Sequential Effects in Facial Expression Categorization

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Facial expressions are highly dynamic signals that are rarely categorized as static, isolated displays. However, the role of sequential context in facial expression categorization is poorly understood. This study examines the fine temporal structure of expression-based categorization on a trial-to-trial basis as participants categorized a sequence of facial expressions. The results showed that the local sequential context provided by preceding facial expressions could bias the categorical judgments of current facial expressions. Two types of categorization biases were found: (a) Assimilation effects– current expressions were categorized as close to the category of the preceding expressions, and (b) contrast effects– current expressions were categorized as away from the category of the preceding expressions. The effects of such categorization biases were modulated by the relative distance between the preceding and current expressions, as well as by the different experimental contexts, possibly including the factors of face identity and the range effect. Thus, the present study suggests that facial expression categorization is not a static process. Rather, the temporal relation between the preceding and current expressions could inform categorization, revealing a more dynamic and adaptive aspect of facial expression processing.

Keywords: facial expression, categorization, sequential effect, contrast effect, assimilation effect

In daily social life, humans continuously decipher the emotional cues provided by others to respond properly. A particularly important source of such cues is facial expressions. To rapidly and effortlessly make sense of multifarious and fast-changing facial expressions, perceptual categorization is critical in order to simplify the task of interpretation. Previously, two major opposing theories have been proposed to account for categorical processing of facial expressions. According to the discrete-category view (Calder, Young, Perrett, Etcoff, & Rowland, 1996; Ekman, 1992; Young et al., 1997), facial expressions are perceived as belonging to qualitatively discrete categories. Those categories comprise the innate "basic" emotions that are found universally in humans, including anger, fear, sadness, happiness, disgust and surprise. The main alternative to the discrete-category view is the dimensional account (Russell, 1980, 1997), which posits that facial expressions are perceived as varying continuously along two continuous underlying dimensions—valence and arousal.

Facial expressions are highly dynamic signals that are rarely categorized as static, isolated displays. Rather, a facial expression is encountered as part of a sequence in which faces of various configurations and emotional categories are juxtaposed in a temporal order. Although the discrete-category and dimensional accounts hold different views about whether faces convey qualitatively distinct emotions or dimensional information regarding emotions, both focus on how categorical decisions are reached on single percepts, largely ignoring the role of sequential context in facial expression categorization. This neglect is not surprising given that our ability to process facial expressions is thought to reflect part of our functional and neurobiological heritage (Darwin, 1872). It has been argued that facial expression processing, especially for threat-related expressions, is obligatory and independent of contextual modulation (Ekman, 1992; Lane & Nadel, 2000; Luo et al., 2010; Pourtois, Spinelli, Seeck, & Vuilleumier, 2010; Russell, 1997; Vuilleumier, Armony, Driver, & Dolan, 2001).

A large body of evidence suggests that sequential context, or trial-to-trial transition more specifically, plays an important part in shaping behavioral responses. In absolute identification tasks, it has been found that current stimuli are judged as *closer to* immediately preceding stimuli than they actually are—a bias called the assimilation effect (Garner, 1953; Holland & Lockhead, 1968; Lacouture, 1997; Mori, 1989; Ward & Lockhead, 1970). For example, a neutral tone is judged as louder than it actually is if preceded by a loud tone. It is intriguing that such assimilation effects are reversed when the preceding stimuli are presented earlier in the trial sequence. Instead, contrast effects are observed in which the current stimuli are judged as *away from* the previous stimuli (Holland & Lockhead, 1968; Lacouture, 1997; Ward & Lockhead, 1970). For example, a neutral tone is judged as quieter than it actually is if preceded by a loud tone presented two or more trials earlier in the trial sequence.

More recently, evidence of contrast effects has been reported in categorization (Hampton, Estes, & Simmons, 2005; Stewart & Brown, 2004; Stewart, Brown, & Chater, 2002). In the tasks, participants learn to categorize a group of stimuli that vary continuously along a certain dimension, yet are divided into two

categories, such as a continuum of 10 equally spaced tones, with the five lowest frequency tones in Category A (Tones 1 to 5) and the 5 highest frequency tones in Category B (Tones 6 to 10). The results show that categorization of the current stimuli near the category borderline (Tone 5) is more accurate following the distant stimuli from the *opposite* category (Tone 10) than following the distant stimuli from the *same* category (Tone 1). Thus, participants seem to be biased to categorize current stimuli, particularly those whose absolute magnitude information is less readily available, as away from the category of the previous stimuli. In more intuitive terms, the participants tend to believe that the preceding and current stimuli belong to different categories. Moreover, Stewart and Brown (2004) have found that preceding stimuli presented two trials back within the trial sequence could also produce such contrast effects. In contrast, evidence of assimilation effects in categorization remains obscure. The tendency for participants to be biased to categorize the current stimulus as close to the category of the preceding stimulus has either not been found (Hampton et al., 2005), or has occurred only when the preceding and current stimuli are from different categories (Zotov, Jones, & Mewhort, 2011). One study (Jones, Love, & Maddox, 2006) has reported that assimilation effects seem to depend on performance feedback and are evident only when successive stimuli are similar.

In the majority of previous research, categorical responses to facial expressions were averaged over trials, thereby possibly removing potential sequential effects. The current study aimed to investigate the fine temporal structure of the data on a trial-to-trial basis to gain a new source of insight into the mechanisms of facial expression processing: Does sequential context affect the categorization of complex stimuli, such as facial expressions? If the influence of sequential context is observed, what is the underlying mechanism and do the observed sequential effects exhibit in the same manner as those that have been previously reported? Two aspects of sequential effects were specifically investigated to probe their presence in facial expression categorization: (a) Contrast effects in which current stimuli are categorized as further from the category of the preceding stimuli than they actually are, and (b) assimilation effects in which current stimuli are categorized as closer to the category of the preceding stimuli than they actually are. Participants in this study performed a binary categorization task in which the physical features of the facial expression stimuli morphed continuously between two emotion categories—fear and disgust. In line with prior literature, the stimulus continua used here also seem to be unidimensional, as evidence (Calder et al., 2000) has shown that different levels of morphed facial expressions vary linearly with participants' ratings of emotional intensities on those morphed faces, as opposed to the ratings of other dimensional properties. The emotion categories of fear and disgust were chosen given that their neural mechanisms have been explored thoroughly by neuropsychological and functional magnetic resonance imaging (fMRI) investigations, which show that the neural processes of fear and disgust are represented in dissociable areas of the brain (Adolphs, Tranel, Damasio, & Damasio, 1994; Morris et al., 1996; Phillips et al., 1997). Lastly, the expressive faces were randomly presented and no performance feedback was provided so as to mimic typical experiments in facial expression categorization.

Experiment 1: Same-Identity Condition

Method

Participants. Fifteen right-handed participants without past neurological or psychiatric history participated in this experiment (13 women, mean age = 21.13 years, range = 18–35). All had normal or corrected-to-normal vision and provided their written informed consent.

Stimuli. Ten continua of morphed facial expressions from fear to disgust were created using FantaMorph (Abrosoft). In each continuum, a disgusted prototype was morphed 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% of the physical distance to an identity-matched fearful prototype, resulting in 11 face images (i.e., fearful and disgusted prototypes, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 70:30, 80:20 and 10:90 fear-disgust morphed faces). The prototypical expressions of fear and disgust were selected from Facial Expression Of Emotion: Stimuli And Test (FEEST; Young, Perrett, Calder, Sprengelmeyer, & Ekman, 2002). A total of 110 face stimuli were used (10 continua of different identities × 11 stimuli per continuum). The face images subtended a horizontal visual angle of 6.8° and a vertical angle of 8.6° around the center of the screen. The stimulus presentation was controlled by the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997), and the viewing distance was 60 cm.

