Categorical Perception of Facial Expressions Is Not a Homogeneous Effect

Olga A. Korolkova (olga.a.kor@gmail.com)
Moscow State University of Psychology and Education, 29 Sretenka Street, Moscow, 127051 Russia
Moscow Institute of Psychoanalysis, 34 Kutuzovsky Avenue, Moscow, 119334 Russia

Abstract

We studied the categorical perception on transitions between seven basic emotional facial expressions and explored the influencing factors. In Experiment 1, participants performed a multiple-choice emotion labeling task while observing basic or morphed (blended between a pair of basic emotions) facial expressions. In Experiment 2, other participants completed AB-X discrimination task. They observed pairs of images adjacent in a morphing continuum, and matched the test image to one of the pair. The results of Experiment 1 revealed influence of emotional context, formed by the presented expressions, on perception of surprise, anger, disgust, and neutral face. The "categorical field" of morphed expressions includes not only the two relevant emotions (morphing basis) but a number of additional ones. Based on the data of Experiment 1, we selected the pairs of stimuli crossing the categorical boundary, and pairs falling within the category, to predict the discriminability obtained it the Experiment 2. A generalized linear mixed model was fitted to the data. We show the main effect of within/between category pair, type of continuum and continuum/category interaction on the probability of correct discrimination. Overall, our results showed the categorical perception, but its strength depends on particular pair of emotional categories.

Keywords: face, facial expression, emotions, categorical perception, generalized linear model.

Introduction

When we want to test whether the perception of a particular class of objects is categorical, we generally compare the ability to perceive physical differences in pairs of objects belonging to the same and to different categories. Assuming that these differences are equal, the enhanced discriminability in cross-boundary pairs compared to within-category pairs reflects the categorical perception (CP). If categories do not influence the discriminability, we refer to continuously perceived differences.

The classic experimental paradigm for testing the CP was proposed by Liberman et al. (1957) in the studies on phonemes perception. It included an identification (labeling) task aimed at defining the boundary between categories, and a discrimination task, in which subjects were asked to differentiate objects in both cross-boundary and within-category pairs.

Since then, the CP has been extensively studied on a variety of objects, including facial emotional expressions (Calder et al., 1996; Cheal, Rutherford, 2011; Etcoff, Magee, 1992; Fugate, 2013; de Gelder et al., 1997; Herba et al., 2007; McCullough, Emmorey, 2009; Roberson et al., 2007; Roberson, Davidoff, 2000; Suzuki et al., 2005; Teunisse, de Gelder, 2001; Young et al., 1997; etc.). CP has been shown first on faces presented as linear drawings (Etcoff, Magee, 1992), and later also on gray-scale images (Calder et al., 1996; de Gelder et al., 1997; Young et al., 1997). Its specific aspects were revealed in children (Cheal, Rutherford, 2011; Kotsoni et al., 2001), in patients with amygdala damage (Adolphs et al., 1999), schizophrenia (Kee et al., 2006) and autism spectrum disorders (Teunisse, de Gelder, 2001). Although, several studies did not show the CP (Fiorentini, Viviani, 2009; Schiano et al., 2004) or reported the factors reducing this effect (namely, verbal interference: Roberson, Davidoff, 2000; Roberson et al., 2007).

The concept of CP implies that there is a number of discrete emotional categories with qualitative differences between each other, and that each entity of facial emotion can be placed by an observer into one of these alternative emotional categories. Another way of describing emotion and facial expression are continuous spatial models, where the perceived differences between faces are measured as distances in a face-space (Valentine, 1991), or the diversity of emotions is located in a multi-dimensional space with the axes corresponding to physiological properties such as arousal, sleepiness or valence (Russell, 1980). A possible solution of the long-standing debate between categorical (discrete) and dimensional (continuous) understanding of emotion and face perception is by incorporating the both notions into consolidated hierarchical model of higher-level categorical system that interacts with low-level perceptual, non-categorical one (e.g., Fujimura et al., 2012; Roberson et al., 2010).

