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The perception of changing emotion expressions

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The utility of recognising emotion expressions for coordinating social interactions is well documented, but less is known about how continuously changing emotion displays are perceived. The nonlinear dynamic systems view of emotions suggests that mixed emotion expressions in the middle of displays of changing expressions may be decoded differently depending on the expression origin. Hysteresis is when an impression (e.g., disgust) persists well after changes in facial expressions that favour an alternative impression (e.g., anger). In expression changes based on photographs (Study 1) and avatar images (Studies 2a–c, 3), we found hystereses particularly in changes between emotions that are perceptually similar (e.g., anger–disgust). We also consistently found uncertainty (neither emotion contributing to the mixed expression was perceived), which was more prevalent in expression sequences than in static images. Uncertainty occurred particularly in changes between emotions that are perceptually dissimilar, such as changes between happiness and negative emotions. This suggests that the perceptual similarity of emotion expressions may determine the extent to which hysteresis and uncertainty occur. Both hysteresis and uncertainty effects support our premise that emotion decoding is state dependent, a characteristic of dynamic systems. We propose avenues to test possible underlying mechanisms.

Keywords: Emotion perception; Emotion; Expression; Mixed emotions; Dynamic systems; Hysteresis.

Feelings change. For example, in a negotiation, an unexpected obstacle may result in a shift from happiness to anger. An observer who perceives this change has several advantages: She or he may better understand how the opponent assesses the situation, anticipate the other's actions, and monitor the success of her/his attempts to regulate the opponent's feelings (e.g., Kopelman, Gewurz, & Sacharin, 2008; Van Kleef, 2009). More generally, identifying changes in emotion expressions is important for the coordination of social interactions, the assessment of others' attitudes, and emotion regulation (Salovey & Mayer, 1990). In this paper, we examine how changing facial emotion expressions are decoded.

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Although mixed emotions occur frequently in social life (e.g., Scherer & Ceschi, 1997), we know little about the perception of changing expressions. Empirical research has focused predominantly on the study of prototypical emotions and the perception of static expressions (Scherer, Clark-Polner, & Mortillaro, 2011). The current lack of knowledge on the perception of changing emotion expressions may be rooted in the tradition of conceptualising so-called basic emotions as innate and universal (basic emotion theory; Ekman, 1999; Izard, 1994), or as the result of social constructions (core affect theory; Barrett, 2006; Russell, 2003). The questions that seemed critical for evaluating the merits of either theory, and which thus dominated empirical research as reviewed below, were whether decoding is categorical or continuous, and whether contexts influence the perception of *un*ambiguous expressions. However, neither basic emotion theory nor core affect theory provides a theoretical framework to guide research on changing emotion experiences, expressions, and perceptions. In contrast, hypotheses on these topics can be derived from the component process model (CPM; Scherer, 1984, 2009).

The nonlinear dynamic systems viewpoint and hysteresis

The CPM construes emotions as resulting from continuously changing appraisals, which are reflected in changes in action units (AU; Ekman & Friesen, 1978) in the facial expression of emotions (Scherer, 1992; Wehrle, Kaiser, Schmidt, & Scherer, 2000). In the CPM, the dynamic of changes in appraisals and emotion experience has been described using a cusp catastrophe, which is a particular nonlinear dynamic system (Sander, Grandjean, & Scherer, 2005; Scherer, 2000). Nonlinear dynamic systems are increasingly used to describe emotion experience, development, and encoding (e.g., Fogel & Thelen, 1987; Izard, 2007; Lewis, 2005; Thagard & Nerb, 2002; Wolff, 1987; Zeeman, 1976), but experimental hypothesis tests are scarce (Camras, 2011). One of the central questions from a nonlinear dynamic systems view of emotions is whether affective phenomena are state dependent, which is when the state of a system depends on the history of its state. One such effect is hysteresis, which is when an effect lags behind its cause. Hysteresis is one of the characteristics of a cusp catastrophe. From a CPM model that incorporates nonlinear dynamic systems concepts, new hypotheses about emotion experience, encoding, and decoding can be developed, such as whether the perception of changing emotion expression shows a hysteresis (Figure 1).

With a hysteresis in emotion perception, an initial impression persists despite changes in the situation that favour an alternative impression. In other words, the threshold for perceiving a change from one emotion to another may vary depending on the origin of the change. As a result, a particular mixed emotion expression is interpreted as one emotion when this emotion is the origin and as another emotion when the second emotion is the origin. For example, when an expression changes from anger to disgust, a mixed anger–disgust expression may be decoded as anger, but when an expression changes from disgust to anger, the same expression may be decoded as disgust. This means that one is not able to predict how a mixed emotion expression will be decoded without knowing the prior state of the expression. A necessary condition for hysteresis is bistability, which is when a stimulus is associated with two percepts.

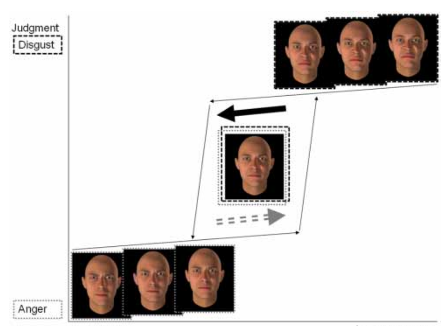


Figure 1. *Hysteresis pattern in emotion perception. When starting with an angry expression, the expression in the middle of the series may be interpreted as anger, but when starting with a disgust expression, the image may be interpreted as disgust.*

In the area of perception, hysteresis effects have been reported for the perception of dot motion, ambiguous figures, speech, sentences, and face identities (e.g., Attneave, 1971; Hock, Bukowski, Nichols, Huisman, & Rivera, 2005; Kim, 2002; Raczaszek, Tuller, Shapiro, Case, & Kelso, 1999; Stewart & Peregoy, 1983; Tuller, Case, Ding, & Kelso, 1994; Wilton, 1985). Concerning the underlying mechanism of hysteresis, research on moving dots shows that the differential activation of detectors (e.g., of horizontal vs. vertical motion) by an originally *un*ambiguous stimulus (e.g., horizontal motion) can stabilise and result in hysteresis when the detectors interact across time so that one inhibits the other (e.g., inhibition of the vertical motion detector by the horizontal motion detector; Hock, Schöner, & Giese, 2003). Without the inhibition of a detector by another detector, no hysteresis occurs. Also, no hysteresis occurs when a stimulus activates a detector more strongly than it is inhibited by another detector. For example, when two unambiguous stimuli in close temporal proximity are shown, hysteresis does not occur (Wilton, 1985), possibly because activations are high and not sufficiently different for both detectors to bias the percept across time. Finally, when a constant stimulus activates a detector for a relatively long time, an adaptation of this stimulus may occur (neural fatigue); when the stimulus ends abruptly, this may lead to the perception of the opposite of the stimulus, and not in hysteresis. Hysteresis is thus the result of the relation of opposing forces activated by the external stimulus and internal stabilisation and adaptation mechanisms, and is only expected for continuously changing stimuli.

Differential detector activation by the stimulus may be the result of stimulus properties (e.g., with unambiguous moving dots) or of selective attention to stimulus features that are significant for a particular interpretation (e.g., with unambiguous figures). For example, perceiving an ambiguous duck–rabbit as a duck or as a rabbit is associated with attention towards the area corresponding to the beak of the duck or the nose of the rabbit, respectively (Tsal & Kolbet, 2007). Although the nose of the rabbit can also be interpreted as the head of the duck, paying attention to the nose area seems to more strongly activate the rabbit schema and to override the duck interpretation for the figure as a whole. As a result, attention guided towards the relevant area by unrelated stimuli influences how an ambiguous duck–rabbit figure is interpreted (Tsal & Kolbet, 2007). This mechanism of selective attention for disambiguating ambiguous figures may also play a role in hysteresis in emotion decoding.

Related work in emotion perception

Although studying the decoding of emotion expressions has a long history, neither research on the perception of dynamic expressions, mixed emotion expressions, nor context effects in emotion perception has examined whether the decoding of changing emotion expressions shows hysteresis. First, research on dynamic emotion expressions has focused on changes to and from neutral expressions, neglecting changes between emotional expressions (e.g., Bassili, 1979; Kamachi et al., 2001; Niedenthal, Halberstadt, Margolin, & Innes-Ker, 2000; Sander, Grandjean, Kaiser, Wehrle, & Scherer, 2007; Sato & Yoshikawa, 2004). To our knowledge, there are only two studies that have examined direction effects in decoding expressions to or from neutral. However, conclusions cannot be drawn, either because a detailed description of the study including test statistics was not provided (Kobayashi & Hara, 1993), or because of interaction effects of direction and poser (Dubé, 1997).

Second, mixed emotion expressions have predominantly been used in a static format, disregarding the importance of dynamic aspects (e.g., Campanella, Quinet, Bruyer, Crommelinck, & Guerit, 2002; Etcoff & Magee, 1992; Kotsoni, de Haan, & Johnson, 2001; Young et al., 1997). An exception is a study on the influence of mood on the decoding of expression changes from happiness to sadness and vice versa (Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001). However, state dependence was not systematically examined. More recently, Fiorentini and Viviani (2011) studied the decoding of mixed emotion expressions that emerge dynamically from a neutral expression. However, in keeping the expression origin constant, the authors did not analyse hysteresis effects, and, in contrast to the current study, did not examine changes from one expression to another.

Third, research on context effects for emotion decoding has neglected continuously evolving expressions as a context for decoding. Mixed facial emotion expressions may be disambiguated by body postures, emotion labels, encoder gender, and previously seen expressions (e.g., Halberstadt, Winkielman, Niedenthal, & Dalle, 2009; Hess, Blairy, & Kleck, 1997). For example, the adaptation to a prototypical facial expression shown for a long time (3–5 min) may bias the encoding of static mixed emotion expressions to the opposite of the adapted expression (e.g., Webster, Kaping, Mizokami, & Duhamel, 2004). In other cases, such as with body postures, a context may lead to assimilation to the context (e.g., Van den Stock, Righart, & de Gelder, 2007). Even the decoding of unambiguous expressions may be influenced by contexts, such as the trigger of an emotion (e.g., situations), other response channels (e.g., gestures), and others' simultaneously and sequentially presented expressions (see Matsumoto & Hwang, 2010). The assimilation of emotion expressions to a context occurs effortlessly and unintentionally (Aviezer, Bentin, Dudareva, & Hassin, 2011), in contrast to assimilation and contrast effects with social judgements that can intentionally be influenced (e.g., judgements of personality traits; Strack, Schwarz, Bless, Kübler, & Wänke, 1993). Eye-movement studies suggest that context effects in emotion decoding are the result of selective attention to relevant sources of information (Aviezer et al., 2008; Masuda et al., 2008). Similar to research on the disambiguation of ambiguous figures, this suggests that the origin of an expression may bias emotion decoding through selective attention.