Procedure. Each trial began with a 600-ms fixation cross located in the center of the screen, followed by a 400-ms presentation of a facial expression. A blank screen was presented at the offset of the face stimulus and participants were instructed to categorize whether the face was fearful or disgusted via a key press with no time limitation. Performance feedback was not provided during the experiment. The key press initiated a new trial after a 500-ms intertrial interval. Trials were blocked by continua. In other words, participants had to complete 10 blocks, with a break between blocks. Within each block, the order of face stimuli from the same continuum was randomized. Each face was repeated nine times, resulting in a total of 99 trials in each block (9 Repetitions × 11 Expressions per Continuum). To acquaint the participants with the procedure, the experiment began with one–two blocks of practice trials, with different sets of face continua not being used in the experiment.

Results and Discussion

Categorization data of expression continua. For each expression continuum, categorization data were calculated as the percentage of choices corresponding to the fear or disgust emotion category for each morphed face (see Figure 1). Responses to stimuli at the same morph steps were averaged, irrespective of their sequential context. Although the exact data patterns varied across continua and participants, a highly consistent picture emerged. In accord with previous evidence (Calder et al., 1996; Etcoff & Magee, 1992), the categorization data of each continuum fell into two clear regions with an abrupt category shift, and each region belonged to the emotion category that corresponded to the prototype at that end. In general, a morphed face blended with more elements of fear or disgust from the prototypes, that is, a smaller distance between the prototype and the morphed face, was more likely to be categorized as fear or disgust, respectively.
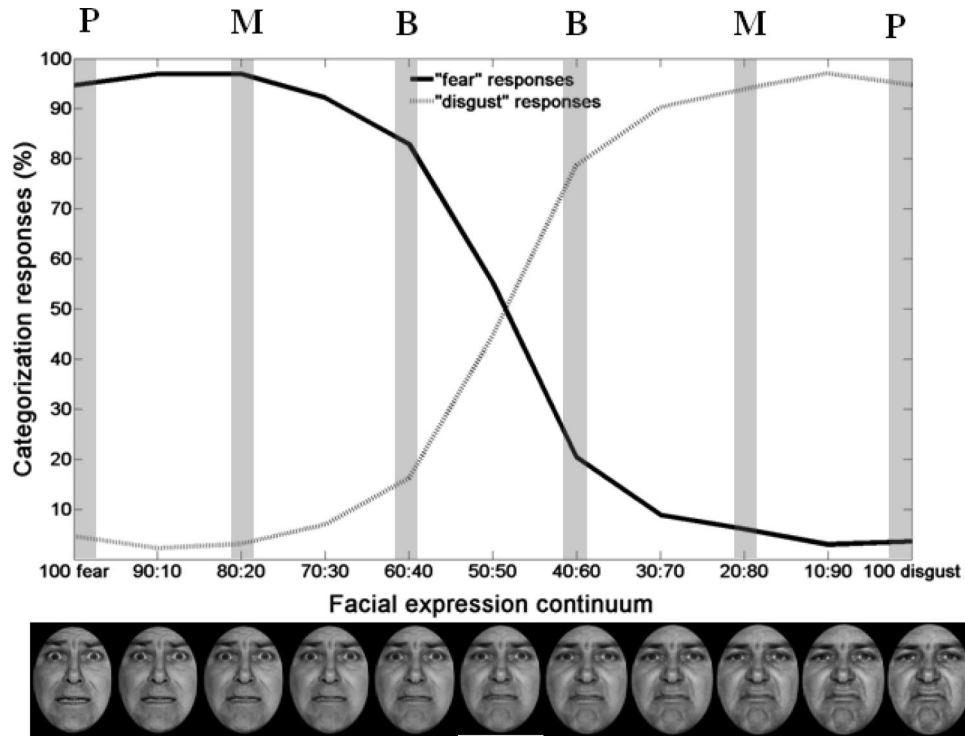
Figure 1. An example of the categorization data. The data were taken from one of the fear-disgust continua from a single participant. The expression continuum ranges from the prototypical expression of fear to the prototypical expression of disgust in 10 morphing steps. It should be noted that depending on the continua and individuals, the exact location of a category boundary was between 70:30 and 30:70 fear-disgust morphs. The gray bars indicate the expression stimuli selected for analyzing sequential effects in this example. The notations P, M and B represent the P, M and B faces, respectively.

General sequential effects. To control for the variability in the locations of the fear–disgust borderline across continua and participants so as to properly examine the effect of sequential context, we chose to analyze three types of face images from each emotion category: the prototypes (P face), the morphs close to the category boundary (B face), and the morphs lying at the midpoints of the P and B faces (M face). These faces were all highly recognizable and were judged as belonging to a distinct emotion category with categorization rates above 77.78% for each continuum and each individual (P face: $M \pm SEM = 95.59 \pm 0.88\%$, after collapsing across continua, emotion categories, and participants; M face: $94.56 \pm 0.66\%$; B face: $87.95 \pm 0.73\%$). The gray bars in Figure 1 illustrate an example of how these target faces were selected.

Figure 2A shows how the accurate (dominant) categorization responses to the three types of current faces varied as a function of the six different preceding stimuli: P, M, B faces from the *same* emotion category (white zone), and P, M, B faces from the *opposite* category (gray zone). It is important to note that categorization performance was averaged across the two emotion categories. The results showed that categorization of the current facial expressions differed according to the preceding stimulus types (current P face: one-way repeated-measures ANOVA, $F(5, 70) = 2.87$, $p < .05$; M face: $F(5, 70) = 2.34$, $p = .05$; B face: $F(5, 70) = 9.99$, $p < .001$), indicating that categorical judgments of the

current expressions depended on the local sequential context provided by the immediately preceding trials.

Additionally, we explored whether such sequential effects were limited to the effects of the immediately preceding stimuli, or whether the stimuli presented earlier in the trial sequence, such as two trials back, still had an impact on the categorization responses to the current expressions. As shown in Figure 3A, the sequential effects derived from the preceding expressions presented up to two trials back were diminished for all three types of current faces (P face: one-way repeated-measures ANOVA, $F(5, 70) = 0.54$, $p = .75$; M face: $F(5, 70) = 1.71$, $p = .33$; B face: $F(5, 70) = 0.81$, $p = .55$). Taken together, general sequential effects were only observed between two successively presented expressions, with the effects significantly reduced when there was a one-trial gap between the current and preceding expressions.