In line with the discrete emotions theory, at least seven basic emotions, universal among cultures, were revealed by P. Ekman (Ekman, Friesen, 1976), and 21 emotional continua, representing transitions from one basic emotion to another, can be constructed between each pair of emotions to test the categorical perception hypothesis. Although, the majority of the facial expressions CP studies explored the perception and differentiation of face images belonging to only a few of these emotional continua. In particular, CP has been shown on continua between happiness and six other emotional expressions, but results on CP of happiness / surprise and happiness / sadness are controversial (see Calder et al., 1996; de Gelder et al., 1997; Etcoff, Magee, 1992). The continua most frequently used in studies are those between anger, sadness, fear and happiness. Though, even on these expressions, the results are ambiguous and do not always show the CP (Calder et al., 1996; de Gelder et al., 1997; Fiorentini, Viviani, 2009). Other continua were rarely included in the stimuli for discrimination task, and for 8 out of 21 continua, no experimental data is available.

An extensive study of facial expressions CP was conducted by Young et al. (1997) and included all possible

21 continua between pairs of seven basic emotions, but only in the labeling (alternative forced-choice) task. In the study of expression discrimination, 6 continua (happiness / surprise / fear / sadness / disgust / anger / happiness) were used, and significant low to moderate correlations were found between the discrimination results and the predicted discriminability which was based on identification task results.

Thus, the results obtained up to date, suggest that the CP can vary in its degree depending on a particular continuum between pair of basic emotional expressions. However, this issue has not been the primary focus of any research yet. To investigate, whether CP depends on the type of emotional continua, and in what continua the CP does not appear at all, we constructed 21 morphing transitions between all pairs of 7 basic emotional facial expressions and carried out two experiments, identification and discrimination tasks, using the whole range of the basic emotional expressions. The procedure of identification task was changed compared to the study by Young et al. (1997) to extend the previously obtained results. The discrimination task procedure was also slightly modified, and the stimuli range was substantially broadened to include all transitions between basic emotions.

To analyze the results, we propose using a generalized linear mixed model, which is generalization of logistic regression and allows to correctly modeling categorical data dependence on various predictors. Mixed logistic regression (multi-level logit modeling) is preferred method of analysis over traditional ANOVA (Jaeger, 2008) as it allows accounting for multiple fixed and random effects simultaneously. This method of discrimination data analysis can be helpful in revealing the influence of continua type, as well as any other significant predictors of the CP.

Method

The aims of the present study were to explore the CP of facial expressions and the factors that influence the discriminability of morphed faces from the same or different emotional categories, and to fit a model to our data.

Stimuli

We used computer morphing to obtain equal distance transitions between seven basic emotions of actor JJ (Ekman, Friesen, 1976), as proposed by P. Ekman: happiness, surprise, fear, sadness, disgust, anger, and neutral face. Before applying the morphing procedure, the gray-scale images (245×350 pixels) were corrected for mean brightness, size and rotation. Then up to 300 reference points were placed onto each image, and 21 morphing continua were produced for each pair of the initial images. We then hid all non-facial features of the images under a black mask, and selected two basic and 4 morphed images (20%, 40%, 60% and 80% impact of one of the two basic emotions) from each continuum, so that the formal differences between the adjacent images remained the same. We estimated the inter-image differences as dot products of vectors composed of the two images' pixels brightness levels.

Twenty-one emotional continua were divided into seven stimuli sets so that each set included three separate transitions organized into a meta-continuum in the form: $Emotion_1 \rightarrow Emotion_2 \rightarrow Emotion_3 \rightarrow Emotion_4$, where "→" stands for sequence of 4 intermediate morphs. The inner structure of these "meta-continua" is similar to the structure of the transitions used in earlier studies, for example, between artificial phonemes /ba/, /da/ and /ga/ in the study by Liberman et al. (1957), where the stimuli with linear change in voice onset time were perceived as a sequence of distinct phonetic categories. In our study, each of the seven meta-continua served as stimuli in two separate experimental series.

Experiment 1: Identification

Participants were 138 university students (median age 21 years, range 18 to 53 years; 41 males) with normal or corrected-to-normal vision. They participated in the study for credits. Each subject performed the identification task with one of the seven stimuli sets, thus, 18 to 23 subjects worked with each set.

