves for different masking types

Identification performance was compared across all 11 morphing grades using paired t-tests for repeated measures and the Wilcoxon signed rank test as its non-parametric equivalent. Results were only considered significant if the p-value for both metrics fell below $\alpha=0.05$. Participants' performance is illustrated in Fig. 2.

Identification performance was significantly best (i.e., farthest from guessing for the whole face, compared both to the upper (all $p<.05$, except 50% angry morphs) and lower half (all $p<0.05$, except 60% angry morphs). Furthermore, performance was significantly better for the upper than for the lower half (all $p<.05$ except for 50% and 60% angry morphs). This indicates that observers were able to make the most accurate decisions when presented with a whole face, followed by face halves containing only the eye region and only the mouth region, respectively.

Judgements of the eye region closely resembled the whole face responses, as indicated by a significantly smaller difference between upper and whole face decisions compared to lower and whole face decisions (all $p<0.05$ for pairwise comparisons of differences, except for 50% and 60% morphs).

[**Figure 2. Main Results Experiment 1.** Percent angry responses (y-axis) across the 11 morphing grades morphed from fear to anger (x-axis) for the three different visibility conditions (coloured lines); smaller right hand figures depict responses on single-participant level for each condition; 'whole', whole face is visible (no masking); upper', upper face half is visible (lower half is masked); 'lower', lower face half is visible (upper half is masked).]

2.5.2 Cross-validation of conditions

If differences between conditions are genuine and stable, each condition should be best at predicting itself, e.g. the whole face condition of the first half of the experiment should be most similar to the whole face condition of the second half.

This was confirmed by split-half cross-validation with each half of the experiment used once as test and as training set, within each participant. Each condition was significantly closest to its analogue form the other half of the experiment, as expressed in significantly smallest ss^2 for these pairings (all $p<0.01$ for pairwise comparisons).

Furthermore, the upper and whole face conditions were significantly more similar to each other than to the lower half condition ($p<0.01$). This stronger similarity of the eye region to the whole face ratings further corroborates that the upper half carries more information about fear and anger expressions than does the mouth region.

2.5.3 Comparison of linear and logistic fit to the data

A linear and logistic function were both fitted to the data of each participant and ss^2 were computed for all three masking conditions (Fig. 3a), with a better fit indicated by smaller ss^2. The logistic function provided the significantly best fit for all three conditions (all $p<0.01$ for pairwise comparisons). The superiority of the logistic over the linear function was significantly greatest for the whole face, followed by the upper face half , and lower face half, respectively (pairwise comparisons regarding the logistic-linear difference; all $p<0.001$).

[Figure 3. Curve Fitting for Experiment 1. Results of fitting different functions to the data set; red bars indicate 95% confidence intervals of the mean for each condition; line graphs in the background depict the raw data of each participant; black lines indicate that the participant's value for the left-hand condition is numerically smaller than the right-hand value; blue line indicates that the value is bigger for the left-hand compared to right-hand condition; a, fit of a logistic or a linear function to the data, with smaller sums of squared errors (ss^2) indicating a better fit; b, slope parameter of a logistic function fitted to the data; higher value indicates steeper slope; c, ss^2 of training and test data (split-half within each participant) indicating similarity of training and test data, with smaller ss^2 indicating closer resemblance of training and test set; 'log', logistic function, 'lin', linear function, 'raw', raw data; 'whole', whole face is visible (no masking); 'upper', upper face half is visible (lower half is masked); 'lower', lower face half is visible (upper half is masked).]

2.5.4 Comparison of the slopes of the logistic function between conditions

When fitting a logistic function to each participant's data for each condition, the steepness of the slopes can be compared as measure for the presence of a category boundary, with a steep slope indicating stronger categorical perception (Fig. 3b).

Results show that the slopes were steepest for the whole face condition, followed by the upper and lower half (all $p<0.001$). Thus, categorical perception was strongest when all face features were visible and weakest when only the mouth region was shown.

2.5.5 Cross-validation of response curves for different masking types

One can investigate whether left-out data can be best predicted by using raw data from the training set or by a linear or logistic function fitted to the training data. If left-out data can be better predicted by a fitted function than with the raw data used to fit that function, this might indicate that the simplifying assumption made by the psychometric function are sensible and add to our understanding of the underlying perceptual mechanisms.

The results of the cross-validation analysis (Fig. 3c; one extreme outlier with very bad fit ($z>4.8$) removed) show that the logistic function is significantly best for predicting left-out data compared to both a linear function and to the left-out raw data. This holds true for all three masking conditions (all $p<0.05$ in pairwise comparisons). This indicates that an s-shaped function is best suited for describing the observers' responses in the present experiment.

3. EXPERIMENT 2

3.1 Methods

Mean age of participants was 24 years (range 19-29). Of the 30 participants, 24 were female. Participants received course credit or 7EUR for participation and gave oral informed consent before starting the experiment.

The same boundary to divide faces into lower and upper halves as in experiment 1 was used and all other design choices were identical to experiment 1, with the following exceptions: This time 100% fearful or 100% angry expression halves were combined with the morphed pictures to create the composite face illusion. There were four conditions: 'lower half 100% angry' (Fig. 4a), 'lower half 100% fearful (Fig. 4b), 'upper half 100% angry' (Fig. 4c) and 'upper half 100% fearful' (Fig. 4d). The complementary half was presented in 11 morphing steps, and was the part which the observers were asked to identify as either angry of fearful. This part was always framed by a red square (cf. Fig. 4). Participants were explicitly instructed to focus only on the framed face half and to ignore the other half. Unlike experiment 1, order of conditions was blocked, to make it easier for the participants to focus on the part of interest. Each block required either always judging the upper half or always judging the lower half, and consisted of 440 trials, with block order counterbalanced between participants. Within blocks, order of the 20 face identities, the 11 morphed face halves and whether the to-be-ignored half was fearful or angry were randomised.