In an additional analysis, we investigated whether the general sequential effects could be observed individually for fearful and disgusted current faces. Similar to the results obtained when both emotion categories were combined, categorical responses to either fearful or disgusted current faces were affected by the immediately preceding stimuli (fearful current P face: one-way repeated-measures ANOVA, $F(5, 70) = 2.78$, $p < .05$; M face: $F(5, 70) = 1.06$, $p = .39$; B face: $F(5, 70) = 4.29$, $p < .01$; disgusted current P face: $F(5, 70) = 2.01$, $p = .09$; M face: $F(5, 70) = 4.73$, $p < .001$; B face: $F(5, 70) = 3.02$, $p < .05$), suggesting that the
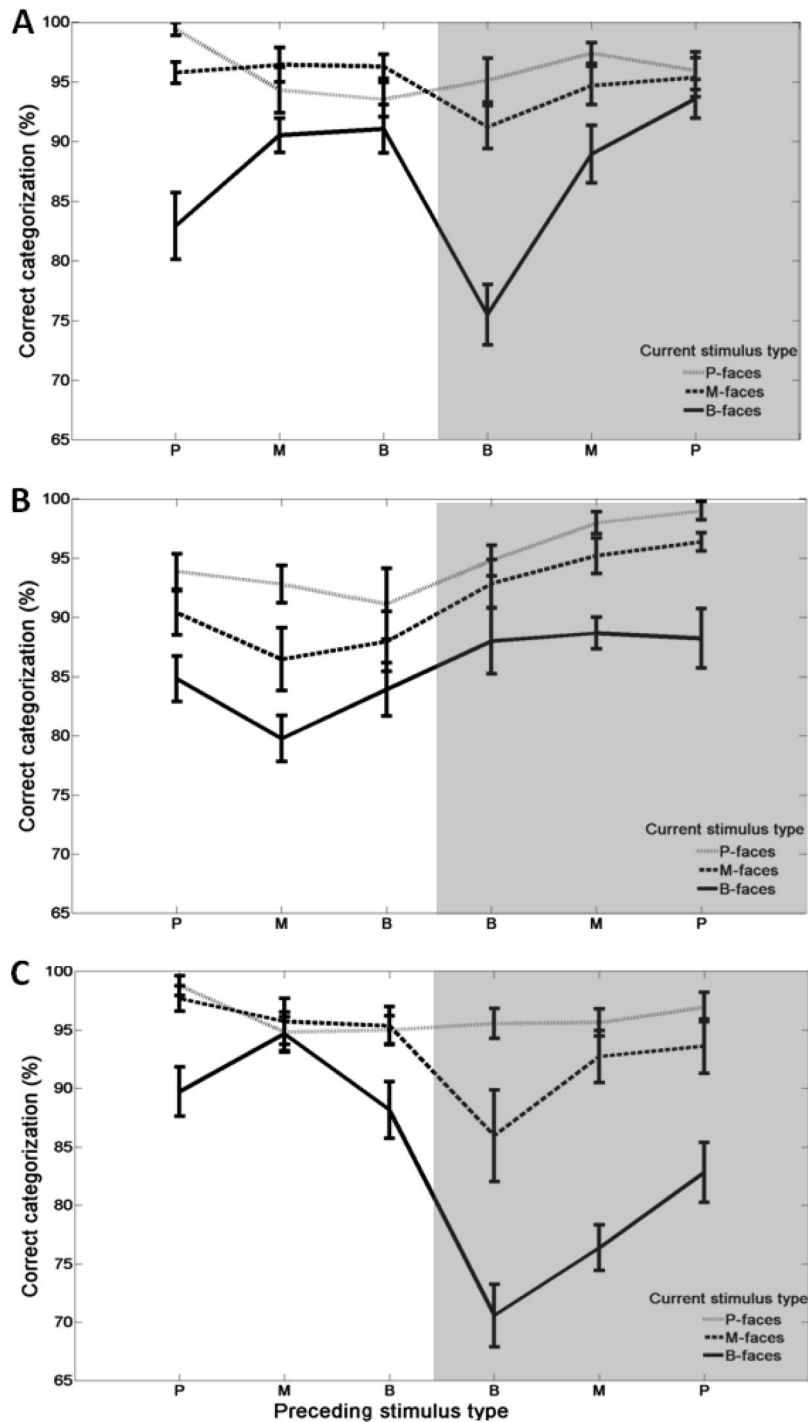
Figure 2. Categorization accuracy on current expressions as a function of different types of immediately preceding expressions in (a) the same-identity condition in Experiment 1, (b) the different-identity condition in Experiment 2, and (c) the same-identity condition in Experiment 2. The data are collapsed across categories. The gray zone indicates that the preceding and current stimuli have different category memberships. Error bars represent ± *SEM*.

sequential effects were not driven by any particular emotion category. Furthermore, the sequential effects observed in the two emotion categories were comparable in general, given that no significant interaction effects between categorization performance

of fearful and disgusted current expressions were found when the current stimuli were the P faces (2×6 repeated-measures ANOVA, $F(5, 70) = 0.38$, $p = .86$) or the B faces, $F(5, 70) = 1.55$, $p = .19$. However, a significant interaction effect was found
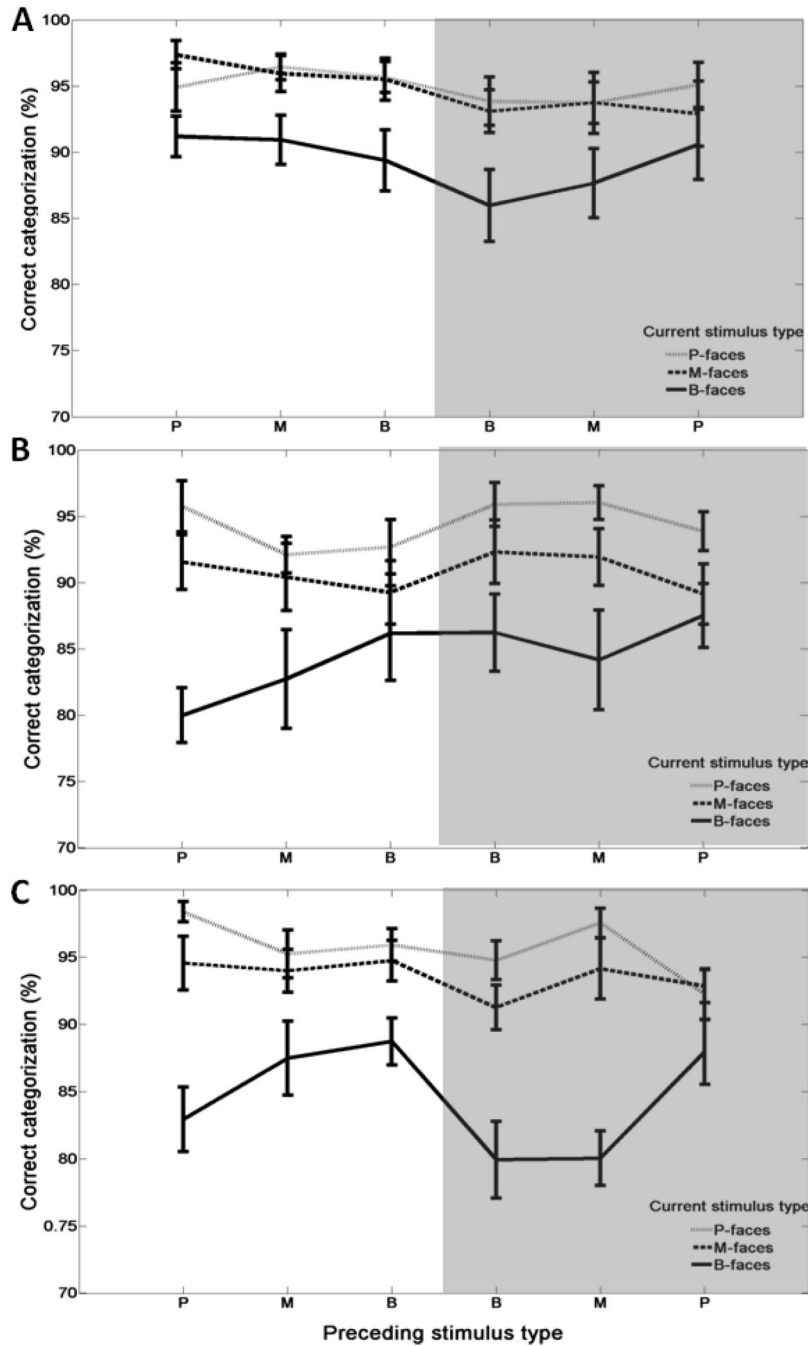
Figure 3. Categorization accuracy on current expressions as a function of different types of preceding expressions presented two trials back in (a) the same-identity condition in Experiment 1, (b) the different-identity condition in Experiment 2 and (c) the same-identity condition in Experiment 2. The data are collapsed across categories. The gray zone indicates that the preceding and current stimuli have different category memberships. Error bars represent $\pm$ *SEM*.

for the M faces, $F(5, 70) = 3.8$, $p < .01$. Additionally, the preceding stimuli from two trials back did not significantly bias the judgments of fearful and disgusted current expressions (fearful P face: one-way repeated-measures ANOVA, $F(5, 70) = 0.70$, $p = .62$; M face: $F(5, 70) = 1.93$, $p = .10$; B face: $F(5, 70) = 0.95$, $p = .45$; disgusted P face: $F(5, 70) = 0.74$, $p =$ .59; M face: $F(5, 70) = 0.24$, $p = .95$; B face: $F(5, 70) = 0.35$, $p = .88$). It should be emphasized here that some of the data points were based on as few as two trials when the fearful and disgusted faces were studied individually. As a consequence, we restricted the following analyses to the data collapsed across emotion categories.