Special considerations for hysteresis in emotion perception

Applying a nonlinear dynamic systems perspective to emotion perception is not trivial, as emotions are much more complex compared to other stimuli. Two characteristics of emotion expressions may influence the likelihood of finding hysteresis effects. First, the similarity of particular emotion expressions may increase the likelihood of finding hysteresis. A context biases decoding of an expression towards the context particularly when the actual expression and the emotion expression suggested by the context have similar perceptual features (Aviezer et al., 2008), or similar underlying arousal and valence (Carroll & Russell, 1996). This suggests that hysteresis may be more likely for more similar expressions. Indeed, there is a reliable similarity structure among emotion expressions (e.g., anger is more similar to disgust than happiness; e.g., Young et al., 1997), although emotion expressions are perceived categorically rather than continuously (e.g., Etcoff & Magee, 1992; Kotsoni et al., 2001; Young et al., 1997). The empirically observed similarity structure can be reconstructed by machine learning models of category learning using perceptual inputs without semantic knowledge about the expressions (Dailey, Cottrell, Padgett, & Adolphs, 2002; Susskind, Littlewort, Bartlett, Movellan, & Anderson, 2007), suggesting that the physical, geometric similarity between expressions reflects to some extent the relations among emotion concepts (Adolphs, 2002). One possible cause of similarity in two emotion expressions is the commonality of underlying appraisals and AUs, as suggested by the CPM (Scherer, 1992). For example, AU 4 (brow lowerer) is commonly seen in anger and disgust, and is associated with goal obstructiveness (Fiorentini, 2009; Wehrle et al., 2000). The brow lowering may serve sensory closure (Susskind & Anderson, 2008), indicating a close connection between appraisals, form, and function of expressions.

The second characteristic of emotion expressions that may influence the likelihood of hysteresis is that they may be decoded as mixed emotions or as unidentifiable. Previous research on hysteresis used stimuli that are predominantly, if not exclusively, perceived as one of two so-called attractor states, but not as both or as something entirely different. For example, with ambiguous figures, Wilton (1985) reported that only 10% of responses were either "both" or "neither" figure. Similarly, in the motion quartet, either a vertical or horizontal motion is perceived, but not both (Hock et al., 2003). Compared to these stimuli, the simultaneous perception of two emotions (e.g., happy and sad), or of a third distinct emotion (e.g., nostalgia) may be more prevalent with emotion expressions. Emotions can be experienced as mixed, such as feeling happy and sad (e.g., Larsen & McGraw, 2011; Oceja & Carrera, 2009; Schimmack, 2005), and expressions may be decoded as multiple emotions (e.g., Young et al., 1997).

When the perception of mixed emotions is perceived as mixed or as a distinct category (e.g., nostalgia), a "false" hysteresis pattern may appear as the result of a conservative response strategy to favour a previous interpretation when the given response alternatives (e.g., happy, sad) do not describe the current stimulus well. More generally, judgemental uncertainty may result in an apparent hysteresis pattern due to a lack of adequate response options (Hock et al., 2005). Distinguishing uncertainty from hysteresis resulting from bistability is important, because the consequences of added noise to the percept signal differ with uncertainty and bistability; with uncertainty, random noise in a percept signal decreases the likelihood that a response alternative is perceived, whereas with bistability, noise increases the likelihood that one of the response alternatives is seen, because the noise breaks the symmetry of competing response alternatives (Hock et al., 2005).

Research on happy–sad expression changes suggests that uncertainty may not be an issue for decoding emotion expressions (Niedenthal et al., 2001). However, in that research, changes between only two emotions were repeatedly shown, so that participants may have known which expression change to expect, which may have influenced their responses. For decoding changes between multiple expressions, as in this paper, judgemental uncertainty cannot be ruled out.

Current paradigm

Given the considerations above, we designed a paradigm where hysteresis could be distinguished from uncertainty. In this paradigm, participants see a series of images from one prototypical emotion to another emotion (e.g., happiness → anger), as well as the reverse series (e.g., anger → happiness). For each image of the series, participants indicate whether they perceive a particular emotion (e.g., "happiness" or "not happiness"), and for a repetition of the same series later in the study, whether they perceive the other emotion (e.g., "anger" or "not anger"). In other words, they indicate when the expression initially appears (e.g., with happiness → anger, when does "anger" appear?) or disappears (e.g., when does "happiness" disappear?). This is similar to previous research on hysteresis in motion detection (Hock et al., 2005).

In this paradigm, with a hysteresis, participants should always interpret mixed expressions as one or the other emotion (e.g., "anger", "disgust"), depending on the expression origin. Different response patterns would appear when the stimulus is decoded as both emotions, as a third category, or as unidentifiable. In the first case, participants should always interpret mixed expressions as one or the other emotion (e.g., "anger", "disgust"), regardless of the expression origin. In the latter cases, participants should indicate neither emotion ("not anger", "not disgust"), regardless of the expression origin. See the supplementary materials for more formal notations for hysteresis and uncertainty.

In Study 1, we examined changes between various prototypical emotions. In Studies 2 and 3, we added changes between prototypical and neutral emotions. Our starting point was the expectation that the perception of changing emotion expressions follows a hysteresis pattern, as evidenced by an origin-dependent threshold for perceiving an emotion. The reliability of expected and additional unexpected findings from Study 1 was then tested in Studies 2 and 3.

STUDY 1

In Study 1, using morphed images of photographs, we tested if changing emotion expressions are decoded in a hysteresis pattern. In a morphing paradigm, intermediate images between two prototypical expressions are computer generated. The resulting sequence of mixed emotion images are called inverse when one emotion increases as the other decreases (Oceja & Carrera, 2009). Compared to natural expressions, morphing allows a high degree of control. We created morphed images between six emotions (happiness, anger, sadness, fear, disgust, and surprise). We chose these emotions because they are widely used in emotion research, and have also been referred to as basic or modal emotions (e.g., Ekman & Friesen, 1976; Scherer, 2009).

Method

Participants

Forty-three students (37 women, 6 men) from the University of Geneva participated in the study for partial course credit. Their mean age was 22 (range 16–47, mode = 20).

Procedure

The study was conducted with one to four participants at a time. After signing a consent form, participants were seated at individual computer stations. The first task was a simple emotion decoding task. Participants then did a reaction time task that was unrelated to the purpose of the current paper and will not be discussed further. The procedure of the changing emotion task was then introduced by a gender morph task. The subsequent changing emotion task lasted about thirty minutes. Afterwards, participants filled out a survey with demographic questions, and other questionnaires. Participants were debriefed and thanked. The study lasted about one hour.

Materials

Stimulus material. We used posed expressions from the Ekman Pictures of Facial Affect set (Ekman & Friesen, 1976) that have high decoder agreement, have often been used in previous research, and allow comparability of results across studies.

Simple emotion decoding. For the simple emotion decoding task, the images of a man's and a woman's emotion expressions were used. The study was not designed to test gender differences across posers; however, using a male and a female poser enables us to test the robustness of an effect across gender of poser.

Participants saw a fixation cross for 500 ms, followed by the expression of an emotion (happiness, anger, sadness, disgust, fear, surprise). They then indicated which emotion they perceived. They could select one of seven answers (happiness, anger, sadness, disgust, fear, surprise, neutral). Emotion expressions were presented in random order, and each image was presented until participants selected a response. Thus, all participants saw all prototypical emotion expressions before they completed the changing emotion task.

Gender morph task. Participants watched several clips of morphed images from a man to a woman and indicated the perceived gender with the same presentation and response parameters as in the changing emotion task. Further details about the task and the results are available from the first author upon request.

Changing emotion task. Using a key dots method with 102 dots in the commercial program Fantamorph®, expressions of happiness, anger, sadness, disgust, fear, and surprise from the simple emotion decoding task were morphed from one to another emotion with a total of 29 frames. With 29 frames, differences between frames are subtle but noticeable, and the number of frames is sufficiently large for variance in responses, but sufficiently small to avoid subject fatigue (compare, e.g., Yoshikawa & Sato, 2008). With 15 emotion pairs, two posers, two directions, and two emotion labels per emotion pair, the total number of trials was 120.

For the trials, participants saw a fixation cross for 500 ms, then a fixation cross plus the labels "not happy" to the left and "happy" to the right for 2,000 ms, and then the image of a happy expression plus the labels. Pressing a left or a right key, they indicated their response and progressed immediately to the next image until the series was completed. At the end of the series, participants were prompted to rate the perceived intensity and credibility of the last image on a scale from 1 (*very weak*) to 9 (*very strong*). The results from these questions will not be further discussed in this paper. Starting images, labels, and posers were counterbalanced, and trials were presented in random order. There were no practice trials as the procedure had been trained with the gender morph task.

Results

Simple emotions

On average, participants identified 11 out of 12 (six emotions times two posers) emotions correctly. The men in the sample decoded prototypical emotion expressions equally well as the women (10.8, 10.5), $t(41) = 0.71$, $p = .48$ (note that there were only six men). Out of 43 participants, the lowest decoding rates emerged for the female poser's disgust and surprise display with 30 and 31 correct responses, and the male poser's anger display with 31 correct responses. The greatest confounds occurred between fear and surprise, and anger and disgust (see supplementary materials for the confusion matrix).

Changing emotions

In some trials, participants did not perceive a change between emotions. The fewest changes were perceived for fear–surprise and anger–disgust. Trials with no changes were excluded from the analysis (see the corresponding *df*s in the test statistics provided in Table 1), leaving insufficient participants for testing direction effects in the fear–surprise series.

The dependent variable was the frame at which participants perceived emotion x of the respective emotion pair x–y for the first time (when this emotion appeared) or for the last time (when this emotion disappeared), corresponding to the smallest percentage of x where an expression change was perceived. For example, in a happiness–anger change, the dependent variable was the first frame at which happiness was perceived when happiness appeared from anger, and the last frame at which happiness was perceived when happiness disappeared to anger. We conducted a series of repeated-measures analyses with Direction ($x \rightarrow y$, $y \rightarrow x$), Poser (man, woman), and Label ("x", "y") for each emotion pair x–y. Because of multiple comparisons, we used a Bonferroni adjusted $\alpha = .003$ (.05/15) for each initial analysis of variance (ANOVA), and followed-up on significant effects at $\alpha = .05$. The means, expressed as the percentage frame of emotion x in each emotion pair x–y, and test statistics for significant tests are displayed in Table 1. Here, we summarise the findings and elaborate on the patterns of interaction effects.

Three types of patterns emerged: Hysteresis, reverse hysteresis, and uncertainty (Figure 2). A hysteresis pattern is indicated when there is a main effect of direction and when emotion x is perceived at a lower percentage frame of x in an $x \rightarrow y$ series than in a $y \rightarrow x$ series. A hysteresis pattern emerged in the anger–disgust and sadness–disgust series. With the female poser, for example, in a change from anger to disgust, anger was perceived until the 36% frame (36% anger, 64% disgust), but in a change from disgust to anger, anger was perceived only at the 57% frame (compare Figure 2). The pattern was similar when the disgust label was used, and also emerged for the male poser. Follow-up analyses of a significant interaction of direction and poser effect showed that the hysteresis was particularly pronounced for the female poser. For a change between sadness and disgust, follow-up analyses of an interaction of direction and poser showed that hysteresis only emerged for the male poser, $F(1, 35) = 5.68$, $p = .023$, $\eta_p^2 = .14$.