Procedure Each of 16 images from a meta-continuum was presented using PXLab software (Irtel, 2007) to a subject for 3 seconds in the center of 85 Hz CRT display (visual angle of 6.7°×9.3°), followed by invitation to choose one or several out of seven basic emotions that were expressed on the face. Each image was presented twice; the order of presentation was randomized. The trial sequence is shown on Figure 1, a. The participants were not instructed to answer as quickly as possible, but to be attentive to the images presented to them and to give accurate responses.

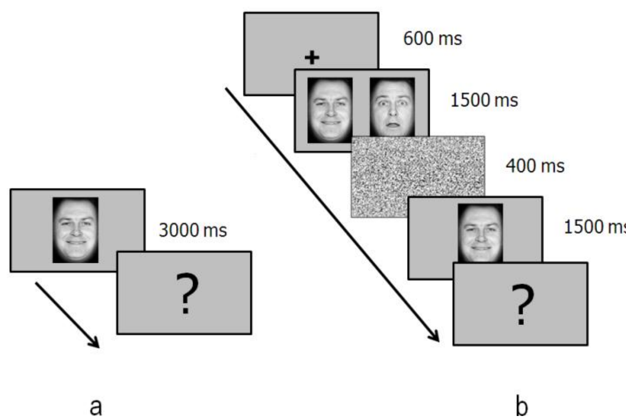

Figure 1: a) Identification task trial. Sixteen images belonging to one of meta-continua were presented in random order, each image twice. The task was to match one or several emotion labels to the presented expression; b) Discrimination task trial. A pair of adjacent images from a meta-continuum was presented side-by-side, preceded by fixation cross. Then they were masked by black-and-white noise pattern, and the test image appeared, equal to one of the pair. The task was to match the test image to one from the pair.

Experiment 2: Discrimination

Participants were 140 university students (median age 20 years, range 17 to 47 years; 40 males) with normal or corrected-to-normal vision, none of them performed the identification task. Twenty of the subjects worked with each of 7 stimuli sets, similarly to the identification task.

Procedure We used AB-X discrimination task to estimate the perceived differences between images of facial expressions. Sixteen stimuli from a meta-continuum were organized in 15 pairs of adjacent images. In each trial, a fixation cross was presented for 600 ms, followed by the stimuli pair simultaneously presented side-by-side for 1500 ms (each image occupied visual angle of 6.7°×9.3°, the distance between them was 2.3°), and a black-and-white noise pattern (400 ms, 17.5°×9.3°). After that, the test stimulus, being one of the pair, appeared in the center of the screen for 1500 ms, and the subject was prompted to answer using the keyboard, which of the two images in the pair corresponded to the test stimulus. Each pair of images was presented 20 times in four possible orders of stimuli in the AB-X triad. The trial sequence is shown on Figure 1, b. All 300 trials in the discrimination task were randomized. A short training was provided before the main experiment to allow subjects to familiarize with the task. Images from the training series were not shown in the following experiment. The simultaneous presentation of the AB pair allows reducing the known sequence, or memory, effects, namely, better performance for sequentially presented stimuli ABB compared to ABA.

Results

Emotions identification

The results of the Experiment 1 are proportions of choosing each of seven emotion labels as matching the presented expressions (see Figure 2).

As same basic expressions were included into several stimuli sets, we are able to assess possible influences of the overall emotional context to their perception and identification. Using Fisher's exact test, we compared the labeling proportions for the same images presented in different settings. The identification of happy, sad, and feared expressions in different contexts did not change. The surprise expression was significantly more frequently labeled as fear when presented in absence of fear expression in the experiment series (Fisher's exact test $p < 0.04$). The same pattern was observed for anger expression labeled as surprise or fear without these two expressions in the emotional context (Fisher's exact test $p < 0.04$). In the same manner, disgust expression was confused with anger and sadness (Fisher's exact test $p < 0.039$), and neutral expression – with happiness and disgust (Fisher's exact test $p < 0.042$).

Next, we analyzed the emotional labeling of intermediate morphs, depending on their position in a particular continuum. In several continua, intermediate images were mainly identified as one of the two basic emotions corresponding to those that form the continuum. Morphs were labeled as other emotions in less than 20% of trials. This was true for happiness / surprise, sadness / neutral, surprise / fear, disgust / happiness, sadness / disgust, neutral / surprise, surprise / disgust, and neutral / happiness continua. In all of them, the categorical boundary is defined as the point of cross of two emotion functions. In the other continua, the intermediate morphs in the center of continuum were identified as other emotions in up to 40% of trials. Intermediate fear / sadness and sadness / anger morphs were confused with disgust; fear / disgust morphs – with sadness, and neutral / fear ones – with surprise. As this occurs in the absence of the "misidentified" emotions in the overall context, we determined the categorical boundary in such continua as the point of crossing for the two relevant emotion functions.