Same- and different-category transitions. To further understand the nature of the sequential effects in facial expression categorization, we investigated how the different types of preceding stimuli affected categorization performance. More specifically, we assessed whether the sequential effects were different depending on whether the preceding and the current stimuli had the same or different emotion category memberships. In addition, trend analyses were conducted *separately* for each type of current expressions to estimate qualitatively whether the relative distance between the preceding and current expressions contributed to the effects in a *linear* manner. To this end, the accurate categorization

responses to the current expressions were reorganized according to their distance from the preceding expressions, as illustrated in Figure 4.

When the preceding and current expressions were from the *same* emotion category (Figure 4A, white zone), categorization responses to the current B faces were less accurate, with increasing relative distances between the preceding and current expressions, $F(1, 28) = 6.70$, $p < .05$. For the current M and P faces, no significant linear relationship between categorization responses and relative distances was found (M face: $F(1, 28) = 0.10$, $p > .05$; P face: $F(1, 28) = 4.12$, $p > .05$). When the preceding and
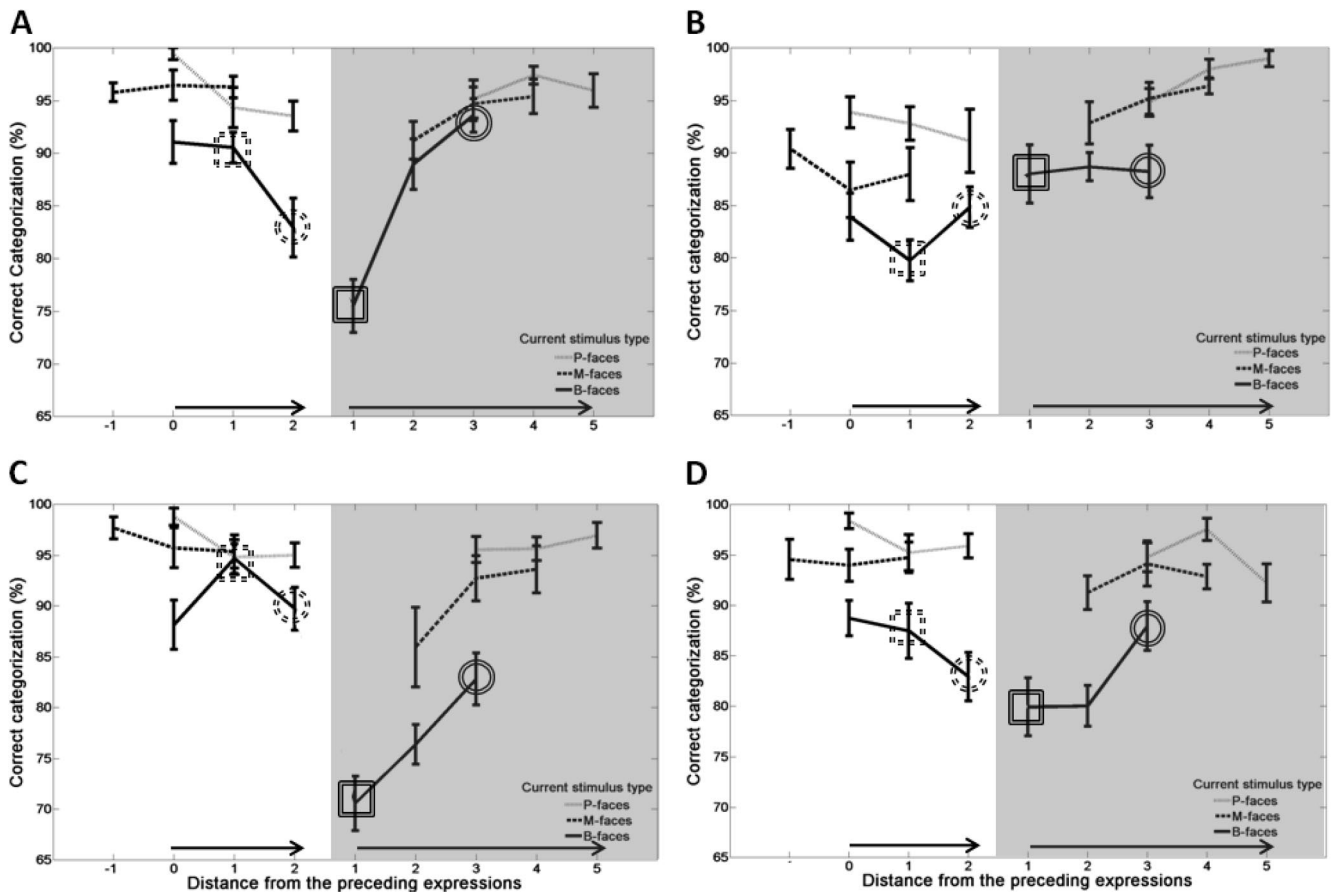

Figure 4. Categorization accuracy on current expressions as a function of their distance from the immediately preceding expressions in (a) the same-identity condition in Experiment 1, (b) the different-identity condition in Experiment 2, (c) the same-identity condition in Experiment 2, and (d) categorization accuracy when the preceding expressions were from two trials back in the same-identity condition in Experiment 2. The data are collapsed across categories. For the same-category preceding-current expression pairs (white zone), a zero-step distance represents a repetition. A one-step distance includes the M (preceding stimulus) →P (current stimulus), B→M, and M→B pairs. A two-step distance includes the B→P and P→B pairs. To better illustrate that the B→M and the P→M pairs have the same distance with opposite directions in reference to the same M faces, a negative one-step distance is used to represent the P→M pairs. For the different-category pairs (gray zone), a one-step distance includes the B (preceding stimulus of the opposite category) →B (current stimulus) pairs. A two-step distance includes the B→M and M→B pairs. A three-step distance includes the B→P, M→M, and P→B pairs. A four-step distance includes the M→P and P→M pairs. A five-step distance includes the P→P pairs. For the current B faces, the solid or dashed circles, respectively, represent the distant preceding expressions from the opposite category or from the same category, whereas the solid or dashed squares, respectively, represent the nearby preceding expressions from the opposite category or from the same category. Error bars represent ± *SEM*.

current expressions were from *different* categories (Figure 4A, gray zone), the categorical judgments of the current B faces were more accurate, with increasing relative distances between the preceding and current expressions, $F(1, 28) = 36.18$, $p < .001$. There was not a significant fit to a linear function for the current M faces, $F(1, 28) = 4.16$, $p > .05$ or P faces, $F(1, 28) = 0.22$, $p > .05$.

Taken together, the data showed that there was decreased accuracy to the current B faces after more distant expressions from the same category or increased accuracy to the current B faces after more distant expressions from the opposite category. This pattern provides evidence for contrast effects when the relative distance between the preceding and current expressions was increasingly large, given that the current stimulus was more likely to be judged as away from the category of the distant preceding stimulus. However, a complementary indication of the present results is that responses to the current B faces were more accurate after more nearby preceding expressions from the same category, or more errors were induced after more nearby preceding expressions from the opposite category. In this view, when the relative distance was increasingly small, the current stimulus was judged as close to the category of the nearby preceding stimulus. This suggests that the findings of this experiment could be alternatively explained in terms of assimilation effects. Which explanation is more compatible with our overall findings will be discussed below.

Between-category comparisons. To better understand the role of the relative distance in the sequential effects and clarify whether the findings in the previous section were due to assimilation effects, contrast effects or both, we examined responses to the current expressions when the expressions were preceded by a member of the *opposite* category relative to when they were preceded by a member of the *same* category. These analyses are in accord with those performed by Stewart et al. (2002).