Reverse hysteresis patterns emerged for happiness–sadness, happiness–anger, and happiness–fear. For example for the male poser, in a change from happiness to sadness, happiness was perceived

Table 1. *Study 1, test statistics and percentage frame of x for each emotion pair by label and direction condition*

	Label, direction, and poser								
	"x"				"y"				
	$x \rightarrow y$		$y \rightarrow x$		$x \rightarrow y$		$y \rightarrow x$		
Emotion pair x–y	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*Test statistics*
Happiness–Anger	64^{a}	57^{b}	57^{b}	$54^{b,c}$	$50^{b,c}$	$43^{d,c}$	$46^{d,c}$	$46^{b,c,d}$	L: $F(1, 36) = 46.06$, $\eta_p^2 = .56$ D*P: $F(1, 36) = 11.05$, $\eta_p^2 = .24$
Happiness–Sadness	68^{a}	$64^{a,c}$	$57^{b,c}$	$50^{b,d}$	54^{b}	$50^{b,d}$	$46^{b,d}$	39^{d}	L: $F(1, 39) = 40.90$, $p < .001$, $\eta_p^2 = .51$ D: $F(1, 39) = 22.77$, $p < .001$, $\eta_p^2 = .37$ P: $F(1, 39) = 15.19$, $p < .001$, $\eta_p^2 = .28$
Happiness–Disgust	$64^{a,c}$	68^{a}	$54^{a,d,e,f}$	$61^{a,e}$	$46^{b,d}$	$57^{c,e}$	43^{b}	$50^{b,f}$	L: $F(1, 36) = 42.86$, $p < .001$, $\eta_p^2 = .54$ P: $F(1, 36) = 29.94$, $p < .001$, $\eta_p^2 = .45$
Happiness–Fear	$61^{a,d}$	$61^{a,d}$	64^{d}	$50^{a,c}$	$50^{b,c}$	$46^{b,c}$	$54^{a,c}$	39^{b}	L: $F(1, 37) = 43.69$, $p < .001$, $\eta_p^2 = .54$ P: $F(1, 37) = 37.72$, $p < .001$, $\eta_p^2 = .51$ D*P: $F(1, 37) = 16.07$, $p < .001$, $\eta_p^2 = .30$
Happiness–Surprise	57^{a}	57^{a}	$43^{b,c,d,e}$	$50^{a,e,f}$	$50^{a,c}$	$57^{a,d}$	$43^{b,c,f}$	$50^{a,e}$	P: $F(1, 35) = 23.59$, $p < .001$, $\eta_p^2 = .40$
Anger–Sadness	$57^{a,d}$	$50^{a,c}$	64^{d}	54^{a}	50^{a}	$43^{c,e}$	$50^{a,e}$	$46^{a,e}$	L: $F(1, 34) = 25.47$, $p < .001$, $\eta_p^2 = .43$ P: $F(1,34) = 21.44$, $p < .001$, $\eta_p^2 = .39$
Anger–Disgust	$50^{a,c}$	36^{a}	61^{c}	$57^{c,b}$	$46^{a,c}$	$39^{a,b}$	$54^{a,c}$	68^{c}	D: $F(1, 17) = 15.28$, $p = .001$, $\eta_p^2 = .47$ D*P: $F(1, 17) = 14.69$, $p = .001$, $\eta_p^2 = .46$
Anger–Fear	$54^{a,c,d}$	$54^{a,c,d}$	$61^{a,d}$	57^{d}	$57^{a,d}$	43^{c}	$57^{a,d}$	$50^{a,c}$	L*P: $F(1, 32) = 11.12$, $p = .002$, $\eta_p^2 = .26$
Anger–Surprise	$54^{a,b,c,d}$	$61^{a,b,c,d}$	$61^{a,b}$	$68^{b,c}$	$50^{a,b,c,d}$	$54^{a,d}$	50^{d}	$54^{a,d}$	L: $F(1, 33) = 20.08$, $p < .001$, $\eta_p^2 = .38$
Sadness–Disgust	$46^{a,c,e}$	71^{b}	$57^{a,c}$	$68^{b,d}$	46^{a}	$61^{c,d,e}$	$54^{a,c,e}$	$54^{a,c,e}$	L: $F(1, 28) = 12.60$, $p = .001$, $\eta_p^2 = .31$ P: $F(1, 28) = 55.64$, $p < .001$, $\eta_p^2 = .67$ L*P: $F(1, 28) = 11.20$, $p = .002$, $\eta_p^2 = .29$ D*P: $F(1, 28) = 20.05$, $p < .001$, $\eta_p^2 = .42$
Sadness–Fear	54^{a}	43^{a}	50^{a}	54^{a}	46^{a}	39^{a}	54^{a}	57^{a}	—
Sadness–Surprise	$50^{a,c}$	61^{b}	50^{a}	$61^{c,b,d}$	46^{a}	$54^{a,d}$	46^{a}	$54^{a,b}$	L: $F(1, 36) = 25.75$, $p < .001$, $\eta_p^2 = .42$ P: $F(1, 36) = 70.11$, $p < .001$, $\eta_p^2 = .66$
Disgust–Fear	$54^{a,f}$	$46^{b,c,g}$	$61^{a,c}$	$46^{d,e,f,g,h}$	$46^{b,d}$	$39^{b,e}$	$50^{a,c,d,e}$	$43^{b,h}$	L: $F(1, 37) = 18.97$, $p < .001$, $\eta_p^2 = .34$ P: $F(1, 37) = 50.75$, $p < .001$, $\eta_p^2 = .58$
Disgust–Surprise	57^{a}	$54^{b,c}$	$57^{a,c,d}$	$50^{a,b,d}$	$46^{b,d}$	43^{b}	46^{b}	43^{b}	L: $F(1, 37) = 33.31$, $p < .001$, $\eta_p^2 = .47$ P: $F(1, 37) = 18.03$, $p < .001$, $\eta_p^2 = .33$

Notes: Different superscript indices indicate significant differences within emotion pair at $\alpha = .0018$ (.05/28 comparisons within emotion pairs).

Test statistics are displayed for significant effects at $\alpha = .003$ (.05/15 emotion pairs) with main effect of Direction (D), Label (L), and Poser (P), and interaction effects (e.g., D*P = interaction of direction and poser).

until the 68% frame (68% happiness, 32% sadness), but in a change from sadness to happiness, happiness was perceived already at the 54% frame. A reverse hysteresis emerged across posers for happiness–sadness, but only for the male poser for happiness–anger, $F(1, 36) = 7.11$, $p = .011$, $\eta_p^2 = .17$, and only for the female poser for happiness–fear, $F(1, 37) = 6.93$, $p = .012$, $\eta_p^2 = .48$.

A main effect of label indicates uncertainty when a change between emotions x–y is seen at a higher percentage frame of x with an "x" label (off- and onset of x), compared to a lower

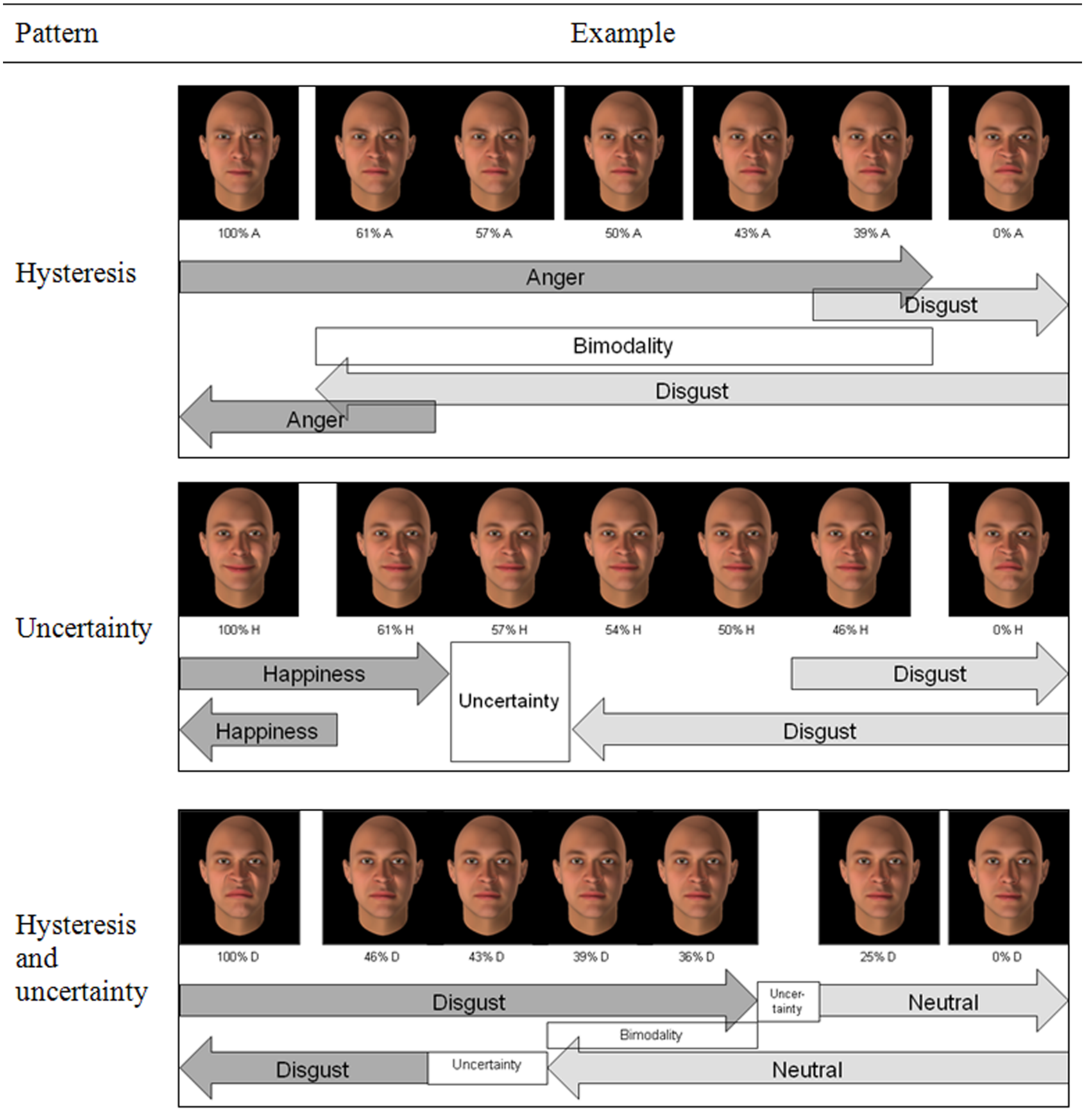
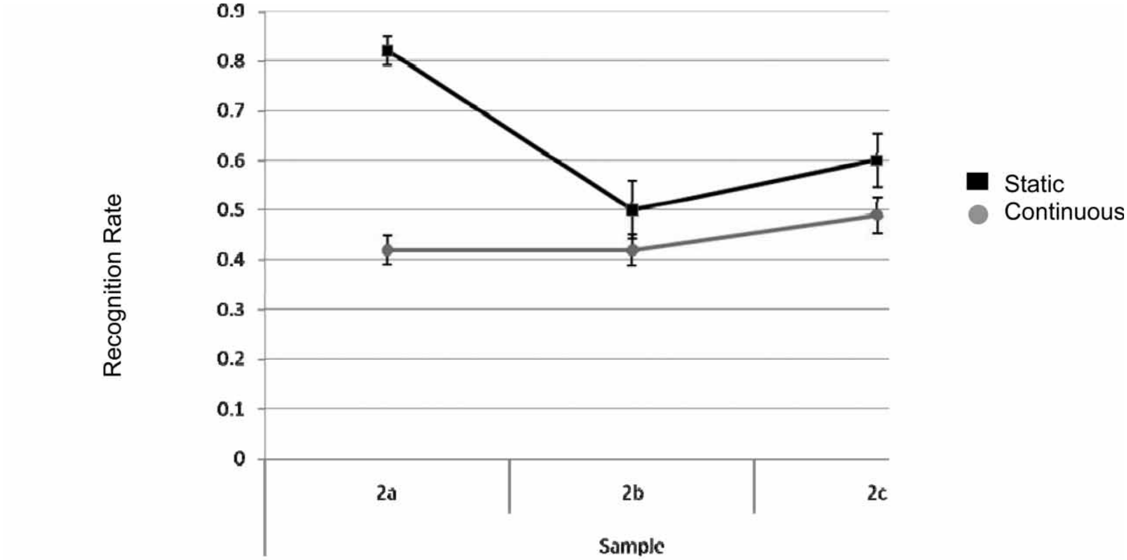