[Figure 4. Design of Experiment 2 (Composite Face). Illustration of a face morphed from the original fearful (outer left) to the original angry expression (outer right) in 9 intermediary steps, resulting in a total of 11 face morphs; a, eye judgements with 100% angry lower face half; b, eye judgements with 100% fearful lower half; c, mouth judgements with 100% angry upper face half; d, mouth judgements with 100% fearful upper half; conditions a and b or conditions c and d were always presented in one block, to aid participants in focusing on one face half only; due to copyright restrictions, the depicted example is an in-house generated face which was not used in the present experiment.]

One participant reported to have only focused on the mouth region throughout the experiment, ignoring which face half was currently framed. These data were excluded, leaving 29 data sets for analysis.

3.2 Results

3.2.1 Comparison of response curves for different composite faces

Depending on the viewing condition, responses for the attended face half were biased in the direction of the to-be-ignored face half (Fig. 5a). Responses for the eye region were shifted towards anger when the lower face half was angry, and towards fear when the lower half was fearful ($p<0.01$ for all 11 morphing grades). The same bias occurred for the judgements of the mouth region, when the upper half was either angry or fearful (Fig. 5c; all $p<0.001$).

The bias was significantly stronger for mouth judgements than for eye judgements, indicating that the upper face half exerts a stronger influence on the lower half than vice versa. Across all 11 morphing grades, fearful and angry distracting halves led to bigger differences in mouth judgements, as compared to the differences in eye judgements (all $p<0.001$, for pairwise comparisons of differences).

[**Figure 5. Main Results for Composite Faces.** Percent angry responses (y-axis) across the 11 morphing grades morphed from fear to anger (x-axis) for the four different composite face conditions (coloured lines); left-hand figures depict mean results with 95% confidence intervals on group level; right-hand figures depict responses on single-participant level for each condition; 'lower half fearful', observers judge the upper half, while the lower half is always 100% fearful; 'lower half angry', observers judge the upper half, while the lower half is always 100% angry; 'upper half fearful', observers judge the lower half, while the upper half is always 100% fearful; 'upper half angry', observers judge the lower half, while the upper half is always 100% angry.]

3.2.2 Cross-validation of conditions

Split-half cross-validation with each half of the experiment used once as test and as training set showed that each condition was significantly closest to its analogue form the other half of the experiment (all $p<0.01$, pairwise comparisons), indicative of reliable differences between conditions.

3.2.3 Comparison of linear and logistic fit to the data

When fitting a logistic and linear function, the logistic function provided a significantly better fit to the data (Fig. 6a), but only when observers judged the upper face half ($p<0.05$, pairwise comparisons; two extreme outliers ($z>4.8$) with bad fit removed). When comparing the fit between conditions, the superiority of a logistic function over a linear function was significantly stronger for eye judgements as compared with mouth judgements (all $p<0.05$ for pairwise comparisons of differences).

[**Figure 6. Curve Fitting for composite faces.** Results of fitting different functions to the data set; red bars indicate 95% confidence intervals of the mean for each condition; line graphs in the background depict the raw data of each participant; 'rating upper/lower fearful', observers judge the upper half, while the lower half is always 100% fearful; 'rating upper/lower angry', observers judge the upper half, while the lower half is always 100% angry; 'rating lower/upper fearful', observers judge the lower half, while the upper half is always 100% fearful; 'rating lower/upper angry', observers judge the lower half, while the upper half is always 100% angry; for more information please refer to the legend of figure 3.]

3.2.4 Comparison of the slopes of the logistic function between conditions

When fitting a logistic function to each participant's data for each of the three conditions, the steepness of the slopes was significantly higher for upper than for lower face half judgements (Fig. 6b; all $p<0.001$, pairwise comparisons), indicative of a more pronounced categorical perception when making decisions about the upper half. However, since lower half judgements were biased by the eye region to the point where for many participants performance never crossed 50% guessing, slope parameters for the mouth regions are difficult to interpret.

3.2.5 Cross-validation of response curves for different masking types

In analogy to experiment 1, left-out data from one half of the experiment were predicted using data from the other half of the experiment. The two runs of the experiment were used for cross-validation. Each condition was modelled for one half of the experiment using either raw data or a linear or logistic function fitted to these data. These training sets were then compared to the left-out half of the experiment to check how the models compare to each other in predicting new data.

The logistic function was significantly better than a linear function at predicting upper half judgements, when a fear mouth was present ($p<0.05$, pairwise comparison) but was only numerically superior when an anger mouth was present (Fig. 6c).

For the lower half judgements, the linear function was significantly best for predicting left out-data, compared both to the raw data or a fitted logistic function (all $p<0.001$ for pairwise comparisons), indicating that ratings of the lower face half are well-described by linear shifts in the response criterion.

4. RESULTS FOR SINGLE FACE IDENTITIES

Since 20 different face identities were used as stimuli in the experiments, the present results may underestimate or blur the sigmoid shape of the response functions, due to averaging over a heterogeneous set of stimuli with shifted intercepts.
Therefore, data of both experiments were re-analysed by fitting a logistic function to the responses to each of the 20 individual face identities, averaged over participants. Subsequently, the intercepts were shifted to be uniformly at 50%, so that each curve is at 50% guessing (y-axis) when the face is 50% angry (x-axis). The necessary shift was determined from the fitted logistic functions and then applied to the underlying raw data, allowing to compare how the curves would be shaped, given equal intercepts for all face identities. The results are illustrated in Fig. 7 and are described in-depth in Supplement S5. Visual inspection of the data suggests that a sigmoid function clearly emerges for whole face and upper halves in experiment 1 and for upper halves in experiment 2 even when accounting for potential variability between faces.

[**Figure 7. correction for different intercepts between face identities.** Main analyses for both experiments after modelling responses to each face identity individually and shifting the intercepts to be uniformly at 50%; a, results for experiment 1 (masking); b, results for experiment 2 (composite faces); note that a different number of data points is available for each bin on the x-axis, and therefore estimates at the extremes are less reliable; especially in experiment 2, mouth judgements were strongly biased, with few responses at 50% guessing; please refer to Supplement S5 for more details on the analysis procedure.]