As was evident from the findings in the previous section, contrast effects could be observed when the relative distance between successive expressions was large. We thus expected that participants would classify current stimuli as *further from* the category of the *distant* preceding stimuli, leading to increased accuracy if preceded by the distant stimuli from the *opposite* category but to decreased accuracy if preceded by the distant stimuli from the *same* category. Indeed, the present results showed higher accuracy on the current B faces after the distant P faces from the opposite category (P→B pair: 93.59 ± 1.61%, solid circle in Figure 4A) than after the distant P faces from the same category (P→B pair: 82.94 ± 2.80%, dashed circle; paired *t* test, $t(14) = 4.33$, $p < .001$). Given that our previous findings also revealed a possible involvement of assimilation effects when the relative distance was small, we expected that participants would classify current stimuli as *close to* the category of the *nearby* preceding stimuli. As a result, accuracy would be increased if preceded by the nearby stimuli from the *same* category, but more errors would be induced if preceded by the nearby stimuli from the *opposite* category. As expected, responses to the current B faces were more accurate after the nearby M faces from the same category (M→B pair: 90.54 ± 1.44%, solid square in Figure 4A) than by the nearby B faces from the opposite category (B→B pair: 75.5 ± 2.53%, dashed square; $t(14) = 4.67$, $p < .001$). The between-category comparisons confirmed previous analyses and further showed that both contrast and assimilation biases seemed equally involved in the sequential

effects, depending on whether the relative distance was large or small. The data for the current M and P faces were not analyzed because they did not serve as proper candidates for between-category comparisons due to a lack of well-defined distant preceding stimuli of the same category for the M faces and a lack of well-defined nearby preceding stimuli of the opposite category for both the M and P faces.

Summary. During categorization of a sequence of randomly presented expressions with the same identity, categorization performance regarding current expressions was influenced by the local sequential context provided by previous trials. Such sequential effects were observed not only for the current morphed and highly recognizable expressions, but also for the prototypes to some extent. However, the sequential effects only occurred between successive expressions, as expressions presented up to two trials earlier in the sequence had no significant impact on the responses to current expressions. Intriguingly, the relation between two successive stimuli seemed to determine how current expressions, particularly the B faces, were categorized. Two types of categorization biases were likely to be equally involved regardless of whether the preceding and current expressions had the same or different category memberships. On one hand, when the relative distance between two successive expressions was relatively large, participants were biased to categorize the current expressions as away from the category of the immediately preceding expressions (contrast effects). On the other hand, when the relative distance was relatively small, participants were biased to assimilate responses toward the category of the preceding expressions (assimilation effects).

Rather than being construed as supporting the influence of the local sequential context, our findings could simply reflect a response bias. For instance, participants might be biased against making two identical responses in a row. On this account, accuracy on current expressions would be the lowest after presenting the preceding P faces from the *same* category, given that the P faces have the highest correct categorization rates. By the same token, accuracy would be the highest after the presentation of the preceding P faces from the *opposite* category. Such predictive patterns are clearly not fully compatible with the categorization data for the current M and P faces (Figure 2A). Moreover, if the findings could be explained in terms of response-repetition bias, the categorization data of all three types of current expressions should have an identical pattern, irrespective of their perceptual properties. Our data, however, showed that the patterns of categorization for all three types of current expressions were not identical (3 × 6 repeated-measures ANOVA analysis on the interaction effect, $F(10, 140) = 5.05$, $p < .001$).

Could the observed sequential effects be attributed to a well-established perceptual mechanism, such as adaptation effects or emotional priming effects? Although adaptation effects in facial expression recognition involve a biased recognition of a current expression after a period of stimulation from preceding material, evidence has shown that adaptation effects are fleeting (Hsu & Young, 2004). In contrast to the experimental procedure adopted in this study, prolonged presentation of a preceding item is usually required to generate robust adaptation effects. Moreover, during the adaptation times, participants need to attentively inspect the preceding stimulus without performing any cognitive task. Emotional priming effects are also unlikely to be the

major source of the sequential effects. If the present data were due to emotional priming effects, improved categorization accuracy regarding current expressions would only have been observed following the presentation of stimuli from the same emotion category (Carroll & Young, 2005). However, we failed to find such a pattern in the current results.

Experiment 2: Different-Identity/Same-Identity Condition

The data from Experiment 1 provided evidence for sequential effects between successive expressions with the same identity. Traditionally, the processes of facial identity and facial expression have been thought to involve in separate, independent visual routes (Bruce & Young, 1986; Haxby, Hoffman, & Gobbini, 2000). However, some forms of dependencies between these two facial components have also been reported (Ganel & Goshen-Gottstein, 2004; Schweinberger & Soukup, 1998). Experiment 2 therefore aimed to investigate whether the dynamic nature of facial expression categorization as captured by the observed sequential effects could be generalized across different identities. To this end, morphed faces from continua of different identities were mixed and randomly presented. However, in the context of this design, a current face would also be preceded by a face with the same identity in some trials. Experiment 2 therefore provided an additional opportunity to test whether the same-identity sequential effects obtained in Experiment 1 would still be evident when the experimental context differed.

Method

Participants. Fifteen right-handed participants without past neurological or psychiatric history participated in the experiment (13 women, mean age = 20.13 years, range = 18–23). All had normal or corrected-to-normal vision and provided their written informed consent.

Stimuli and procedure. The stimuli and procedure were as in Experiment 1, with the exception that the faces from two different sets of continua of different identities were combined within one block. More specifically, eight continua of morphed faces were selected and organized into 4 pairs. In each pair, categorization performance along the two expression continua was highly correlated (all pairs: $r >= 0.99$, $p < .001$), based on the results from Experiment 1. This indicates that the patterns of categorization in each pair were comparable. Participants had to complete 2 sessions on different days. Each session consisted of 4 blocks, one block for each pair. Each block had 2 runs. Participants had a break between runs and blocks. Within a run and a block, a face stimulus was randomly selected from one of the 4 pairs. Each face image was repeated 6 times, resulting in a total of 132 trials in one run (6 repetitions × 22 expressions per continuum pair).

Results and Discussion

Categorization data of expression continua. As before, for each continuum, categorization data were calculated as the percentage of choices corresponding to the "fear" or "disgust" emotion category for the individual morphed faces. The categorization data for each continuum also fell into two clear regions, each of

which belonged to the emotion category corresponding to the prototype at that end. Further analyses showed that the same expression continuum, respectively studied in Experiment 1 and 2, had comparable patterns of categorization data, as categorization performance along the two expression continua was highly correlated (all continua: $r >= 0.99$, $p < .001$). This suggests that categorization performance along each expression continuum, after being averaged over trials without considering their sequential context, did not change in different experimental contexts. Because a current face could have been preceded by a face with either a different identity or with the same identity, the trials for which the preceding and current expressions had the same identity or different identities were analyzed separately.

General sequential effects: Different identities. Consistent with the analyses performed in Experiment 1, for every continuum, three types of highly recognizable P-, M-, and B face stimuli (categorization rates above 75% for each continuum and individual) from each emotion category were selected (P face: $M \pm SEM = 95.67 \pm 0.58\%$; M face: $92.53 \pm 1.02\%$; B face: $84.52 \pm 0.65\%$). Figure 2B depicts how accurate categorization responses to the three types of current faces, after being collapsed across emotion categories, varied as a function of the immediately preceding stimuli with *a different identity*. The results showed that categorization of the current facial expressions differed according to the preceding stimulus types (current P face: one-way repeated measures ANOVA, $F(5, 70) = 4.17$, $p < .01$; M face: $F(5, 70) = 5.44$, $p < .001$; B face: $F(5, 70) = 3.01$, $p < .05$). Despite the finding that sequential effects generalized across two successive expressions with different identities, the effects obtained here were distinct from the same-identity effects found in Experiment 1, as revealed by significant interaction effects between the categorization data of the current P faces (2×6 mixed ANOVA, $F(5, 140) = 2.21$, $p = .06$), the M faces, $F(5, 140) = 5.85$, $p < .001$ and the B faces, $F(5, 140) = 7.62$, $p < .001$. As shown in Figure 3B, the different-identity sequential effects were limited to the two immediately successive stimuli, given that the stimuli presented two trials previously in the sequence did not have significant impact on the categorization responses to the current P faces, $F(5, 70) = 1.32$, $p = .27$, the M faces, $F(5, 70) = 0.53$, $p = .76$ and the B faces, $F(5, 70) = 0.90$, $p = .49$.