Figure 2. *Examples of response patterns based on stimuli and data from study 2. Arrow fields indicate the direction of an expression change.*

percentage frame of x with a "y" label (off- and onset of y). Thus, there is an area where neither x nor y is perceived. For example, in the happiness–disgust series with the male poser, happiness was perceived until the 64% frame (64% happiness, 32% disgust), but disgust was perceived to appear only after the 46% frame; in a disgust–happiness series, disgust was perceived to disappear already before the 43% frame, and happiness was perceived only at the 54% frame. Thus, there were several frames where neither happiness nor disgust was perceived (compare Figure 2). Uncertainty emerged for multiple expression changes, that is across posers for happiness–anger, happiness–sadness, happiness–disgust, happiness–fear, anger–sadness, anger–surprise, sadness–surprise,



Number of participants (women)	22 (9)	21 (20)	22 (11)
Participant mean age (range)	27 (18–58), one missing information	22 (19–25)	31 (20–53)
Sample recruitment	Psychology subject pool and participant panel	Psychology subject pool	Student population and participant panel
Remuneration	CHF 20	Partial course credit	CHF 15
Study duration	1 h	1.5 h	1 h
Trials changing emotion task	84	120 in three blocks	84 in three blocks
Trials static emotion task	45	270 in three blocks	126 in three blocks
% x in static mixed emotion expression	39, 50, and 61	Emotion pair specific based on study 2a	As in study 2b
Response format for changing emotion task	Is emotion present or not?	Is emotion present or not?	Is any degree of emotion present or not?
Response format for static emotion task	Select all that apply from list and/or provide your own label	Is emotion present or not?	Is any degree of emotion present or not?

Figure 3. *Studies 2a–2c, recognition rate means and standard errors for mixed emotion expressions in continuous and static displays and study characteristics.*

disgust–fear, and disgust–surprise, and for the female poser for sadness–disgust, $F(1, 32) = 28.41$, $\eta_p^2 = .47$, and anger–fear, $F(1, 40) = 21.65$, $p < .001$, $\eta_p^2 = .35$.

Poser main effects without further interactions showed that the male poser was perceived as happier, sadder, and less disgusted than the female poser.

Discussion

The primary interest of Study 1 was to examine whether the decoding of emotional expressions depends on the origin of an expression change. In the changing emotion task, no expression change was perceived in many trials for fear–surprise and anger–disgust changes. Fear and surprise, as well as anger and disgust, are often confounded (i.e., one expression is mistaken for the other, e.g., Young et al., 1997), which may result in not perceiving a psychologically meaningful change between the expressions. For fear–surprise, too few participants perceived a change in emotional expression to analyse direction effects.

We found hysteresis patterns in changes between anger and disgust, and, for the male poser, in changes between sadness and disgust, suggesting that for some expression changes, the evolving expression is a relevant context that influences decoding. Many participants did not perceive any change between anger and disgust, but if they did, the expression had to change a lot before a change in judgement occurred. The specificity of hysteresis to particular expression changes may be related to the similarity of expressions. Finding hysteresis effects for anger–disgust but not anger–fear suggest that perceptual similarity may be a more important criterion for hysteresis (compare Aviezer et al., 2008) than similarity based on arousal and valence (Carroll & Russell, 1996). We discuss explanations for hysteresis further in the general discussion after establishing the robustness of the findings in Studies 2 and 3.

Unexpectedly, we found a reverse hysteresis pattern with expression changes involving happiness. In these changes, happiness was perceived to disappear at a frame with relatively more happiness in the image, but it was perceived to appear at a frame with relatively less happiness in the image. These results could be related to the finding that happiness is often more reliably decoded than other emotions (Calvo & Nummenmaa, 2008; Gosselin, Kirouac, & Doré, 1995; Hess et al., 1997). However, this pattern did not replicate in the subsequent studies, indicating that the effect may not be robust across different stimulus materials.

The most prominent pattern when judging changing emotion expressions was uncertainty, where neither emotion was perceived in the middle of a display series. Here, perception does not depend on the particular expression origin, in contrast to hysteresis or reverse hysteresis. We found this unpredicted pattern for eight out of 15 changes for both posers, and additionally for two changes (anger–fear, sadness–disgust) for the female poser. This suggests that uncertainty is common when decoding continuously changing emotion expressions.

The occurrence of uncertainty from Study 1 raises several new questions. First, how do respondents perceive mixed emotion expressions if not as one of the prototypical emotions? For example, it is possible that the images in the middle of a series were perceived as a third category (e.g., happiness–fear as hope) or as unidentifiable. Second, is judgemental uncertainty specific to changes between emotional expressions, or does it also occur for changes with neutral expressions? Finally, can the effect be attributed to the specific stimulus material used in Study 1? Studies 2a–2c were designed to provide some answers to these questions.

STUDY 2

We conducted a series of three studies to further examine the nature of the uncertainty in decoding continuous changes, and to replicate the findings from Study 1 using different stimulus materials. Despite some differences across Studies 2a–2c (see Figure 3), the tasks and results are more similar than different, and the studies are therefore reported jointly.

A first aim of these studies was to examine whether uncertainty may be due to the stimulus material used in Study 1. The photos from Ekman and Friesen (1976) are grey-scaled and fuzzy. Using a morphing technique further increased the fuzziness of the images. It therefore seemed important to test the robustness of the findings with different stimulus material. Instead of photographs, we used computer-generated facial expressions with a high definition of individual AUs (Ekman & Friesen, 1978) in Study 2.

Even with improved stimulus material, individuals may decode images in the middle of the series as a third category or as unidentifiable. A few studies have used a free response format and found that responses to mixed emotion images sometimes deviate from prototypical emotion categories, but details of free responses are not reported (e.g., Etcoff & Magee, 1992). Also, variations in stimulus material may make it difficult to generalise results across studies. To understand how participants decode the images used in our study, we explored participants' categories for mixed emotion expressions by providing them with an opportunity to create their own label for mixed emotion images (Study 2a). To even better compare uncertainty in decoding static and changing expressions, we proceeded to identify the percentage frames of x for each emotion pair that led to the most uncertainty in Study 2a. We then asked participants to decode these static images in Studies 2b and 2c using the same response format in the changing emotion and the static mixed emotion decoding tasks, with a counterbalanced task order, allowing for a better comparison of decoding rates.

Uncertainty in decoding emotion expressions may also depend on how narrowly an emotion category is defined. In Study 2c, the "emotion" category was specified to include any degree of the emotion, while the "not emotion" category referred to no emotion at all. With a more lenient response format, uncertainty should be reduced because more instances of mixed expressions are included in the response category. For the same reason, hysteresis effects should be enhanced.

Also, uncertainty may only occur when one emotion changes to another, but not when an emotion emerges from or dissipates to a neutral expression. As the research by Niedenthal et al. (2000, 2001) suggests, perceptions of emotions that arise from neutral expressions may be different from perceptions of emotions that change to a different emotion. In Studies 2a–2c, we therefore also included changes to and from neutral expressions.

In Study 2b, we also included a manipulation where we did (not) provide participants with information about the nature of the expression to be judged by showing them the prototypical emotions that comprised the mixed emotion expressions (or scrambled faces) immediately before they judged the changing emotion sequence and the static mixed emotion expressions, respectively. However, exit interviews strongly suggested that participants may not have paid sufficient attention to this information, possibly because no response was required from them during the viewing, and this manipulation did not systematically influence the results. Given the additional manipulation, changes to and from surprise were not examined in Study 2b.

To summarise, Studies 2a–2c aimed to replicate the findings from Study 1 with the following changes. We changed the stimulus material, added expression changes to and from neutral expressions, provided participants with the opportunity to create their own response labels for mixed emotion expressions (Study 2a), and tested the robustness of the findings using different response formats. We predicted hysteresis and uncertainty patterns for the respective expression changes from Study 1 (the prediction of a reverse hysteresis was dismissed after Study 2a). We also explored the patterns for changes to and from neutral expressions.

Method

Participants

Sixty-five participants (40 women) participated in the study. Their mean age was 26 years (range 18–58; see also Figure 3).

Procedure

The procedure was the same as in Study 1. In Study 2a, participants rated static mixed emotion images after the changing emotion task, and in Studies 2b and 2c, the order of these tasks was counterbalanced. In Studies 2b and 2c, a gender task introduced participants to the procedure of the static mixed emotion decoding task. The studies lasted 1–1.5 hours.

Materials

Stimulus material. We used avatar faces created with FaceGen (Singular Inversions Inc., 2007), a program previously applied in research on face perception (e.g., Oosterhof & Todorov, 2009; Todorov, Baron, & Oosterhof, 2008; Verosky & Todorov, 2010). To express different emotions, individual AUs were combined on a male avatar face with the program FACSGen 2.0 (Swiss Center for Affective Sciences). FACSGen is specifically designed for emotions research (Krumhuber, Tamarit, Roesch, & Scherer, in press; Roesch et al., 2011) and has been applied repeatedly in research on expression perception (Cristinzio, N'Diaye, Seeck, Vuilleumier, & Sander, 2010; N'Diaye, Sander, & Vuilleumier, 2009; Roesch, Sander, Mumenthaler, Kerzel, & Scherer, 2010). It provides a high degree of control over expressions and allows one to create clear colour images of simple and mixed emotion expressions. The AUs designed in FACSGen are sculpted based on anatomical descriptions of facial surface changes described in the FACS manual (Ekman, Friesen, & Hager, 2002). A recent validation study showed that individual AUs, combinations of AUs, and prototypical emotion expressions created with FACSGen are well recognised and credible (Krumhuber et al., in press). All images and information on the specific AUs used to create the images are available from the first author upon request (Figure 4).

Simple emotion decoding. Stimulus presentation and response modus were the same as in Study 1.

Gender practice tasks. Gender tasks introduced participants to the procedure for the changing emotion task (Studies 2a–2c) and the static mixed emotion decoding task (Studies 2b & 2c). For detailed task descriptions and results contact the first author.