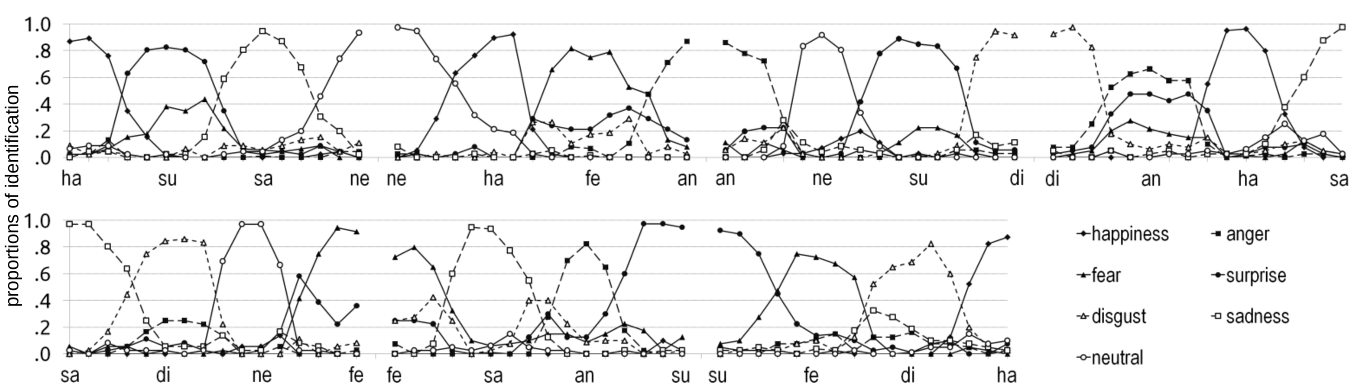

Figure 2: Identification task results. The proportions of choosing each of seven emotion labels are plotted against stimuli from seven meta-continua. Basic, non-morphed, images are indicated with labels: *ha* – happiness; *fe* – fear; *di* – disgust; *ne* – neutral; *an* – anger; *su* – surprise; *sa* – sadness. Intermediate, morphed, images are placed between the corresponding basic ones. Panels are organized by stimuli sets.

Discrimination of facial expressions

The results obtained from the Experiment 2 are dichotomous correct/incorrect discriminations. We fit a generalized linear mixed model to the data, using R (R Core Team, 2013) package lme4 (Bates, 2010; Bates et al., 2013).

The input data for fitting the model has the following structure. The *Response* variable comprises two levels (correct/incorrect). The covariates, possibly influencing the response, include *Category* (3 levels: pair of stimuli crossing the *boundary*; those containing one *basic* (non-morphed) image and one 20% morph, both being within the same category; *intermediate* within-category pairs including only morphs), *Continuum* types (21 levels), arranged in stimuli *Sets* (7 levels), *Age*, *Sex* and unique *ID* of participants, unique index of stimuli *Pair* across all continua (105 levels), and the *Order* of images in an AB-X trial (4 levels). The levels of *Category* covariate were determined on the basis of the Experiment 1 results. We consider a pair of images as crossing the categorical boundary if in the identification task, the emotion identification functions cross between these two images or at one of them. All the other pairs, except for those including a non-morphed emotion, are considered intermediate. We excluded the intermediate pairs from the further analysis and compared only cross-boundary and basic pairs. Thus, the remaining dataset consisted of 27600 observations.

We started fitting the model from including all covariates: *Category*, *Continuum*, *Category* × *Continuum* interaction and *Sex* as fixed factors; stimuli *Order* and *Set*, and participants' *ID* and *Age* as random effects. Then we refitted the model in several steps, each time excluding one of the factors. The initial and refitted models were compared using likelihood ratio test (LRT) statistic, $-2\,(l_1 - l_0)$, where l_1 and l_0 are maximized log-likelihood of the compared models with (l_1) and without (l_0) the factor excluded. To assess, whether the contribution of a factor is significant to fitting the model, we use χ^2 test with degrees of freedom equal to the number of levels of the excluded parameter.