To test whether the different-identity sequential effects were driven by any specific emotion category, the trials that presented fearful and disgusted expressions as the current stimuli were analyzed separately. Although some of the data points were based on as few as 2 trials, in general, both fearful or disgusted current faces were affected by the different types of immediately preceding expressions (fearful current P face: one-way repeated measures ANOVA, $F(5, 70) = 2.34$, $p = .05$; M face: $F(5, 70) = 3.98$, $p < .01$; B face: $F(5, 70) = 2.1$, $p = .07$; disgusted current P face: $F(5, 70) = 2.55$, $p < .05$; M face: $F(5, 70) = 1.98$, $p = .09$; B face, $F(5, 70) = 1.53$, $p = .19$). No significant interaction effect was found for the categorization data of fearful and disgusted current expressions (P faces: 2x6 repeated measures ANOVA, $F(5, 70) = 0.91$, $p = .48$); M faces: $F(5, 70) = 1.5$, $p = .2$; B faces: $F(5, 70) = 1.3$, $p = .27$), suggesting that the different-identity sequential effects observed in the two emotion categories were comparable. Consistent with the results from Experiment 1, the preceding expressions in the two trials back did not significantly bias the judgments of fearful and disgusted current expressions (fearful P face: one-way

repeated measured ANOVA, $F(5, 70) = 1.16$, $p = .34$; M face: $F(5, 70) = 1.00$, $p = .42$; B face: $F(5, 70) = 0.63$, $p = .68$; disgusted P face: $F(5, 70) = 0.94$, $p = .46$; M face: $F(5, 70) = 0.45$, $p = .81$; B face: $F(5, 70) = 1.16$, $p = .34$).

Same- and different-category transitions: Different identities. To clarify the role of the relative distance in the different-identity sequential effects, the trials for which preceding and current stimuli were chosen from the *same* emotion category were first analyzed. As shown in Figure 4B (white zone), a linear relationship between relative distances and categorization performance was not found for all three types of current expressions (B face: $F(1, 28) = 0.11$; M face: $F(1, 28) = 0.81$; P face: $F(1, 28) = 1.13$, all p's > 0.05). On the contrary, when the preceding and current expressions had *different* category memberships (Figure 4B, gray zone), categorization accuracy on the current P faces was linearly *improved* or *impaired* with *increasing* or *decreasing* relative distances between the current and preceding stimuli, $F(1, 28) = 13.22$, $p < .01$. The finding from the different-category transitions could be accounted for by either a contrast effect or an assimilation effect, as explained previously. Which effect was the potential candidate will be discussed next. No significant linear trend was observed when the current expressions were the B faces, $F(1, 28) = 0.01$, $p > .05$ or the M faces, $F(1, 28) = 2.95$, $p > .05$.

Between-category comparisons: Different identities. As in Experiment 1, responses to the current B faces were more accurate after the *distant* P faces from the *opposite* category (P→B pair: $88.22 \pm 2.50\%$, solid circle in Figure 4B) than after the *distant* P faces from the *same* category (P→B pair: $84.82 \pm 1.92\%$, dotted circle), although the comparison was only nearly significantly different (paired *t* test, $t(14) = 2.10$, $p = .06$). This finding suggests that participants were biased to categorize the current expressions as *away from* the category of the *distant* preceding expressions. In contrast to the results obtained in Experiment 1, the current expressions were also categorized as *away from* the category of the *nearby* preceding expressions. Improved accuracy was found when the current B faces were preceded by the *nearby* B faces from the *opposite* category (B→B pair: $88.00 \pm 2.77\%$, solid square) than by the *nearby* M faces from the *same* category (M→B pair: $79.75 \pm 1.95\%$, dashed square; $t(14) = 2.56$, $p < .05$).

In sum, the overall findings point toward a consistent pattern: When the preceding and current stimuli had different identities as well as different category memberships, participants were likely to respond as if the current expressions were away from the category of the preceding expressions - a contrast effect revealed by the data from both the between-category comparisons and the different-category transitions. This contrast effect was enhanced when the relative distance between the preceding and current expressions was increasingly large, leading to increased accuracy on the current expressions after the more distant expressions of the opposite category, as revealed by the data from the different-category transitions.

General sequential effects: Same identity. When the preceding and current expressions had the *same identity* (Figure 2C), the categorical judgments of the current expressions were found to differ as a function of the preceding stimuli when the current expressions were the B faces (one-way repeated measures ANOVA: $F(5, 70) = 17.58$, $p < .001$) or the M faces, $F(5, 70) = 3.64$, $p < .001$, but not when they were the P faces, $F(5, 70) =$

1.59, $p = .18$. In contrast to all of the previous findings, Figure 3C shows that the preceding stimuli from two trials back in the sequence still had a significant impact on the categorization responses to the current P faces, $F(5, 70) = 3.01$, $p < .05$ and the B faces, $F(5, 70) = 2.71$, $p < .05$, but not to the M faces, $F(5, 70) = 0.65$, $p = .67$. However, this observation could be due to the influence from the immediately preceding expressions instead if it happened that the preceding expressions from two trials back were followed by the same type of immediately preceding expressions. For example, if the preceding stimulus from two trials back was a P face from the same category, then the immediately preceding stimulus could also be the P face from the same category. To rule out this possibility, the occurrences of each possible type of immediately preceding expressions were counted with regard to each type of preceding expressions from two trials back for each participant. The data were then analyzed with Chi-Squared Goodness-of-Fit tests. The results did not support the aforementioned possibility, as no particular type of immediately preceding expression was presented more frequently for a given two-trial-back preceding expression (all p's > 0.05 for all participants). The analyses suggest that the observed long-range sequential effects were directly affected by the stimuli presented two trials back in the sequence.

Additional analyses showed that when the current stimuli were the B faces, the same-identity sequential effects observed in Experiment 2 had a distinct pattern of categorization compared to those observed in Experiment 1 (Figure 2C vs. 2A), which was supported by a significant interaction effect in a 2×6 mixed ANOVA analysis, $F(5, 140) = 6.29$, $p < .001$. No significant interaction was found when the current expressions were the P faces, $F(5, 140) = 0.46$, $p = .8$ or the M faces, $F(5, 140) = 0.87$, $p = .5$. As shown in Figure 2B and 2C, the categorization data also had significantly different patterns for the same-identity and the different-identity sequential effects obtained in Experiment 2 (current P face: $F(5, 70) = 2.89$, $p < .05$; M face: $F(5, 70) = 6.66$, $p < .001$; B face: $F(5, 70) = 18.40$, $p < .001$). Altogether, the sequential effects obtained in Experiment 1 and 2 were distinct from one another when the experimental contexts differed.

When current expressions of different emotion categories were investigated separately, the results showed that categorization performance on the fearful or disgusted current B faces was affected by the different types of immediately preceding expressions (fearful current P face: one-way repeated measures ANOVA, $F(5, 70) = 1.16$, $p = .34$; M face: $F(5, 70) = 1.71$, $p = .14$; B face: $F(5, 70) = 3.62$, $p < .01$; disgusted current P face: $F(5, 70) = 2.35$, $p = .05$; M face: $F(5, 70) = 2.93$, $p = .05$; B face: $F(5, 70) = 9.44$, $p < .001$) No significant interaction effect was found between categorization performance of fearful and disgusted current expressions (P faces: 2×6 repeated measures ANOVA, $F(5, 70) = 1.39$, $p = .24$; M faces: $F(5, 70) = 0.38$, $p = .86$; B faces: $F(5, 70) = 1.22$, $p = .31$), suggesting that the same-identity sequential effects observed in the two emotion categories were comparable.

In agreement with the data collapsed across categories, the preceding expressions from two trials back had marginal effects on the categorization of fearful and disgusted current expressions (fearful current P face: one-way repeated measures ANOVA, $F(5, 70) = 0.51$, $p = .77$; M face: $F(5, 70) = 1.05$, $p = .40$; B face: $F(5, 70) = 2.08$, $p = .08$; disgusted current P face: $F(5, 70) = 2.11$, $p = .07$; M face: $F(5, 70) = 0.45$, $p = .81$; B face: $F(5, 70) = 2.19$,

$p = .06$). No significant interaction effect was found between categorization performance of fearful and disgusted current expressions when the preceding expressions were from two trials earlier (P faces: 2x6 repeated measures ANOVA, $F(5, 70) = 0.58$, $p = .72$; M faces: $F(5, 70) = 1.360$, $p = .17$; B faces: $F(5, 70) = 1.80$, $p = .12$).