Changing emotion task. Mixed emotion expressions were created by specifying varying percentages of the full expressions of each emotion with FACSGen Swiss Center for Affective Sciences. Percentages were based on creating a linear change and a total of 29 images per series, with an inverse pattern for the two emotions involved (see Figure 4). In Studies 2a and 2c, the presentation and response modes were the same as in Study 1. Study 2b had the following change: for 3,000 ms prior to the emotion sequence to be decoded, the starting and ending prototypical emotion of the respective emotion sequence (or two identical scrambled faces) were shown in the upper left and right corner of the screen. See Figure 3 for the numbers of trials.

Static mixed emotion decoding. Study 2a: Participants saw mixed emotion expressions containing the mix of two emotions (only mixes between prototypical emotions) at the following percentage frames of x: 39%, 50%, and 61%. They checked all that applied from a response field with happiness, anger, sadness, disgust, fear, surprise, neutral, and other (with an optional fill in the blank field). This mixed recognition and production task allowed participants, for each expression, to select multiple prototypical emotions, to select other (with no further specification), or to generate their own emotion label. This way, participants had room to express if an expression was unidentifiable (e.g., by checking other without further specification) or was a third category (e.g., happiness–fear as hope).

Studies 2b and 2c: We identified mixed expressions with high uncertainty in the continuous task of Study 2a (see Figure 4). The percentage frames of x were 39% (disgust–neutral), 43% (happiness–fear, happiness–neutral, disgust–fear), 46% (happiness–anger, anger–neutral, sadness–neutral, fear–neutral), 50% (happiness–sadness, anger–disgust, sadness–fear, fear–surprise), 54% (anger–sadness, anger–fear, disgust–surprise), 57% (happiness–surprise, sadness–disgust, sadness–surprise), and 61% (happiness–disgust, anger–surprise). Additionally, relatively unambiguous mixed expressions at a percentage frame of x of 21% and 79% were shown so that participants would not solely be faced with highly ambiguous stimuli, similar to

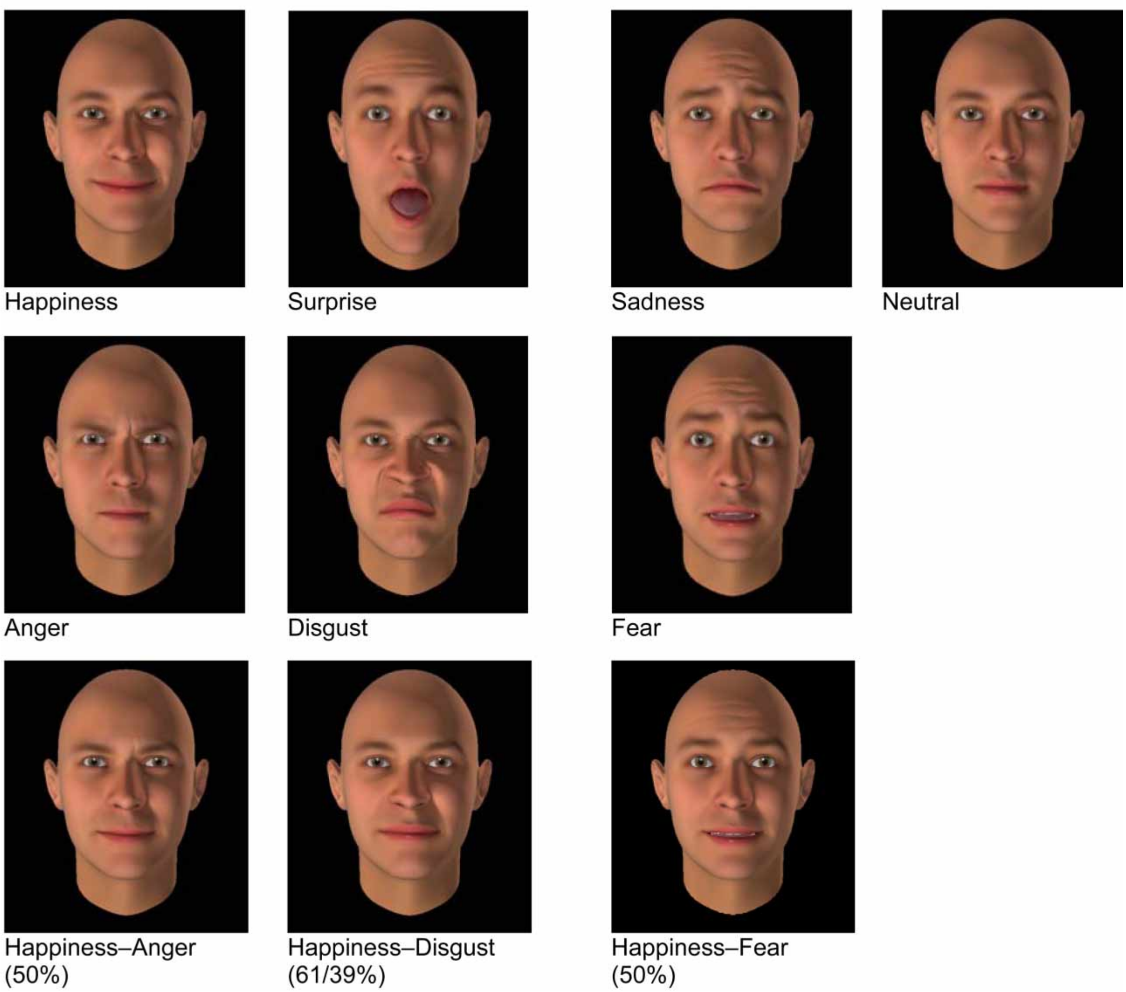


Figure 4. *Avatar emotion expressions generated with FACSGen 2.0 Swiss Center for Affective Sciences used in Studies 2 and 3. Shown are apex expressions and examples of mixed expressions.*

the changing emotions task. The response modus was the same as for the changing emotions task; that is, participants indicated whether emotion x (y) was present or not. See Figure 3 for the number of trials. There were no time constraints.

Results

Simple emotions

On average, participants identified 5.4 out of 7 expressions correctly. There were no gender differences. Recognition rates out of 65 were 62 for happiness, 61 for sadness, 59 for anger and surprise, 57 for disgust, and 30 for fear. Anger and disgust, and fear and surprise were confounded. Also, fear was seen as sadness five times. The confusion matrix is available in the supplementary materials.

Changing emotions

The analysis strategy was the same as for Study 1 without poser effects, and with Sample (a, b, and c) and Task Order as additional between-subjects

Table 2. *Studies 2a–2c, test statistics and percentage frame of x for each emotion pair by label and direction condition*

	Label and direction				
	"x"		"y"		
Emotion pair x–y	$x \rightarrow y$	$y \rightarrow x$	$x \rightarrow y$	$y \rightarrow x$	*Test statistics*
Happiness–Anger	54^{a}	50^{a}	43^{b}	43^{b}	L: $F(1, 57) = 37.98, p < .001, \eta_p^2 = .40$
					O: $F(1, 57) = 119.65, p = .002, \eta_p^2 = .16$
Happiness–Sadness	57^{a}	57^{a}	43^{b}	43^{b}	L: $F(1, 60) = 61.90, p < .001, \eta_p^2 = .51$
Happiness–Disgust	$61^{a,b}$	64^{a}	50^{c}	57^{b}	L: $F(1, 59) = 56.88, p < .001, \eta_p^2 = .49$
Happiness–Fear	50^{a}	46^{a}	36^{c}	43^{b}	L: $F(1, 55) = 47.44, p < .001, \eta_p^2 = .46$
Happiness–Surprise	61	61	57	61	—
Happiness–Neutral	46^{a}	36^{b}	39^{b}	36^{b}	D*L: $F(1, 55) = 10.61, p = .002, \eta_p^2 = 16$
Anger–Sadness	54^{b}	64^{a}	43^{c}	57^{b}	D: $F(1, 56) = 29.08, p < .001, \eta_p^2 = .34$
					L: $F(1, 56) = 25.35, p < .001, \eta_p^2 = .31$
Anger–Disgust	39^{b}	61^{a}	43^{b}	64^{a}	D: $F(1, 36) = 76.18, p < .001, \eta_p^2 = .68$
Anger–Fear	54^{a}	61^{a}	43^{b}	54^{a}	D: $F(1, 52) = 12.78, p = .001, \eta_p^2 = .20$
					L: $F(1, 52) = 16.23, p < .001, \eta_p^2 = .24$
Anger–Surprise	57	64	57	61	—
Anger–Neutral	46^{b}	57^{a}	20^{c}	46^{b}	D: $F(1, 53) = 39.67, p < .001, \eta_p^2 = .43$
					L: $F(1, 53) = 45.34, p < .001, \eta_p^2 = .46$
Sadness–Disgust	50^{a}	61^{b}	54^{a}	61^{b}	D: $F(1, 53) = 26.45, p < .001, \eta_p^2 = .33$
Sadness–Fear	36^{c}	61^{a}	43^{b}	68^{a}	D: $F(1, 32) = 37.39, p < .001, \eta_p^2 = .54$
Sadness–Surprise	54^{a}	68^{b}	54^{a}	64^{b}	D: $F(1, 38) = 19.14, p < .001, \eta_p^2 = .34$
Sadness–Neutral	39^{a}	54^{b}	36^{a}	54^{b}	D: $F(1, 55) = 75.96, p < .001, \eta_p^2 = .58$
Disgust–Fear	$46^{b,c}$	50^{a}	$39^{b,c}$	$46^{a,b}$	D: $F(1, 53) = 11.16, p = .002, \eta_p^2 = .18$
					L: $F(1, 53) = 6.96, p = .011, \eta_p^2 = .12$
Disgust–Surprise	54	57	50	57	—
Disgust–Neutral	36^{b}	46^{a}	29^{c}	$43^{a,b}$	D: $F(1, 55) = 43.16, p < .001, \eta_p^2 = .44$
					L: $F(1, 55) = 16.34, p < .001, \eta_p^2 = .23$
Surprise–Neutral	$32^{a,b}$	39^{a}	18^{c}	32^{b}	D: $F(1, 32) = 14.16, p = .001, \eta_p^2 = .31$
					L: $F(1, 32) = 20.35, p < .001, \eta_p^2 = .39$
Fear–Surprise	50^{c}	$71^{a,b}$	$64^{b,c}$	$79^{a,b}$	D: $F(1, 6) = 20.83, p = .004, \eta_p^2 = .77$
Fear–Neutral	43^{b}	64^{a}	22^{c}	46^{b}	D: $F(1, 45) = 104.21, p < .001, \eta_p^2 = .70$
					L: $F(1, 45) = 53.72, p < .001, \eta_p^2 = .54$

Notes: Different indices indicate significant differences within emotion pair at $\alpha = .008$ (.05/6 comparisons within emotion pairs). Test statistics are displayed for significant effects at $\alpha = .002$ with effects of Direction (D), Label (L), and Task Order (O). Effects for disgust–fear (significant in Study 1) and fear–surprise (few *df*) at $\alpha = .05$ are also displayed. Sample size is 44 instead of 65 for changes with surprise, which were not included in Study 2b.

factors. See Table 2 for means, standard deviations, and test statistics, and Table 3 for an overview of the results across studies. Differences between samples were not significant (no main or interaction effects of sample). Only in one case did a task order effect emerge (for happiness–anger), but there was no interaction with other factors.