5. DISCUSSION

The present study set out to investigate what part of the face is most diagnostic for categorical perception of fear-anger morphed expressions, and how this information is integrated when presented in a composite face.

Experiment 1 showed that the upper face half is more diagnostic than the lower half for deciding between fearful and angry expressions in an identification task. The upper half alone was sufficient for high identification performance, closely following the whole face condition. Its perception could also be well-described by a logistic function with a steep category boundary, providing converging evidence for categorical perception based on the upper face half alone.

When viewing the lower half, responses were significantly closer to chance and could not be described better by an s-shaped than by a linear function.

In experiment 2, it was expected that the to-be-ignored halves of the face would bias performance, and that regions that have proven most diagnostic in experiment 1 should exert a stronger biasing influence over complementary face parts than vice versa. Accordingly, results indicated that both eye and mouth regions bias judgements on the respective other face half, with strongest influences exerted by the eyes, leading to what might be considered a breakdown of performance for mouth judgements. This effect is noteworthy, as information in the mouth region is equally present in both experiments. Nevertheless, when instructed to evaluate the mouth and ignore the eyes in a composite face, the participants' ratings reflect the expression of the eyes numerically more strongly than they reflect mouth judgements. This means that a cue that is reasonably useful for expression recognition in isolation, will be of almost no use when exposed to the influence of a strongly diagnostic cue.

The influence of the mouth on eye judgements should be considered equally striking, since it illustrates that even a very diagnostic cue that allows for recognition levels almost as high as a whole face, can be subject to significant bias form a substantially weaker cue. This suggests that even when analytical processing of a single feature is sufficient to allow for categorical perception, human observers seem to integrate features into a whole whenever possible. This held true in the second experiment, even though participants were explicitly instructed to process the features of one face half only.

The dominance of the eye region in the present experiments is well in line with masking studies which point towards their prominent role for both fear and anger recognition [13]. Studies with neurological patients also indicate a specific importance of the eyes in fear detection [22]. Also, when asked to evaluate expressions of emotion, observers most readily fixate the eyes [14], irrespective of the emotion in question.

Regarding identity recognition, there are many studies which demonstrate the importance of the eyes. For example, when a face has to be learned in a training run and later distinguished from distractors differing in one feature, it is easier to recognize identity changes due to differences in the eyes, compared to nose or mouth changes [27]. Anonymisation of pictures by masking out the eyes even represents a legal requirement in some contexts, although the scientific basis for the effectiveness of this procedure is equivocal at best (cf. [28]). Regarding mental states, it is also commonly assumed that they can be assessed best from the eye region, as reflected for example in the 'reading the mind in the eyes' test [29]. Accordingly, one must ask whether the eye advantage reported in the present study, can be generalised to other features and other expressions of emotion.

Even though the eyes may be most likely fixated when judging emotions from intact faces [14], this does not necessarily imply that most information is coded in the eye region. This becomes obvious when considering the studies carried out with patient SM, who exhibits major difficulties at recognizing fear from faces, due to a failure to fixate the eyes [22].

Nevertheless, she is virtually unimpaired at recognizing all other basic emotions. This indicates that it must be possible to recognize those emotions utilising other diagnostic features. Accordingly, masking studies [13] and coding systems for basic emotion expressions [10], suggest that each expression can be best recognized from a set of features specific to that emotion and that focusing on the eyes cannot be the optimal strategy in all cases.

Therefore, regarding the results of the present experiments, we would predict that the basic mechanisms outlined here will be replicated with other facial expressions, but perhaps not for the same features. For example, happy-surprised pairings should be best recognized from the mouth, as both involve mainly muscles of the lower face half [10,13,30].

The present findings should not only be extended to investigate other expressions, but also further elaborated for the currently used fear-anger pairing, to shed light on the basic perceptual mechanisms at work. The employed identification task could be complemented by a discrimination task. There, it should be easier to discriminate two images when they are on opposing sides of the category boundary, compared with being both sampled from within the same category [8,9]. Thus, the sigmoid curves from the present experiments could be used to predict the discrimination performance in a follow-up experiment.

On the basis of the present data from experiment 1, we would therefore predict that discrimination performance at the category boundary should be higher for eye than mouth judgements, in accordance with the steepness of their slopes in the identification task.

In the composite face task, the peak of the discrimination function should be shifted to the right and left when judging the eyes, in accordance with the intercept shifts due to the mouth expressions. Finally the discrimination function should be almost flat when judging the mouth in a composite face, as there is virtually no crossing of a category boundary in the present data.

To further generalise the present findings regarding fear-anger pairings, averaged faces could be used, which have the advantage that idiosyncrasies would average out while expressions prototypical for a certain emotion would be emphasized [31, p. 76]. While studies on categorical perception are often performed with a very limited number of identities (<=4; [4–6,21]), the 20 different faces used in the present experiments should be considered a valuable step towards greater generalisability. However, the fact that the mouth provided so little diagnostic information might be partly due to the fact that 12 out of the 20 face identities expressed the emotions with a closed mouth. While this might have reduced variance in the expressiveness of the lower face half, both the pressing of the lips as well as the baring of the teeth are valid anger expressions [10,12]. Of the two, lip pressing is probably much more frequent in everyday life. Also, when making statements about the importance of either eyes or mouth for recognizing an expression, it should be kept in mind that these features were rather crudely operationalised as the upper and lower face half, respectively. While such a division is standard practice in the field [18,21,32], the muscles around the nose have likely contributed to the judgements of both face halves, and the eyebrows [33] and forehead [11] might have contributed to judgements of the upper face half. While the sclera of the eyes seems crucial for fear detection [34], anger judgements might depend more on the surrounding muscles of the eyes and the eyebrows [13,33], especially since patient SM shows no difficulty at recognizing anger [22].

Another interesting question is to what degree the failure to concentrate on one half of a composite face can be voluntarily overridden. This could be investigated by introducing training blocks before the experiment proper, a forced minimum exposure time to discourage spontaneous responses, biofeedback from an eye-tracking device helping to fixate on a specific face part, and rewards for correct responses.