The random effects of stimuli *Set* [Pearson's $\chi^2(1) = 0$, $p = 0.996$; SD = 0.000015] and participants' *Age* [$\chi^2(1) = 0$, $p = 1$; SD = 0.00011] in the initial model did not change significantly the model fit, but excluding *Order* [$\chi^2(1) = 67.403$, $p < 0.001$; SD = 0.118], and participants' *ID* [$\chi^2(1) = 280.72$, $p < 0.001$; SD = 0.301], resulted in considerably lower fit.

The fixed effect of participants' *Sex* did not contribute to the model's fit [$\chi^2(1) = 0.0004$, $p = 0.984$], so we excluded it as not influencing the result. The fixed effects of *Category* [$\chi^2(1) = 224.2$, $p < 0.001$], *Continuum* [$\chi^2(20) = 279.02$, $p < 0.001$], and *Category* × *Continuum* interaction [$\chi^2(20) = 94.953$, $p < 0.001$] were highly significant.

The probabilities of correct discrimination in pairs of adjacent images, computed from the final model, are presented on Figure 3. The computed probabilities show high correlation with the mean values for raw data [$r = 0.9998$, $p < 0.0001$], therefore, we can conclude that the final model describes the discrimination data rather well.

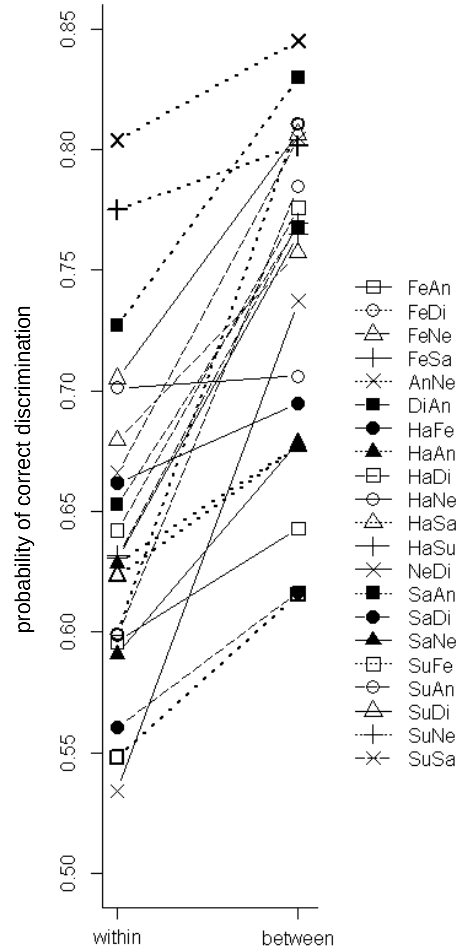

Figure 3: Probability of correct discrimination in pairs of images that cross the categorical boundary (*between*) and include basic emotion image (*within*). The probabilities are computed using the fixed effects of the fitted model. The continua are named by the corresponding basic emotions: *Ha* – happiness; *Fe* – fear; *Di* – disgust; *Ne* – neutral; *An* – anger; *Su* – surprise; *Sa* – sadness.

Discussion

The two experiments described in the present paper accounted for categorical perception of emotional facial expressions. This phenomenon has been of interest for many researchers over the last 20 years, but the issue whether we perceive emotions categorically or continuously is not fully resolved yet. In our study, we tested the hypothesis of CP dependence on emotion continua type. We implemented modified procedures and advanced method of analysis to our experimental data.

In Experiment 1, the multiple-choice labeling task let us to obtain not only matching of the basic and morphed images with one most relevant emotion category, but to estimate broad "category fields" of facial expressions, and therefore, explore the structure of possible systematic “misidentifications” of emotional expressions.

The results of the identification task revealed strong context-based effects for expressions of surprise, anger, disgust and neutral face. When we do not present the full range of the emotions in the same experimental series, these four expressions can be “confused” with those not being presented. In classical model (Liberman et al., 1957), the CP is considered to be independent of any contextual interference, although, such influences in fact can be prominent. More recently Treisman et al. (1995) proposed a criterion setting theory, according to which, the subjective criterion of signal detection is reset in each new experimental trial, and, therefore, depends on short-term influence of the previous trials (the two mechanisms of criterion setting are its stabilization – a shift towards the stimulus value after each trial, and continuous assessment of signal probability causes shift in opposite direction), as well as on long-term overall context influence and individual experience.