No reverse hysteresis pattern was found. Hysteresis patterns emerged for anger–disgust, sadness–neutral, sadness–disgust, sadness–fear, sadness–surprise, and fear–surprise; hysteresis as well as uncertainty for anger–sadness, anger–fear, anger–neutral, disgust–fear, disgust–neutral, surprise–neutral, and fear–neutral changes (see

Table 3. *Overview of findings across studies*

Cluster	*Emotion pair x–y Hysteresis*	*Uncertainty*	*Neither*	*Comment*
Hysteresis	Anger–Disgust	1, 2, 3		
	Sadness–Disgust	1 (man), 2, 3		
	Sadness–Neutral	2, 3		Not tested in 1
	Fear–Surprise	(2), 3		Not tested in 1
	Sadness–Fear	2, 3	1	
Uncertainty and hysteresis	Sadness–Surprise	2, 3	1	
	Anger–Sadness	2, 3	1, 2, 3	
	Anger–Fear	2, 3	1 (woman), 2, 3	
	Fear–Neutral	2, 3	2 (3, 200 ms)	Not tested in 1
	Surprise-Neutral	2, 3	2, 3	Not tested in 1
	Anger–Neutral	2, 3	2, 3	Not tested in 1
	Disgust–Neutral	2	2, 3	Not tested in 1
	Disgust–Fear	2	1 (2), 3 (d → f)	
Uncertainty	Happiness–Anger	1, 2, 3		
	Happiness–Sadness	1, 2, 3		
	Happiness–Disgust	1, 2, 3		
	Happiness–Fear	1, 2, 3		
	Anger–Surprise	1, 3 (200 ms)	2	
Neither	Happiness–Surprise		1, 2, 3	
	Disgust–Surprise	1	2, 3	
	Happiness–Neutral		2, 3	Not tested in 1

Notes: Numbers 1–3 indicate the study in which the respective pattern was found at $\alpha = .003$ (Study 1) and $\alpha = .002$ (Studies 2 & 3). Number in parenthesis indicates significant effect at $\alpha = .05$.

Figure 2); and only uncertainty for happiness with any of the negative emotions. Many participants did not indicate a change at all in fear–surprise and anger–disgust changes, similar to Study 1, or in sadness–fear changes (see *df*s in Table 2). Detailed results for Studies 2a–2c are available in the supplementary materials.

Static mixed emotion decoding

We computed a dummy code of 1 when one of the target emotions was selected and 0 when none of the target emotions was selected. In Study 2a, when decoding the static mixed emotion images, participants could select all that applied from eight response options that included "other" and a fill-in-the-black field. The chance of selecting one of the two target emotions was 2/8. A series of NPar Tests with a test probability of 25% showed that the target emotions were correctly identified for all emotion pairs (*p*s $\leq$ .001). With three images for 15 emotion pairs and 22 participants, there were 990 opportunities to select "other", but participants used this response option only 39 times. Out of these, participants specified their choice only 28 times. For example, happiness–fear mixed images were decoded as hope four times, and happiness–disgust images as disdain twice. Similar to simple emotion recognition, fear was sometimes perceived as surprise and disgust as anger.

Across three studies, a repeated-measures ANOVA with Task (static, continuous) and Sample (a, b, c) as repeated factors for 10 emotion pairs (changes with neutral were not included in the static decoding task of Study 2a, and changes with surprise were not included in Study 2b) showed a main effect of Task, $F(1, 9) = 268.07$, $p < .001$, $\eta_p^2 = .97$, of Sample, $F(2, 8) = 15.98$, $p = .002$, $\eta_p^2 = .80$, and an interaction effect of Task and Sample, $F(2, 8) = 20.14$, $p = .001$, $\eta_p^2 = .83$. For each sample, recognition rates were significantly higher with static images than with dynamic images. Furthermore, recognition rates were highest when selecting "all that apply" of several emotions (sample a) than when affirming an emotion category (samples b, c), and higher when affirming a broadly defined category (sample c) than an undefined emotion category (sample b; see Figure 3). Including surprise and neutral changes in analyses of the individual samples led to similar results. We further examined emotion pairs that showed hysteresis and uncertainty in the current study. The overall identification rate for hysteresis emotion pairs was lower with continuous images than with static images because participants neglected to identify the emerging expression and stuck with their response to the expression origin. This mattered less for uncertainty emotion pairs where recognition rates were lower on average in continuous expressions than in static expressions.

Discussion

A simple emotion recognition task showed that the emotion expressions created in FACSGen 2.0 Swiss Center for Affective Sciences were generally well recognised. An exception was the expression of fear, which was often confused with surprise. The observed confusions were similar to those found with photographs (e.g., anger and disgust, fear and surprise; Young et al., 1997).

With different stimuli than in Study 1, a reverse hysteresis pattern for changes between happiness and other emotions did not emerge. This suggests that the observed effect from Study 1 may not be robust across stimulus material.

In contrast, as can be seen from Table 3, the findings for hysteresis and uncertainty from Study 1 were mostly replicated in Study 2. Additional effects in Study 2 can partially be attributed to a larger total sample size; e.g., for anger–fear and anger–sadness, hysteresis was apparent neither in Study 1 nor in individual samples 2a, b, or c. For sadness–surprise, the likelihood for hysteresis may have been increased by a more lenient response format, because this effect was significant in Study 2c but not in Study 1 or Study 2a. See the general discussion for a discussion of underlying mechanisms.

In addition to replicating the findings from Study 1, in Study 2 we examined possible reasons for uncertainty in decoding changing expressions. Uncertainty may result from decoding the mixed emotion images as something entirely different than either one of the emotions (e.g., happiness–disgust as cynicism), or as unidentifiable. When we presented the same images that participants did not decode as a prototypical emotion in the continuous display in a static form, most participants in Study 2a referred to the target emotions even though they could suggest their own response. This rules out the possibility that the images we used were perceived as unidentifiable, or as a different emotion.

Furthermore, in Studies 2a–2c, prototypical emotions were decoded in static expressions to a significantly larger extent than when the identical images were presented as part of a continuous display. The highest recognition rates emerged in Study 2a, with a "select all that apply" response format, where participants may have asked themselves "which category does this expression resemble the most?" and looked for a minimal match. However, when they were asked whether a particular category was present, as in Studies 2b and 2c, they may have asked themselves "is this expression a good exemplar of the category?" and have been less lenient, particularly when the emotion category could be interpreted narrowly (Study 2b). Thus, with different response formats, the occurrence of hysteresis may be increased and the occurrence of uncertainty may be decreased. Importantly, even with narrow categories, hysteresis is evident for some expression changes, and even with broad categories, uncertainty in continuous displays is higher than uncertainty in static displays. That the unfolding of an expression results in increased uncertainty compared to context free static images underscores the importance of context for expression decoding.

A limitation of the paradigm used in Studies 1 and 2 is that the displays of emotion changes were not truly dynamic. Instead, participants saw a sequence of changing emotion expressions and responded to each static image. In these studies, participants proceeded quickly from image to image; for example, in Study 2a, participants' average reaction time was 270 ms ($SD = 188$ ms) once the initial judgement was performed. Nonetheless, the presentation was not truly dynamic. This limitation was addressed in Study 3.

STUDY 3

In Study 3, we tested whether the patterns found in Studies 1 and 2 could be replicated with a reaction time paradigm. In Study 3, participants saw a dynamic display and stopped the display when they thought the emotion had changed. The time from video onset to the time the participant stopped the display (the reaction time) was the dependent variable.

A paradigm that involves reaction time is not adequate to directly examine hysteresis. For example, when an expression changes from anger to disgust, a hysteresis would be reflected in long reaction times. Similarly, the reverse expression change would also lead to long reaction times. Testing the hypothesis of no difference between the two conditions (anger → disgust vs. disgust → anger) is not adequate. Also, identifying at which frame a change is perceived (as in Studies 1 and 2) is not possible, because reaction times are greatly influenced by the slowness of generating a motor response. Therefore, reaction time is ambiguous for testing hysteresis (Hock, Kelso, & Schöner, 1993). It is also not useful to compare reaction times between emotion pairs (e.g., compare happiness → anger with disgust → anger). This is because each pair may have a specific bias towards one or the other end of the continuum, e.g., due to differences in the initial intensity of an expression.

However, an indirect examination of hysteresis is possible. With hysteresis, longer trials should result in longer total reaction times within an emotion pair (e.g., total reaction time for all trials involving anger–disgust compared to all trials involving happiness–anger). The total reaction time is independent of an emotion pair specific bias. Of course, it is not clear which specific trial contributed most to the total reaction time (e.g., trials from anger to disgust with a "disgust" label or with an "anger" label). Thus, a reaction time paradigm only allows for an indirect test of hysteresis by comparing the total reaction times across trials for hysteresis and non-hysteresis emotion pairs (as identified based on Studies 1 and 2).

By comparison, a reaction time paradigm is well suited to test uncertainty. With a reaction time experiment, uncertainty is indicted by shorter reaction times when an initial expression is perceived to disappear, and longer reaction times when a new expression is perceived to appear.

To create a dynamic display, the sequence of individual frames from Study 2 was shown at two display rates. The first display rate was 200 ms per image, which was close to participants' average progression speed in the previous studies. The second display rate was 50 ms per image, at which the clip appeared even more dynamic. Some emotions appear more natural when displayed at slow speeds (Kamachi et al., 2001; Sato & Yoshikawa, 2004). Different display rates allowed us to explore potential effects of velocity on emotion perception.

Method

Participants

Thirty-seven students (31 women) participated in the study for partial course credit. Their mean age was 22 years (range 18–44).

Procedure

The general procedure was the same as in the prior studies.

Materials

Stimulus material. See Study 2.

Simple emotion decoding. See Study 2.

Gender morph task. Presentation and response modes were similar to the changing emotion task described below (contact the first author for further details).

Changing emotion task. Stimuli were the same as in Study 2. For the trials, participants saw a fixation cross for 1,000 ms, then a fixation cross plus the labels "not happy" to the left and "happy" to the right for 3,000 ms, and then the image of a happy expression plus the labels. Pressing a left or a right key, they indicated their response and started a clip of 28 frames displayed at 50 ms. By pressing a left or right key once the display had changed, the clip stopped, and the next trial began. There were no practice trials. With 21 emotion pairs, two directions, two emotion labels per emotion pair, and two display rates (50 and 200 ms), the total number of trials was 168.

Results

Simple emotions

One participant only saw five of seven emotions due to a computer error, and identified them all correctly. The remaining 36 participants identified six out of seven expressions correctly on average. Sadness expressions were recognised by all 36 participants, happiness and neutral by 35, anger and disgust by 34, surprise by 32, and fear by 22. Confusions were highest between fear–surprise and anger–disgust. See supplementary materials for the confusion matrix.