To summarise, the present studies show that identification of fear and anger in morphed faces relies heavily on the eye region, corroborating previous research [10,13,14,20]. Expanding previous work, the study showed that categorical perception with a steep boundary is preserved even when only the upper face half is visible. As evident in the composite face task, performance for mouth judgements breaks down when the eyes serve as distractors. Likewise, even though the eye region is almost as diagnostic as the whole face, it is not immune to biasing influences, as evident in a shift of the psychometric curves.

In combination, the two experiments indicate that categorical perception is possible when only parts of the face are visible, but that observers nevertheless process faces as a gestalt whenever possible, even if this proves to be detrimental.

ACKNOWLEDGEMENTS

We would like to thank Maleen Fiddicke for help with data collection.

REFERENCES

1. Keltner D, Haidt J. Social Functions of Emotions at Four Levels of Analysis. Cogn Emot. 1999;13: 505–521. doi:10.1080/026999399379168

2. Ekman P. Are there basic emotions? Psychol Rev. 1992;99: 550–553. doi:10.1037/0033-295X.99.3.550

3. Du S, Tao Y, Martinez AM. Compound facial expressions of emotion. Proc Natl Acad Sci. 2014;111: E1454–E1462. doi:10.1073/pnas.1322355111

4. Young AW, Rowland D, Calder AJ, Etcoff NL, Seth A, Perrett DI. Facial expression megamix: Tests of dimensional and category accounts of emotion recognition. Cognition. 1997;63: 271–313. doi:10.1016/S0010-0277(97)00003-6

5. Calder AJ, Young AW, Perrett DI, Etcoff NL, Rowland D. Categorical Perception of Morphed Facial Expressions. Vis Cogn. 1996;3: 81–118. doi:10.1080/713756735

6. De Gelder B, Teunisse J-P, Benson PJ. Categorical Perception of Facial Expressions: Categories and their Internal Structure. Cogn Emot. 1997;11: 1–23. doi:10.1080/026999397380005

7. Etcoff NL, Magee JJ. Categorical perception of facial expressions. Cognition. 1992;44: 227–240. doi:10.1016/0010-0277(92)90002-Y

8. Fugate JMB. Categorical Perception for Emotional Faces. Emot Rev. 2013;5: 84–89. doi:10.1177/1754073912451350

9. Harnad SR. Categorical Perception. Categorical perception: the groundwork of cognition. Cambridge; New York: Cambridge University Press; 1990.

10. Ekman P, Friesen WV, Hager JC. Facial action coding system. Salt Lake City UT Hum Face. 2002;

11. Ekman P, Friesen WV. Unmasking the face: a guide to recognizing emotions from facial clues. Cambridge, MA: Malor Books; 1975.

12. Matsumoto D, Ekman P. Facial expression analysis. Scholarpedia. 2008;3: 4237. doi:10.4249/scholarpedia.4237

13. Smith ML, Cottrell GW, Gosselin F, Schyns PG. Transmitting and Decoding Facial Expressions. Psychol Sci. 2005;16: 184–189. doi:10.1111/j.0956-7976.2005.00801.x

14. Guo K. Holistic Gaze Strategy to Categorize Facial Expression of Varying Intensities. Verdejo García A, editor. PLoS ONE. 2012;7: e42585. doi:10.1371/journal.pone.0042585

15. McKone E, Yovel G. A single holistic representation of spacing and feature shape in faces. J Vis. 2010;8: 163–163. doi:10.1167/8.6.163

16. Rossion B. Picture-plane inversion leads to qualitative changes of face perception. Acta Psychol (Amst). 2008;128: 274–289. doi:10.1016/j.actpsy.2008.02.003

17. Sergent J. An investigation into component and configural processes underlying face perception. Br J Psychol. 1984;75: 221–242. doi:10.1111/j.2044-8295.1984.tb01895.x

18. Young AW, Hellawell D, Hay DC. Configurational information in face perception. Perception. 1987;16: 747–759. doi:10.1068/p160747

19. Calder AJ, Jansen J. Configural coding of facial expressions: The impact of inversion and photographic negative. Vis Cogn. 2005;12: 495–518. doi:10.1080/13506280444000418

20. Tanaka JW, Kaiser MD, Butler S, Le Grand R. Mixed emotions: Holistic and analytic perception of facial expressions. Cogn Emot. 2012;26: 961–977. doi:10.1080/02699931.2011.630933

21. Chen M-Y, Chen C-C. The contribution of the upper and lower face in happy and sad facial expression classification. Vision Res. 2010;50: 1814–1823. doi:10.1016/j.visres.2010.06.002

22. Adolphs R, Gosselin F, Buchanan TW, Tranel D, Schyns P, Damasio AR. A mechanism for impaired fear recognition after amygdala damage. Nature. 2005;433: 68–72. doi:10.1038/nature03086

23. Lundqvist D, Flykt A, Öhman A. The Karolinska directed emotional faces (KDEF). CD ROM Dep Clin Neurosci Psychol Sect Karolinska Institutet. 1998; 91–630.

24. Tottenham N, Tanaka JW, Leon AC, McCarry T, Nurse M, Hare TA, et al. The NimStim set of facial expressions: Judgments from untrained research participants. Psychiatry Res. 2009;168: 242–249. doi:10.1016/j.psychres.2008.05.006

25. Kingdom FAA, Prins N. Psychophysics: a practical introduction. London: Academic; 2010.

26. Hilborn R. The ecological detective: confronting models with data. Princeton, NJ: Princeton University Press; 1997.

27. Tanaka JW, Farah MJ. Parts and wholes in face recognition. Q J Exp Psychol Sect A. 1993;46: 225–245. doi:10.1080/14640749308401045

28. Newton EM, Sweeney L, Malin B. Preserving privacy by de-identifying face images. IEEE Trans Knowl Data Eng. 2005;17: 232–243. doi:10.1109/TKDE.2005.32