Same- and different-category transitions: Same identity. When the preceding and current expressions had the *same* category membership (Figure 4C, white zone), categorization accuracy on all three types of current expressions did not vary linearly with their relative distances from the preceding expressions (P face: $F(1, 28) = 2.23$; M face: $F(1, 28) = 1.07$; B face: $F(1, 28) = 0.32$, all p's > 0.05). In contrast, when the preceding and current expressions were from *different* emotion categories (Figure 4C, gray zone), categorization accuracy on the current B faces, $F(1, 28) = 16.48$, $p < .001$ and the M faces, $F(1, 28) = 4.84$, $p < .05$, but not the P faces, $F(1, 28) = 0.65$, $p > .05$, was linearly *improved* or *impaired* with *increasing* or *decreasing* relative distances. Again, these findings could indicate evidence either of a contrast effect with increasing relative distances or of an assimilation effect with decreasing relative distances (See below for further discussion).

As shown in Figure 4D, a similar pattern of results was observed when the preceding expressions were from two trials back in the sequence. When the preceding and current expressions had the *same* category membership (Figure 4D, white zone), no linear relationship between categorization performance and relative distances was found for any type of current expressions (P face: $F(1, 28) = 1.86$; M face: $F(1, 28) = 0.01$; B face: $F(1, 28) = 3.21$, all p's > 0.05). When the preceding and current expressions were from *different* emotion categories (Figure 4D, gray zone), categorization accuracy on the current B faces, $F(1, 28) = 6.79$, $p < .05$, but not the M faces, $F(1, 28) = 0.38$, $p > .05$ or the P faces, $F(1, 28) = 2.04$, $p > .05$, was linearly *improved* or *impaired* with *increasing* or *decreasing* relative distances.

Between-category comparisons: Same identity. In contrast with the different-identity effects, participants seemed to categorize the current expressions as *close to* the category of both *distant* and *nearby* expressions that immediately preceded the current expressions (Figure 4C). The between-category comparisons showed increased accuracy on the current B faces following the *distant* P faces from the *same* category (P→B pair: 89.72 ± 2.12%, dashed circle in Figure 4C) than following the *distant* P faces from the *opposite* category (P→B pair: 82.80 ± 2.56%, solid circle; paired t test, $t(14) = 2.11$, $p = .05$). In a similar vein, responses to the current B faces were more accurate after the *nearby* M faces from the *same* category (M→B pair: 88.16 ± 2.43%, dashed square) than after the *nearby* B faces from the *opposite* category (B→B pair: 70.57 ± 2.68%, solid square; $t(14) = 7.06$, $p < .001$).

When preceding expressions were from two trials back, the current B faces were categorized more accurately following the *nearby* M faces from the *same* category (M→B pair: 87.48 ± 2.41%, dashed square in Figure 4D) than following the *nearby* B faces from the *opposite* category (B→B pair: 79.93 ± 1.75%, solid square; $t(14) = 2.16$, $p < .05$). However, analyses failed to show any significant accuracy differences for the current B faces when they were presented after the *distant* P faces from the *same* category (P→B pair: 82.94 ± 2.41%, dashed circle) compared to

when they were presented after the *distant* P faces from the *opposite* category (P→B pair: 87.96 ± 2.43%, solid circle; paired t test, $t(14) = 1.32$, $p > .05$). The overall results suggest that, similar to the effects between successive expressions, the current expressions were also categorized as close to the category of the *nearby* expressions that preceded the current expressions in two trials earlier although such assimilation effects were reduced.

To account for the overall results obtained in the same-identity condition in Experiment 2, we suggest that when the preceding and current expressions had different category memberships, participants were biased to respond as if the current expressions were close to the category of the previous ones—an assimilation effect revealed by the data from both the between-category comparisons and the different-category transitions. As revealed by the results from the different-category transitions, such assimilation effects were enhanced when the relative distance between the preceding and current expressions was increasingly small, leading to increasingly impaired performance on current expressions following the presentation of the more nearby expressions of the opposite category.

Summary. Experiment 2 extended our previous findings, showing that sequential effects may generalize across different identities. However, the different-identity sequential effects in Experiment 2 appeared to involve a categorization process distinct from the same-identity effects in Experiment 1. In Experiment 2, only contrast effects were observed when the preceding and current expressions were from different categories, and the effects were enhanced with increasing relative distances. As in Experiment 1, we also observed the same-identity sequential effects in Experiment 2; however, the effects exhibited some distinct characteristics. First, only assimilation effects were observed when the preceding and current expressions were from different categories, and the effects were enhanced with decreasing relative distances. Second, the same-identity effects in Experiment 2 were more sustained, as expressions presented up to two trials back could still exert their influence. This long-range sequential effect suggests that there is a context-dependent selection of particular stimuli presented previously in the sequence, particularly when those stimuli could provide useful information for categorizing current stimuli (Petzold & Haubensak, 2001; Stewart & Brown, 2004).

General Discussion

The present study demonstrated that facial expression categorization was influenced by the local sequential context provided by previous stimuli. Two types of categorization biases were found: (a) Assimilation effects in which current expressions were categorized as close to the category of the preceding expressions and (b) contrast effects in which current expressions were categorized as away from the category of the preceding expressions. However, different experimental contexts determined which bias might be involved. When participants categorized a sequence of expressions from the same identity (Experiment 1), assimilation effects occurred if the relative distance between the preceding and current stimuli was small, whereas contrast effects occurred if the relative distance was large. Both biases occurred regardless of whether the preceding and current expressions had the same or different category memberships. When participants categorized a sequence of expressions from two different identities (Experiment 2), only

contrast effects were observed if the preceding and current expressions had different identities as well as different category memberships, whereas only assimilation effects were observed if the preceding and current expressions had the same identity as well as different category memberships. Furthermore, the contrast or the assimilation effects observed in Experiment 2 could have been enhanced with increasing or decreasing relative distances, respectively.

Relevance to Existing Accounts of Facial Expression Categorization

Our findings highlight limitations of the two leading accounts of facial expression categorization. In contrast to the discrete-category account, we found that facial expressions were not perceived as belonging to qualitatively discrete categories, but instead, the categorization processes could be modulated by the local sequential context. The dimensional account is also not free from difficulties in accounting for our findings. According to this account, fearful expressions are more likely to be judged as "fear" after viewing disgusted expressions and vice versa because of shifts in the values of arousal and valence (Russell & Fehr, 1987). Accordingly, categorization accuracy would always be higher when the preceding and current expressions are from different categories than when the two are from the same category. However, the results of the same-identity sequential effects in both Experiment 1 and 2 clearly contradict this prediction. Moreover, the current study has shown that different experimental contexts may produce differential sequential effects with distinct natures, which is a result that the dimensional account cannot fully explain.

Underlying Mechanisms of the Expression-Based Sequential Effects

Several recent models have been proposed to account for sequential effects during supervised categorization, in which performance feedback is given. Although it remains unclear to what extent those models could be generalized to account for unsupervised categorization as shown in the current study (but see Hampton et al., 2005), the models may still hint at the potential mechanisms underlying the expression-based sequential effects.

Similarity-dissimilarity generalized context model (SD-GCM). The (SD-GCM) suggests that sequential effects are the result of a particular decision strategy in which relative difference information between successive items is used by participants to inform their categorization decisions (Stewart & Brown, 2005; Stewart & Morin, 2007). In this view, when two successive stimuli are *similar*, participants may believe that the current stimulus has the same category membership as that of the preceding stimulus (assimilation effects). When facing two successive stimuli that are quite *dissimilar*, participants tend to judge these two stimuli as belonging to different categories (contrast effect). Consistent with the model, the results of Experiment 1 showed assimilation effects when the relative distance between the preceding and current expressions was increasingly small (more similar) and showed contrast effects when the relative distance was increasingly large (more dissimilar).