Changing emotions

The dependent variable was the reaction time after starting the clip. To examine uncertainty effects, we conducted a series of repeated-measures analyses with Display Rate (50 ms/200 ms), Uncertainty (emotion disappears/appears), and Starting Emotion (emotion x, y) as within-subjects factors for each emotion pair, with a Bonferroni corrected alpha level. Trials where no expression change was perceived were not included (see Table 4 for test statistics, means, and *df*s). For all comparisons, a main effect of Display Rate indicated that reaction times were longer with a 200 ms display rate than with a 50 ms display rate, *p*s $< .001$, $\eta_p^2 = .76$ to .88. See also Table 3 for an overview of results across studies.

Uncertainty emerged for pairings of happiness with any of the negative emotions, and anger–sadness, anger–fear, anger–neutral, and disgust–neutral changes. For a surprise–neutral change, the uncertainty was more pronounced with a display rate of 200 ms per image, $F(1, 35) = 62.66$, $p < .001$, $\eta_p^2 = .64$, than with a display rate of 50 ms, $F(1, 35) = 10.89$, $p = .002$, $\eta_p^2 = .24$. For an anger–surprise change, uncertainty only emerged with a rate of 200 ms per image, $F(1, 36) = 27.16$, $p < .001$, $\eta_p^2 = .43$. There was only uncertainty with changes from disgust to fear, $F(1, 35) = 31.89$, $p < .001$, $\eta_p^2 = .48$, but not vice versa. Also, for fear–neutral changes, an uncertainty pattern emerged as a trend with a display rate of 200 ms/image, but not with a display rate of 50 ms/image.

In addition to uncertainty, there were multiple effects for starting emotion. Differences in reaction time depending on the starting emotion indicate that the change point between emotions was biased towards either end of the video clip. The effect did not interact with the effects of interest in this paper, and detailed results are available in the supplementary materials.

As an indirect test of hysteresis, for each emotion pair, we computed the total reaction time across label and starting emotion trials at each display rate. We expected longer total reaction times for hysteresis emotion pairs (anger–disgust, fear–surprise, sadness–disgust, and sadness–neutral) than for uncertainty emotion pairs (happiness and any negative emotions). Reaction times for emotion pairs with uncertainty and hysteresis should be in between (fear–neutral, surprise–neutral, anger–neutral, disgust–neutral, disgust–fear, anger–sadness), as should be reaction times for emotion pairs with no uncertainty or hysteresis (happiness–surprise, happiness–neutral, disgust–surprise). No predictions could be made for sadness–surprise, anger–surprise, and sadness–fear, because Studies 1 and 2 showed different results for these emotion pairs.

We computed mean total reaction times across uncertainty emotion pairs at each display rate, and compared them with the reaction times of each of the remaining 17 emotion pairs. The alpha level was adjusted accordingly to .003 (.05/17). All repeated-measures analyses with Reaction Time

Table 4. *Study 3, test statistics and reaction time (ms) at which an emotion (dis)appears*

	Display rate, change type, and expression origin								
	50 ms				*200 ms*				
	Disappear		*Appear*		*Disappear*		*Appear*		
Emotion pair x–y	*x*	*y*	*X*	*y*	*x*	*y*	*x*	*y*	*Test statistics*
Happiness–Anger	1514[a,c]	1433[c]	1741[a]	1649[a,c]	3088[b]	3108[b,d]	3837[d]	3489[b,d]	Z: $F(1, 35) = 17.62$, $p < .001$, $\eta_p^2 = .34$
Happiness–Sadness	1694[a]	1614[a]	1870[a]	1997[a]	2924[b]	3337[b]	3946[b,c]	4021[c]	Z: $F(1, 35) = 24.04$, $p < .001$, $\eta_p^2 = .41$
Happiness–Disgust	1815[a]	1667[a]	1871[a]	1979[a]	2877[b]	3323[b,c]	3412[b]	4285[c]	Z: $F(1, 36) = 12.67$, $p = .001$, $\eta_p^2 = .26$
									R*S: $F(1, 36) = 13.46$, $p = .001$, $\eta_p^2 = .27$
Happiness–Fear	1858[a]	1798[a]	2179[a]	1856[a]	3201[b]	3350[b,c]	4257[c]	3674[b,c]	Z: $F(1, 36) = 19.19$, $p < .001$, $\eta_p^2 = .35$
Happiness–Surprise	1653[a]	1878[a,b]	1540[a]	2001[b]	2970[c]	3874[c]	3288[c]	4048[c]	S: $F(1, 35) = 16.20$, $p < .001$, $\eta_p^2 = .32$
Happiness–Neutral	1954[a]	1634[a,b]	1846[a,b]	1481[b]	3083[c]	2939[c]	3634[c]	3347[c]	—
Anger–Sadness	1834[a]	1995[a]	2032[a]	1990[a]	3472[b]	3836[b]	4073[b]	3927[b]	Z: $F(1, 36) = 11.14$, $p = .002$, $\eta_p^2 = .24$
Anger–Disgust	1995[a,b]	2006[a]	1884[b]	1957[a,b]	3882[b]	4211[b]	3707[b]	4264[b]	—
Anger–Fear	1841[a]	1811[a]	2353[a]	1911[a]	3603[c]	3667[c,d]	4639[d]	3875[c,d]	Z: $F(1, 33) = 33.16$, $p < .001$, $\eta_p^2 = .50$
Anger–Surprise	1540[a]	1850[a]	1648[a]	1940[a]	2881[b]	3745[b,c]	3556[b,c]	4463[c]	Z: $F(1, 36) = 19.23$, $p < .001$, $\eta_p^2 = .35$
									S: $F(1, 36) = 23.30$, $p < .001$, $\eta_p^2 = .39$
									R*Z: $F(1, 36) = 14.19$, $p = .001$, $\eta_p^2 = .28$
Anger–Neutral	2051[a]	1518[b]	2195[a]	1837[a,b]	4017[c,d]	3233[c]	4304[d]	3818[c,d]	Z: $F(1, 36) = 12.08$, $p = .001$, $\eta_p^2 = .25$
									S: $F(1, 36) = 12.88$, $p = .001$, $\eta_p^2 = .26$
Sadness–Disgust	1726[a]	2159[a]	1905[a]	2053[a]	3482[c,d]	4058[b,d]	3083[c]	4303[b]	S: $F(1, 36) = 33.54$, $p < .001$, $\eta_p^2 = .48$
Sadness–Fear	2465[a,b]	2189[a]	2925[b,d]	2021[a]	4998[c]	4360[c]	4558[c]	3857[c,d]	S: $F(1, 35) = 16.06$, $p < .001$, $\eta_p^2 = .31$
Sadness–Surprise	1685[a]	2052[b]	1791[a,b]	2073[b]	3170[c]	3991[c,d]	3644[c]	4560[d]	S: $F(1, 35) = 29.31$, $p < .001$, $\eta_p^2 = .46$
Sadness–Neutral	2273[a]	1763[b]	2183[a,b]	1891[a,b]	3780[c,d]	3197[c]	4143[d]	3797[c,d]	S: $F(1, 34) = 16.79$, $p < .001$, $\eta_p^2 = .33$
Disgust–Fear	1820[a]	1730[a]	2368[b]	1661[a]	3533[c]	3122[c]	4568[d]	3352[c]	Z: $F(1, 35) = 19.32$, $p < .001$, $\eta_p^2 = .36$
									S: $F(1, 35) = 27.42$, $p < .001$, $\eta_p^2 = .44$
									Z*S: $F(1, 35) = 23.79$, $p < .001$, $\eta_p^2 = .41$
Disgust–Surprise	1908[a]	1738[a]	1769[a]	1847[a]	3365[b]	3359[b]	3815[b]	3891[b]	—
Disgust–Neutral	1884[a]	1301[b]	2117[a]	1493[b]	3513[c]	3008[c]	4856[d]	3179[c]	Z: $F(1, 36) = 32.69$, $p < .001$, $\eta_p^2 = .48$
									S: $F(1, 36) = 73.45$, $p < .001$, $\eta_p^2 = .67$
									R*S: $F(1, 36) = 15.47$, $p < .001$, $\eta_p^2 = .30$
Fear–Surprise	2109[a]	2388[a]	2131[a]	2515[a]	3839[b]	5255[c]	3951[b,c]	4860[b,c]	S: $F(1, 34) = 17.48$, $p < .001$, $\eta_p^2 = .34$
Fear–Neutral	2566[a]	1817[b]	2198[a,b]	2326[a,b]	3920[c]	3427[a,c]	4597[c]	4278[c]	—
Surprise-Neutral	2223[a,d]	1283[b]	2315[a]	1723[d]	4250[c]	2445[a]	5571[e]	3403[c]	Z: $F(1, 34) = 58.34$, $p < .001$, $\eta_p^2 = .63$
									S: $F(1, 34) = 79.08$, $p < .001$, $\eta_p^2 = .70$
									R*Z: $F(1, 34) = 30.43$, $p < .001$, $\eta_p^2 = .47$
									R*S: $F(1, 34) = 41.03$, $p < .001$, $\eta_p^2 = .55$

Notes: Different indices indicate significant differences within emotion pair at $\alpha = .0018$ (.05/28 comparisons within emotion pairs). Test statistics are displayed for significant effects at $\alpha = .002$ (.05/21 emotion pairs) with main effect of zone of uncertainty (Z) and starting emotion (S). Not shown are the test statistics for the main effect of display rate (R), which was significant with each emotion pair, *p*s $< .001$, $\eta_p^2 = .76$ to .88.

(e.g., anger–disgust vs. zone of uncertainty emotions) and Display Rate (50 and 200 ms/image) showed that reaction times were shorter at the 50 ms/image than at 200 ms/image display rate, all *p*s $< .001$. As expected, there were longer reaction times for each of the hysteresis emotions, all *p*s

$\leq$ .001. With the exception of disgust–fear and disgust–neutral, all emotion pairs with uncertainty and hysteresis in previous studies also had longer reaction times than uncertainty emotions, all *p*s $\leq$ .001. Additionally, sadness–surprise, $F(1, 35) = 18.79$, $p < .001$, $\eta_p^2 = .35$., and sadness–fear, $F(1, 35) = 79.24$, $p < .001$, $\eta_p^2 = .69$, showed significantly longer reaction times. Emotion pairs without hysteresis or uncertainty in previous studies did not differ from uncertainty emotions, nor did anger–surprise. Further repeated-measures ANOVAs showed that the reaction times of the emotion pairs that showed hysteresis and uncertainty in previous studies did not differ significantly from the hysteresis emotion pairs (sadness–fear had even longer reaction times), nor did sadness–surprise, whereas the remaining emotion pairs showed shorter reaction times. On the whole, the results from Study 3 replicated the uncertainty and hysteresis findings from Studies 1 and 2 (see Table 3).

GENERAL DISCUSSION

Although changing emotion expressions are ubiquitous in everyday life, we know little about how they are perceived. This lack of knowledge may be rooted in the limited theoretical development regarding the dynamic nature of emotions in dominant theories of emotions, such as basic emotion and core affect theories. In contrast to these theories, the CPM (Scherer, 2000, 2009) incorporates nonlinear dynamic systems concepts, and allows one to develop new hypotheses for changing emotion experience, expression, and perception. The hysteresis hypothesis based on this perspective is that when emotion expressions change, the threshold for perceiving an expression depends on the expression origin. As a result, the perception of mixed emotion expression can only be predicted when knowing the history of the expression change. We examined this hypothesis with different stimuli and response paradigms.