29. Baron-Cohen S, Wheelwright S, Hill J, Raste Y, Plumb I. The “Reading the Mind in the Eyes” Test Revised Version: A Study with Normal Adults, and Adults with Asperger Syndrome or High-functioning Autism. J Child Psychol Psychiatry. 2001;42: 241–251. doi:10.1111/1469-7610.00715

30. Leppänen JM, Hietanen JK. Is there more in a happy face than just a big smile? Vis Cogn. 2007;15: 468–490. doi:10.1080/13506280600765333

31. Bruce V, Young AW. Face perception. London ; New York: Psychology Press; 2012.

32. Grand RL, Mondloch CJ, Maurer D, Brent HP. Impairment in Holistic Face Processing Following Early Visual Deprivation. Psychol Sci. 2004;15: 762–768. doi:10.1111/j.0956-7976.2004.00753.x

33. Tipples J, Atkinson AP, Young AW. The eyebrow frown: A salient social signal. Emotion. 2002;2: 288–296. doi:10.1037/1528-3542.2.3.288

34. Whalen PJ. Human Amygdala Responsivity to Masked Fearful Eye Whites. Science. 2004;306: 2061–2061. doi:10.1126/science.1103617

Fig1

Click here to download high resolution image

a

b

c

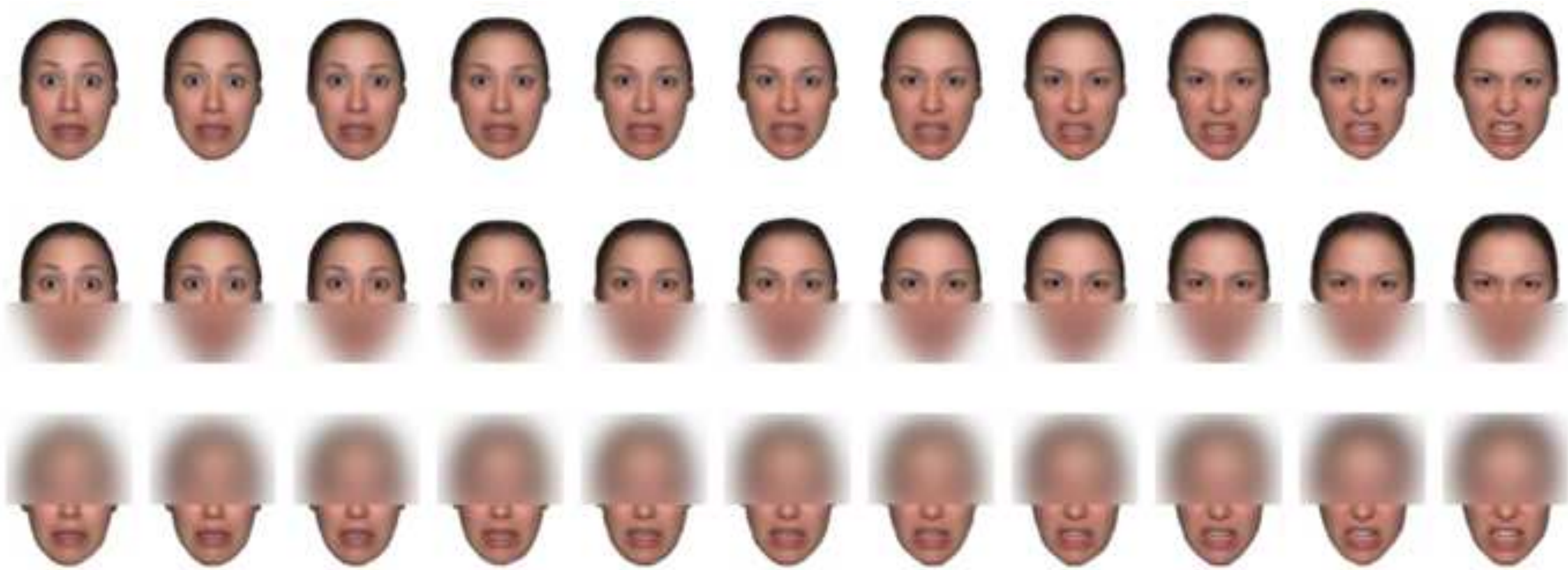


Fig2

Click here to download high resolution image

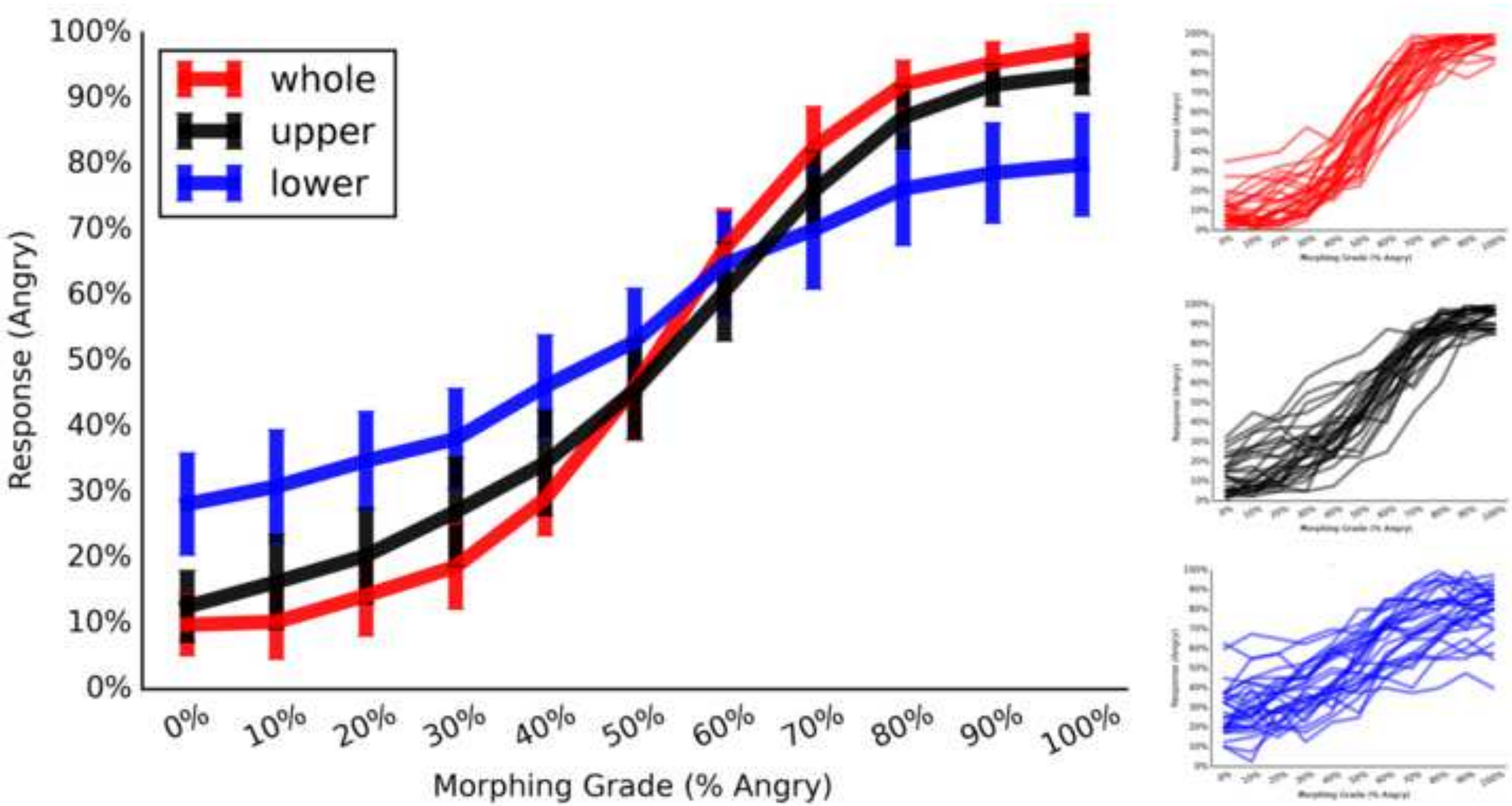


Fig3

Click here to download high resolution image

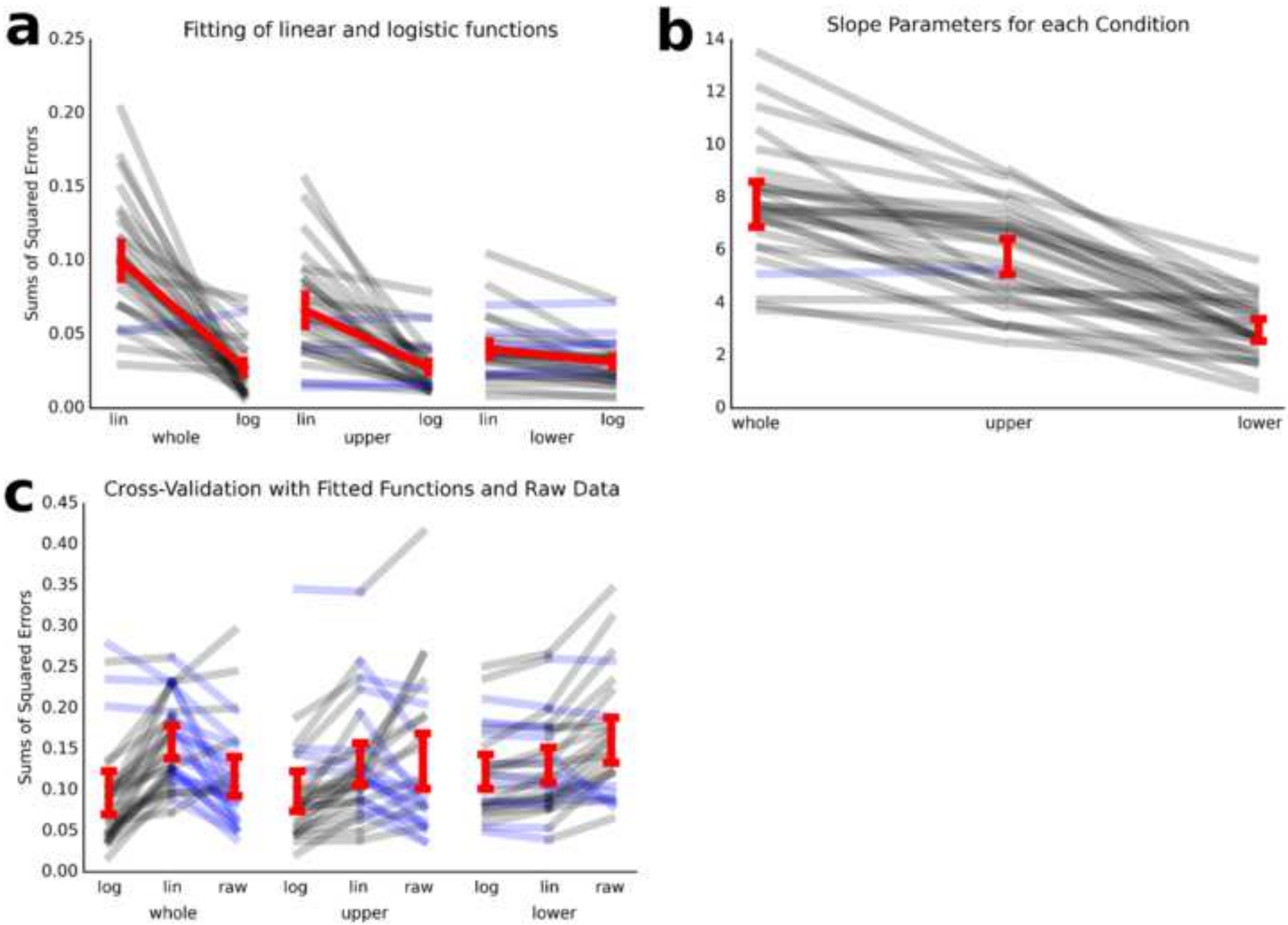


Fig4
Click here to download high resolution image

Fig5
Click here to download high resolution image

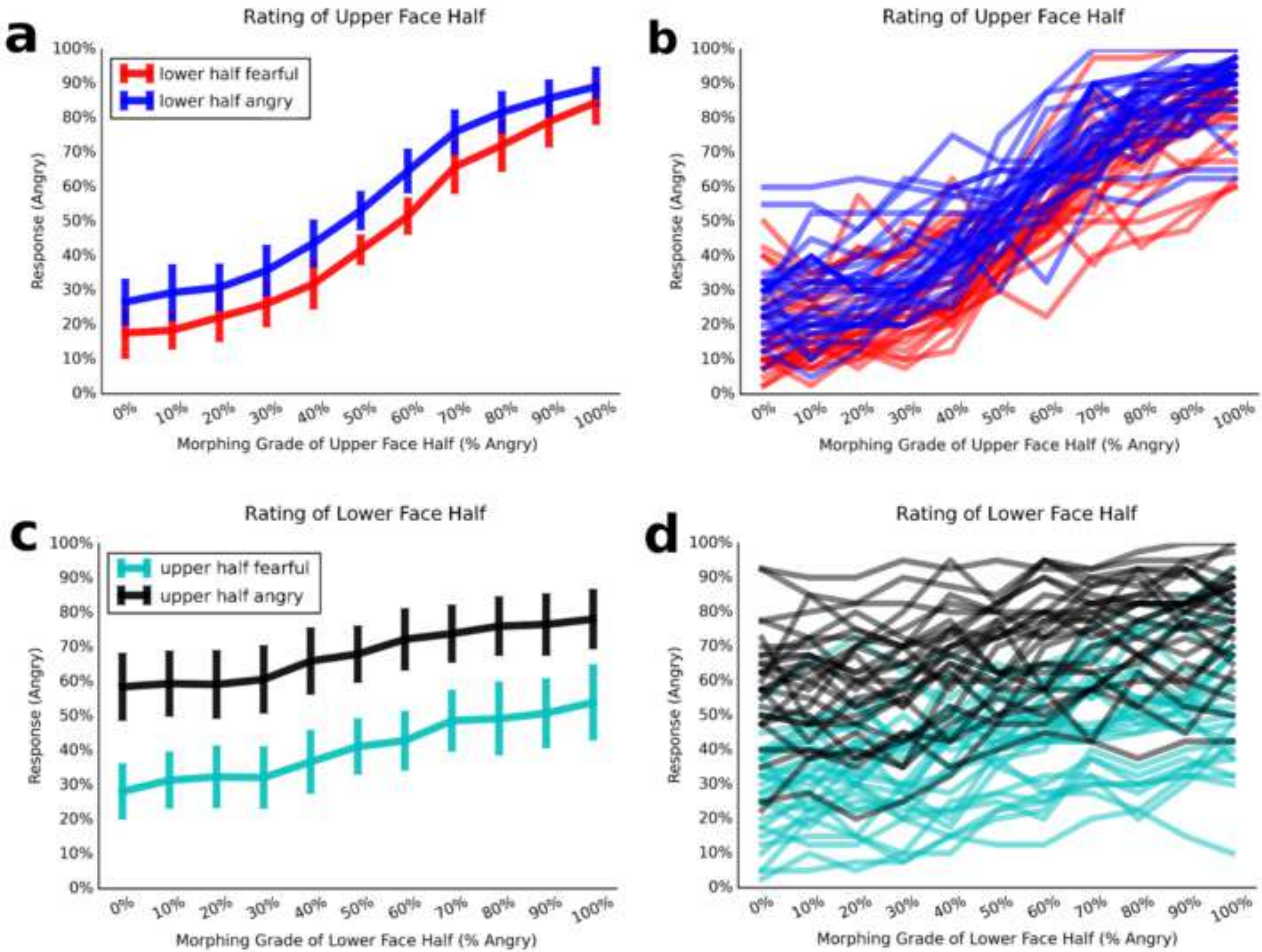