Is the SD-GCM model also compatible with the results of Experiment 2? We suggest that, in facial expression categoriza-tion, participants estimate not only the differences in the perceptual attributes between the successive stimuli but also the differences in the emotional attributes of the stimuli. As a result, sequential effects may be observed even when the preceding and current expressions are taken from two sets of continua with different identities, yielding different-identity sequential effects.

In line with previous behavioral evidence showing that face identity interferes with expression categorization (Ganel & Goshen-Gottstein, 2004; Schweinberger & Soukup, 1998), we suggest that face identity information may have been involved in similarity/dissimilarity comparisons between successive expressions in Experiment 2. If the preceding and current expressions have different identities, the expressions may appear more dissimilar due to their contrastive facial configurations. As a consequence, only contrast effects would be found, as is evident in the different-identity sequential effects. In contrast, if the preceding and current expressions have the same identity, the preceding and current stimuli may appear more similar when facial expressions are categorized in the context of multiple face identities. As a consequence, only assimilation effects would be observed, as is evident in the same-identity sequential effects. Given that assimilation of stimulus categories might be enhanced for faces of the same identity, this offers a potential explanation why assimilation effects persist for preceding expressions up to two trials back in the same-identity sequential effects found in Experiment 2. From the above perspectives, our findings lend additional support to the view of interdependencies between facial identity and facial expression. We suggest that the contextual information imposed by facial identity could shape the dynamic nature of facial expression processing.

In Experiment 2, the relative distance significantly contributed to the sequential effects only when the preceding and current expressions were from different categories. The nature of the mechanisms regarding why the similarity/dissimilarity comparison strategy did not operate on two successive stimuli from the same category remains unclear. In the different-identity condition, it was likely that the preceding and current expressions were from different sets of continua so that facial features supporting expressions of the same emotion category differed. Outweighed by such differences in feature, the preceding and current expressions of the same category may have appeared equally dissimilar, irrespective of the relative distance between the two. In the same-identity condition, given that the range along the fear-disgust emotional dimension in Experiment 2 was increased after combining two sets of continua, participants might have perceived the preceding and current expressions of the same category as equally similar, such that the impact of the relative distance was diluted.

Representation-shift account. Alternatively, our current findings could be explained in terms of shifts in the participants' internal representations or criteria of categories (Petrov & Anderson, 2005; Treisman & Williams, 1984; Zotov et al., 2011). As illustrated in Figure 5, there are two types of shifts. The first type is the same-category shift (Figure 5, right panel): After presenting a stimulus from Category A, the center of the representation of Category A is shifted toward that stimulus. For example, the category representation is shifted right following the presentation of the P faces (Figure 5A, right panel) and shifted left after the B faces (Figure 5C, right panel). Because the position of the M faces corresponds to the center of the category representation, the shift
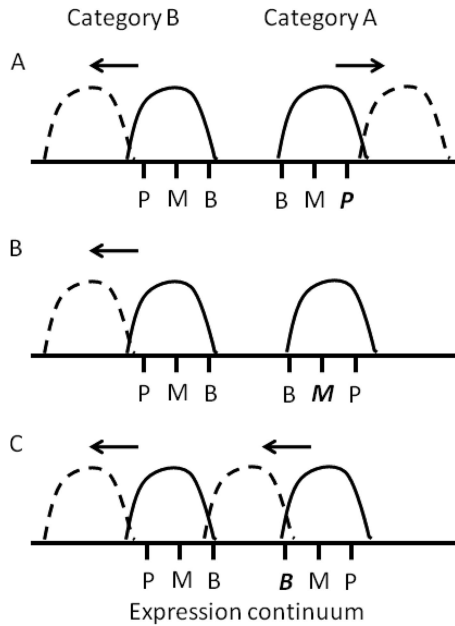
Figure 5. A schematic diagram illustrating the representation-shift account, adapted with permission from Zotov et al. (2011). The black arcs indicate the initial representations of the categories, whereas the dotted arcs indicate the shifted representations of the categories. The italics in each graph indicate the positions of the preceding expressions.

does not occur (Figure 5B, right panel). The second type is the different-category shift (Figure 5, left panel): After presenting a stimulus from Category A, the internal representation of Category B is pushed away.

What are the consequences of these shifts? Due to the same-category shift, the position of the current B faces of Category A, for example, is located outside the shifted representation of Category A if preceded by the distant P faces of the same category (Figure 5A, right panel). However, the position of the B faces is still within the shifted representation if preceded by the nearby M or B faces of the same category (Figure 5B and 5C, right panel). Therefore, in agreement with the results of the same-category transitions in Experiment 1, when the preceding and current expressions are from the same category, participants would be more likely to respond as if the current B faces were *away from* the category of the more *distant* preceding expressions (i.e., contrast effects with increasing relative distances). A complementary indication is that participants would be more likely to respond as if the current B faces were *close to* the category of the more *nearby* preceding expressions (i.e., assimilation effects with decreasing relative distances).

The results of the different-category transitions in Experiment 1 could be explained in terms of both the different-category and the same-category shifts. For example, due to the different-category shifts, the position of the current B faces of Category B is located outside the shifted representation of Category B following the presentation of an item from Category A (Figure 5, left panel). However, the position of the current B faces of Category B falls within the shifted representation of Category A if preceded by the nearby B faces of Category A (Figure 5C) compared to if preceded

by the distant M or P faces (Figure 5A and 5B), due to same-category shifts. As a result, when the preceding and current expressions are from different categories, the current expressions would also be categorized as close to or away from the category of the preceding expressions with decreasing or increasing relative distances.

Although the representation shift could account for our findings in Experiment 1, it is less clear how this account explains the findings in Experiment 2. It is possible that, in Experiment 2, participants' internal representations of face identities and the range effect may interact with the category representations of facial expressions, yielding differential patterns of sequential effects.

Characteristics of the Expression-Based Sequential Effects

Both the SD-GCM model and the representation-shift account suggest that contrast and assimilation effects reflect a common bias in decision-making. A recent study, however, has argued that the locus of contrast effects operates during the early perceptual stage of stimulus processing (Jones et al., 2006). Our findings appear to favor the decision-bias view, given that the contrast effects were found in the same-identity condition in Experiment 1, but not in Experiment 2, despite the perceptual information between two successive expressions being the same in both experiment (identical sequential contexts derived from identical sets of facial expression stimuli).

The current study also reveals that sequential effects may operate on more complex stimuli, such as facial expressions. Moreover, expression-based sequential effects exhibit a number of features that are distinct from those reported in previous research using simple, neutral stimuli during category learning. First, the effects were labile, in general. The expressions presented two trials back had little impact on the categorical judgments of current expressions, except with regard to the same-identity effects found in Experiment 2. Second, when results across Experiments 1 and 2 are taken into account, the experimental contexts, which include the face identities and the range effect, could completely change the nature of the sequential effects. Third, the sequential effects could be observed not only for the current stimuli close to the category borderline but also for the current stimuli that were the prototypes to some extent (but see Jones et al., 2006). Lastly, in contrast to prior literature, assimilation effects could be robustly observed even when the preceding and current stimuli had the same category membership, as demonstrated in Experiment 1. However, it should be pointed out that different from most prior research (but see Hampton et al., 2005), no performance feedback was provided during categorization in this study. Therefore, further investigations are needed to clarify whether the aforementioned characteristics of the expression-based sequential effect are due to feedback-related effects or the intrinsic nature of facial expression stimuli.

Conclusions

The findings from the present study suggest that facial expression categorization is not a static process. Rather, the relation between the preceding and current expressions could provide a

basis for categorization, revealing a more dynamic and adaptive aspect of facial expression categorization. Our findings are also in accord with a broader trend in recent research that shows that the perception of emotional faces can be influenced by various forms of contextual information, such as body posture (Aviezer et al., 2008), language (Lindquist, Barrett, Bliss-Moreau, & Russell, 2006; Roberson, Davidoff, & Braisby, 1999), and scenes (Barrett & Kensinger, 2010; Righart & De Gelder, 2008). With this study, we contribute to this body of research by suggesting that temporal contextual information may interact in guiding our categorical decisions on emotional faces. Acknowledgment and consideration of this phenomenon in future research would provide a better understanding of the nature of emotional processing.

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