Before we discuss the results, we want to acknowledge the limitations of our approach. A limitation of the current studies is that the meaning of specific percentage values of morphed images is not clear. Percent changes between morph images are not based on perceptual differences. For example, a change from 80% to 70% of x may be less perceivable than a change from 70% to 60% of x. In the extreme case, the difference between 80% and 70% of x may not be recognisable at all. As a result, a presentation series of 100%, 96%, 93%, etc., may be perceived as a series of 100%, 100%, 90%. Therefore, singular thresholds cannot meaningfully be interpreted, and thresholds cannot be compared across emotion pairs without further studies on the subjective scaling of the images.

Another limitation of the current studies is that the change from one emotion to the other does not necessarily reflect the natural change of emotion expression. For example, with natural changes in expression, there may be differences in the time scales for changes in the area of the eyes and the area of the mouth, which are not captured in morphs. Despite this criticism, morphed images are a commonly used research tool to study mixed emotion effects because of the high level of control (Campanella et al., 2002; Etcoff & Magee, 1992; Kotsoni et al., 2001; Niedenthal et al., 2000; Suzuki, Hoshino, & Shigemasu, 2006; Young et al., 1997). Programs like FACS-Gen Swiss Center for Affective Sciences that allow one to manipulate individual AUs provide a particularly high degree of control. A less controlled but more realistic approach would be to use videos of people's changing emotion expressions. Although databases with naturalistic dynamic emotion expressions exist for changes to and from neutral expressions (e.g., https://dynemo.liglab.fr/), comparable stimulus material for expression changes between emotions has, to our knowledge, not yet been developed. The balance would be shifted even further towards realism and away from control by examining emotion decoding in ongoing interactions. These research approaches complement each other, and it is an empirical question for future research if study results would differ depending on the approach.

Using highly controlled stimuli and different response paradigms, we consistently found hysteresis patterns for seven emotion pairs (anger–disgust, sadness–disgust, fear–surprise, sadness–, fear–, surprise–, and anger–neutral). Hysteresis was not a result of judgemental uncertainty, which was assessed independently of hysteresis.

The specificity of hysteresis patterns to particular emotion pairs suggests that properties of the particular expression change have to be taken into account for hysteresis in emotion decoding. A possible explanation may be that the more perceptually similar expressions are, the more the new stimulus further activates the detector previously activated by the expression origin, resulting in hysteresis. For example, due to perceptual similarity between anger and disgust, a mixed emotion expression may contain information compatible with anger and disgust. The stabilisation of detector activation by a context, such as a prior expression of disgust, may increase the total detector activation for disgust. This may bias decoding towards disgust. Furthermore, research on prototypical emotion and ambiguous figure decoding suggests that the information for one or the other emotion is located in different focal areas of the ambiguous expression, and that a context, such as an expression origin, may guide attention to a specific area. Specifically, context information in the form of postures shown with a facial expression influences both selective attention to particular areas of the face and decoding of expressions (Aviezer et al., 2008, 2011). Similarly, unrelated tasks may guide attention to particular areas in ambiguous figures and influence the interpretation of the figures (Tsal & Kolbet, 2007). The importance of selective attention for decoding emotion expressions also seems consistent with the theory in developmental research that emotion decoding ability evolves with children's shifts in attention from the mouth region to the eye region (Johnston et al., 2011). This mechanism suggests that hysteresis may be the result of a purely perceptual process, which is independent of the semantics underlying emotions. Manipulating emotion changes in particular facial regions, e.g., with FACSGen technology Swiss Center for Affective Sciences, monitoring selective attention to facial areas with eye-movement recordings, or manipulating selective attention (e.g., Tsal & Kolbet, 2007) may be good starting points to test this explanation.

Note that perceptual similarity may not be the only route to hysteresis in emotion expressions. For example, the natural speed of displaying sadness may make this expression prone to hysteresis effects. In contrast to other emotions, sadness is more easily identified and perceived as more intense and natural when displayed slowly rather than quickly (Kamachi et al., 2001; Sato & Yoshikawa, 2004). Unless changes occur to or from expressions that are naturally displayed quickly (e.g., happiness, surprise), sadness may be decoded according to a hysteresis pattern. One way to examine this explanation could be to manipulate subjective time perception with visual flicker or auditory train click paradigms (e.g., Droit-Volet & Wearden, 2002). The hysteresis effect for sadness may disappear when subjective time passes faster.

Initially unexpected, uncertainty was the most common finding for emotion decoding, as it was consistently found for eleven emotion pairs (see Table 3). Here, one emotion is perceived to disappear before a new emotion is decoded, leaving displays in between to be decoded as neither of the two emotions. Although this pattern was not initially predicted based on theory, it can be considered an important finding because it replicated across all studies. Specifically, we found this pattern for changes involving happiness and negative emotions, less consistently between several negative emotions, and for some changes to and from neutral expressions.

These results seem to contradict previous research, which suggested that the offset of one emotion may be decoded as the onset of a different emotion (Niedenthal et al., 2001). However, in that research, there were only two emotional expressions (happiness, sadness). As a result, there may have been less judgemental uncertainty, because participants could anticipate the nature of the emotion change and only had to differentiate one expression from the other. However, with an increase in the number of alternatives as to which emotion will arise, this strategy is not available to respondents who have to recognise the emerging expression (see Calvo & Nummenmaa, 2008, for a similar rationale).

Uncertainty did not appear to the same extent in judgements of static mixed emotion expressions. In Study 2a, participants had the option to select "other" as a response category for static mixed emotion images, and to suggest their own labels for the expression. However, we found that, unlike continuous displays, static mixed emotion expressions were overwhelmingly interpreted as a prototypical emotion, or mixes of prototypical emotions. Studies 2b and 2c ruled out that uncertainty with continuous displays could be attributed to the response format or task order. Instead, uncertainty seems to be a result of the continuous change of the expression, particularly for expressions that are perceptually dissimilar, such as happiness and the negative emotions.

A dynamic systems-based explanation is that uncertainty may result from an impasse between different detector activations. With perceptually dissimilar expressions, the stabilised percept activated by the expression origin may compete with the simultaneous activation of another detector by the stimulus. For example, a mixed emotion expression may contain information compatible with anger and happiness in different areas of the face. A context, such as a prior expression of happiness, may activate happiness detectors and focus attention on an area previously informative of happiness. When the current stimulus only contains information for anger in this area due to perceptual dissimilarity between anger and happiness, an impasse of happiness and anger detector activations may occur. In static displays, this impasse would not occur because there would be no stabilisation of the initial happiness detector activation, resulting in the perception of anger when attending to this area, or because attention may be allocated to areas that remain indicative of happiness even in the mixed expression, resulting in the perception of happiness.

Thus, to what extent uncertainty (hysteresis) occurs in continuous displays may depend on the similarity between expressions, selective attention to focal regions, and the degree of stimulus-driven competition (support) of detector activations with internal stabilisation mechanisms. Very similar expressions may predominantly show hysteresis, less similar ones may show hysteresis and uncertainty, and very dissimilar expressions may show only uncertainty. Further research is needed to identify the underlying control parameters that drive shifts between emotion states. The similarity of the expressions in focal regions may be related to their associated appraisals (Scherer, 1992), such that similar appraisals (e.g., goal obstructiveness) may activate similar AUs (e.g., AU 4) resulting in more similar expressions (e.g., anger, disgust), whereas incompatible appraisals (e.g., pleasantness vs. unpleasantness) may activate different, and possibly incompatible AUs (e.g., 12, 15), resulting in more dissimilar expressions (e.g., happiness, sadness). Underlying the hysteresis and uncertainty in expression decoding may thus be the (in)compatibility of the appraisals associated with the (dis)similar expressions. Further comparisons of continuous and static display encoding of particular focal areas in conjunction with the degree of similarity of expressions and their associated appraisals are needed to test this explanation.

An alternative explanation is that for some emotion changes, contrast effects occur so that a mixed emotion expression is contrasted away from the expression origin. Contrast effects have been demonstrated, particularly for expressions of different valence. For example, expressions of happiness and sadness are judged as more intense when preceded by expressions of the opposite valence (Thayer, 1980). Also, shifts in valence and arousal ratings of target expressions in the context of anchor expressions have been reported (Russell & Fehr, 1987). However, this explanation can less easily accommodate cases where both hysteresis (equivalent to an assimilation to prior stimuli) and uncertainty (equivalent to a contrast to prior stimuli) occur.

Hysteresis and uncertainty in emotion perception have important implications for social interactions. With a hysteresis, an observer will not readily perceive a change in expression, e.g., from disgust to anger. This may have significant consequences because disgust is associated with avoidant behaviour, but anger is associated with antagonistic approach behaviour, such as attacking (Frijda, Kuipers, & ter Schure, 1989). For example, in a negotiation, both anger and moral disgust may occur. Moral and non-moral disgust share similar expressive patterns in the face (Chapman, Kim, Susskind, & Anderson, 2009). When an expression changes from disgust to anger, an observer may underestimate the expressed anger and not sufficiently prepare for an attack. Conversely, when an expression changes from anger to disgust, an observer may underestimate the expressed disgust and not take sufficient measures to keep the opponent from walking away from the negotiation table. Uncertainty, too, may cause problems in social interactions. For example, an observer in a negotiation may notice that the opponent is not happy anymore, but may be uncertain as to whether fear or anger is surfacing. The observer's expectation will have different consequences for the negotiation (e.g., Kopelman et al., 2008; Van Kleef, 2009).

We believe that a major contribution of our paper is the direct test of one of the central hypotheses from a nonlinear dynamic systems approach to emotions, but the observation of reliable hysteresis and uncertainty effects is only an initial step in the study of the dynamics underlying changing emotions more generally. For example, can patterns of hysteresis also be found for emotion experience as predicted by the CPM? Specifically, Scherer (2000) proposed that when coping potential is high, gradual changes in goal obstructiveness may lead to sudden jumps in felt affect depending on the affect origin. It is intuitive that small changes in the situation may lead to abrupt changes in affect. The CPM suggests specific empirically examinable appraisals as control parameters to describe when such phase shifts occur. Indeed, "the identification of control parameters in both real and ontogenetic time must remain an empirical exercise, because [researchers] have too easily sought to explain phase shifts by resorting to neurology or black-box cognitive reorganisations" (Fogel & Thelen, 1987, p. 751). Furthermore, different variables may function as control parameters in different contexts (Fogel & Thelen, 1987). Clearly, more theoretical and empirical work on the dynamics of the experience, expression, and perception of changing emotions is needed.

To summarise, we found that decoding of continuous emotion changes shows hysteresis, particularly in changes between emotions that are perceptually similar, and uncertainty, particularly in changes between emotions that are perceptually dissimilar, such as changes between happiness and negative emotions. Both hysteresis and uncertainty effects underscore that emotion decoding is state dependent, a characteristic of dynamic systems. A nonlinear dynamic systems view of emotions may furthermore provide the concepts needed to examine the potential mechanisms underlying hysteresis and uncertainty effects, and to develop new hypotheses regarding changing emotions. Although the nonlinear dynamic systems approach to describing phenomena in psychology is not new (Flay, 1978; Zeeman, 1976), experimentally testing the hypotheses from this approach has only just begun in the affective sciences.

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