Fig6

Click here to download high resolution image

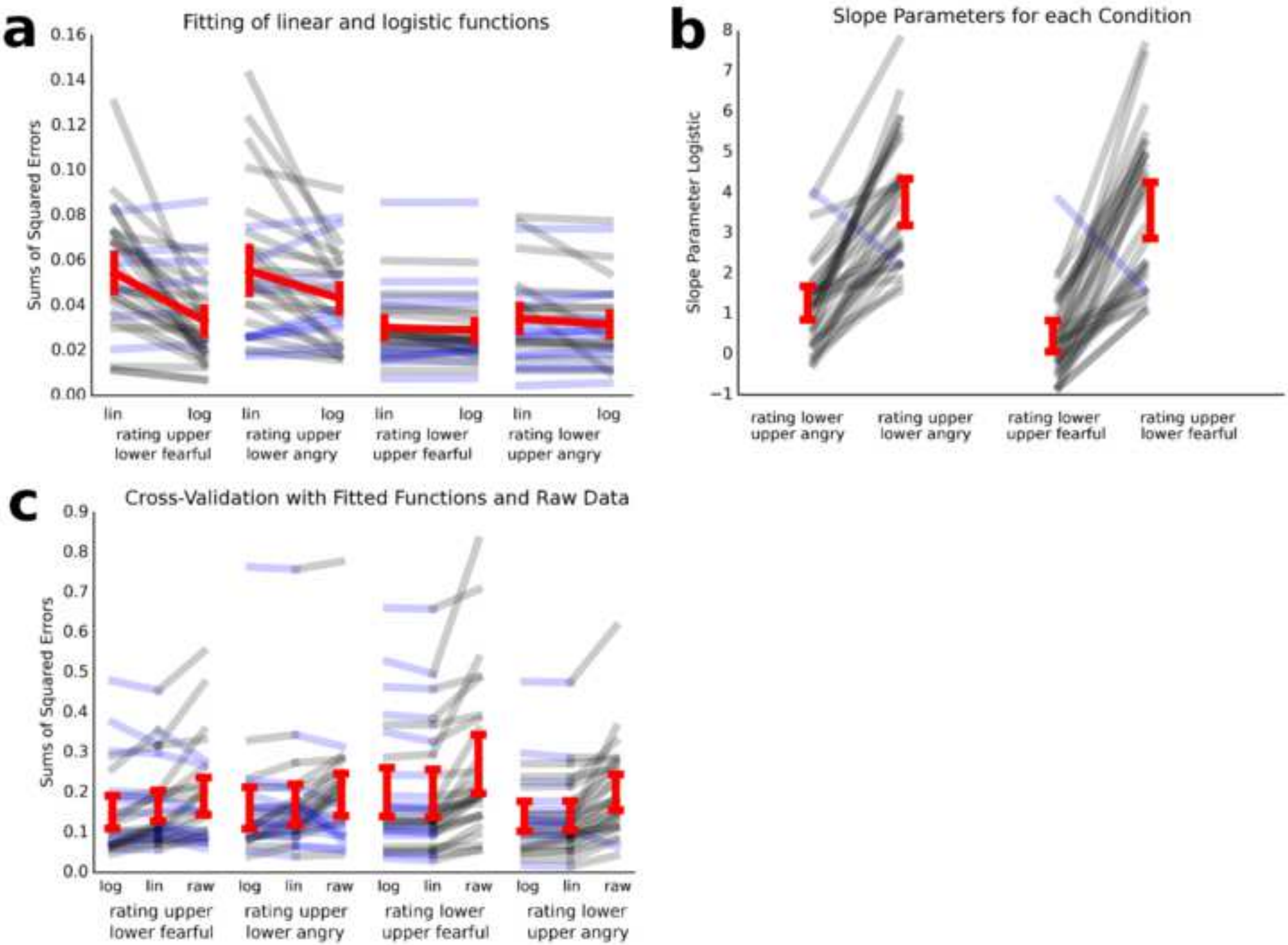
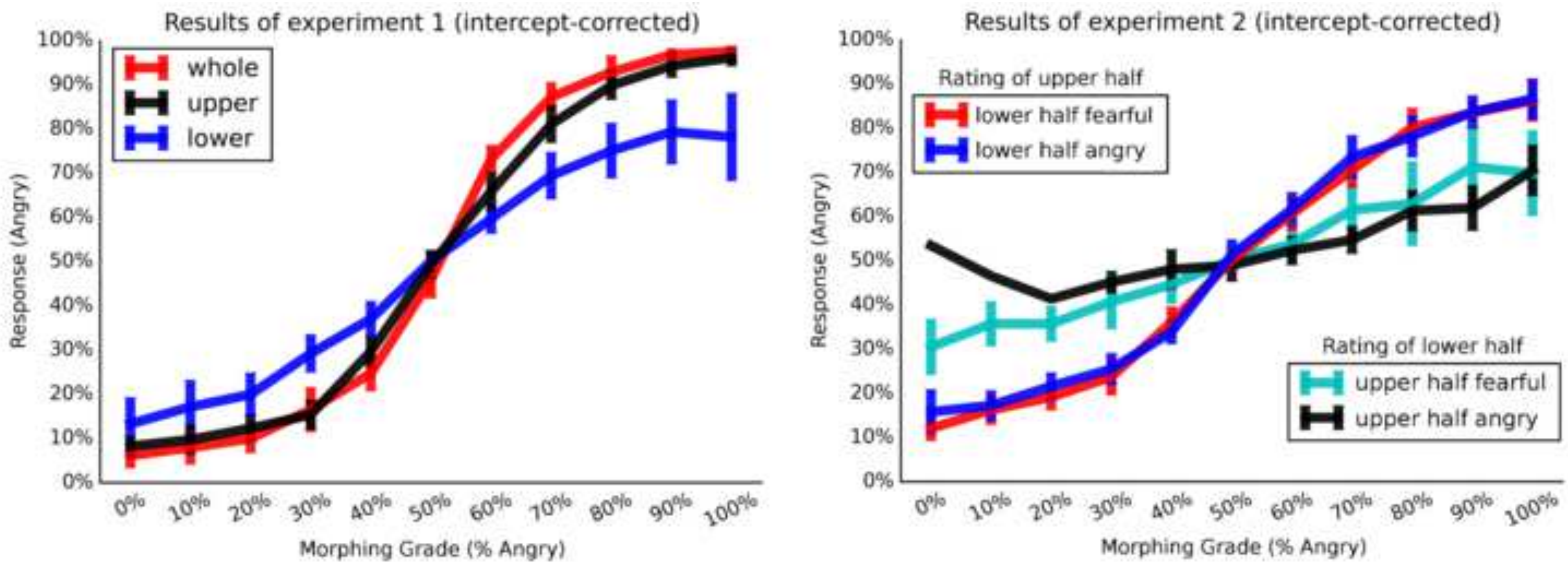


Fig7

Click here to download high resolution image



S1 File. IPython Notebook documenting data import of Exp. 1

Click here to download Supporting Information: SupplementS1_Experiment1_Data_Import.html

S2 File. IPython Notebook documenting data import of Exp. 2

Click here to download Supporting Information: SupplementS2_Experiment2_Data_Import.html

S3 File. IPython Notebook documenting Main Analyses

Click here to download Supporting Information: SupplementS3_MainResults.html

S4 File. IPython Notebook documenting Cross-Validation

Click here to download Supporting Information: SupplementS4_Functions_CrossValidation.html

S5 File. IPython Notebook documenting additional Analyses

Click here to download Supporting Information: SupplementS5_AdditionalIdentityAnalyses.html

S6 File. Experimental Paradigms in Presentation Format.
Click here to download Supporting Information - Compressed/ZIP File Archive: ExperimentFiles.zip

S7 Dataset. Raw Logfiles with Participant Data.

Click here to download Supporting Information - Compressed/ZIP File Archive: RawData.zip

S8 File. Executable IPythonNotebooks (complement to S1-S5)

Click here to download Supporting Information - Compressed/ZIP File Archive: IPythonNotebooks.zip