Global context effects on perception of objects from different categories and within the same category are also incorporated into category adjustment model (Huttenlocher et al., 2000), in which categories are described in terms of prototypes theory, and pertinence of each object to each category is probabilistic. According this model, the global aim of an observer is to increase mean accuracy of judgments by combining the information about a particular stimulus with information about its category prototype stored in long-term memory. If the former is incomplete, it can be partially of entirely substituted by the latter. The model was tested in experiment with facial expression differentiation (Roberson et al., 2007). Our identification data is in line with this model, as our subjects were probably adjusting their judgments to the full range of basic emotion categories presented to them as possible labels for the restricted stimuli set, and, therefore, were more sensitive to, say, subtle disgust cues in ambiguous morphed images between sadness and anger, if they were not shown the intense disgust expression.

The context adaptation can be avoided if one would present the whole range of facial expressions in the same experimental series. This paradigm was used in Experiments 1 and 2 by Young et al. (1997), with alternative choice of one out of 6 or 7 basic emotions labels. Though, even in this study, pure surprise, sadness / anger and anger / surprise morphs were sometimes confused with fear; and fear / disgusts morphs – with anger of sadness. Another effect revealed in our study is inclusion of additional categories in the center of continuum, between the two main categories (surprise identified in intermediate morphs between neutral and feared face; disgust – between sadness and anger or between fear and sadness; sadness between fear and disgust). It is also similar to Young et al. (1997) results and cannot be fully explained by context adaptation or category adjustments. We propose to explain this issue using the concept of “category field” of facial expression, which include the core emotion – the center of category – and a number of additional emotions that form the periphery, with probabilistic identification of the face images with these emotions. If an expression is far from category center, it can be associated with several adjacent categories. To be so, a direct categorical boundary should exist between each pair of confused categories. The existence of such direct boundaries is to be verified in future research.

Based on the results of Experiment 1, we chose the pairs of adjacent stimuli that cross the categorical boundaries, and presented them along with other pairs in parallel AB-X discrimination task in Experiment 2. Compared to other studies of facial expressions discrimination, the present one included transitions between all possible basic emotions, and along with substantial amount of individual raw data, it allowed us to construct an integral model describing the factors that underlie the categorical perception.

In our discrimination data modeling, the influence of stimuli *Set* (the context effect), though, was not significant. Rather, a multi-level logit modeling of the data showed main effects of within- versus between-category position of equidistant stimuli pairs; influence of the type of continua, and the interaction of the two factors, on the proportions of correct discrimination of the images. We therefore obtained the categorical perception of facial expressions found previously in many studies.

Moreover, according to our results, the CP of facial emotional expressions indeed has different intensity, depending on the pair of emotional categories being considered. In particular, there were no large differences in discrimination of within- and between-category expressions in happy / neutral, happy / feared, happy / angry, happy / sad, surprised / neutral, sad / disgusted, angry / neutral, feared / angry continua. On the contrary, in other continua (happy / disgusted, happy / surprised, neutral / disgusted, feared / sad, feared / disgusted, feared / neutral, surprised / sad, surprised / angry, surprised / feared, surprised / disgusted, sad / angry, sad / neutral, disgusted / angry) the CP effect is pronounced. Possible explanations of such pattern may include: initial difference of particular emotion categories in their affective or perceptive power; perception of other, probably non-emotional, but rather conversational meaning in intermediate morphed images; or relying on low-level configural cues of the stimuli (opened or closed mouth, morphing artifacts, etc.). Further studies should reveal the right one.

In conclusion, the present study provided new data of emotional labeling and discrimination of facial expressions, contributed to better understanding the categorical perception of emotional faces. We revealed dependence of this well-documented and previously considered as homogeneous effect on the type of emotional categories. Finally, we proposed using the “category field” concept to describe the results of emotional misidentification and to discuss them not as accidental errors of perception, but as systematical “adjustments” or “re-calibration” of categorical structure of emotions depending on particular context.

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