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Infant Smiling Dynamics and Perceived Positive Emotion

Daniel S. Messinger · Tricia D. Cassel · Susan I. Acosta · Zara Ambadar · Jeffrey F. Cohn

Abstract To better understand early positive emotional expression, automated software measurements of facial action were supplemented with anatomically based manual coding. These convergent measurements were used to describe the dynamics of infant smiling and predict perceived positive emotional intensity. Over the course of infant smiles, degree of smile strength varied with degree of eye constriction (cheek raising, the Duchenne marker), which varied with degree of mouth opening. In a series of three rating studies, automated measurements of smile strength and mouth opening predicted naïve (undergraduate) observers' continuous ratings of video clips of smile sequences, as well as naïve and experienced (parent) ratings of positive emotion in still images from the sequences. An a priori measure of smile intensity combining anatomically based manual coding of both smile strength and mouth opening predicted positive emotion ratings of the still images. The findings indicate the potential of automated and fine-grained manual measurements of facial actions to describe the course of emotional expressions over time and to predict perceptions of emotional intensity.

Keywords Facial expression · Emotion · Infant · Automated measurement · Facial action coding system · Perceived emotion intensity · Smiling

Infant smiles communicate joy, eliciting affiliative interaction and positive emotional responses in adults (Bowlby 1982; Oster 2003). Much remains to be known, however,

D. S. Messinger (✉) · T. D. Cassel · S. I. Acosta
Department of Psychology, University of Miami, P.O. Box 249229,
Coral Gables, FL 33124-0751, USA
e-mail: dmessinger@miami.edu

Z. Ambadar · J. F. Cohn
University of Pittsburgh, Pittsburgh, PA, USA

J. F. Cohn
Carnegie Mellon University, Pittsburgh, PA, USA

about how early smiles unfold in time and the features of early smiles that communicate positive affective intensity. To better understand the dynamics of infant smiling, we described the relationship between several features of smiling using automated software measurements supplemented with anatomically based manual measurements. These measurements were then used to predict positive emotion ratings of both static images and dynamic displays.

While infant smiles are generally emotionally positive, smiles involving specific constellations of facial features appear to be more emotionally positive than others (Ekman and Friesen 1978; Messinger et al. 2001). Facial features associated with positive emotional intensity in infant smiles are eye constriction caused by contraction of orbicularis oculi, pars lateralis (the Duchenne marker), a stronger smiling action caused by greater contraction of Zygomaticus major (the zygomatic), and mouth opening. These features are the focus on the current investigation and we describe evidence for their emotional significance below.

As in adults and children, infant smiles involving eye constriction (Duchenne smiles) tend to occur during emotionally positive events (Ekman and Friesen 1982; Schneider and Uzner 1992). Infants, for example, tend to engage in smiles involving eye constriction when they are being smiled at by their mothers (Fox and Davidson 1988; Messinger et al. 2001). Infant smiles involving eye constriction also tend to involve mouth opening (Fogel et al. 2006; Messinger et al. 1999).

Smiles involving mouth opening caused by jaw dropping are often referred to as play smiles, because a similar facial expression occurs during the rough and tumble play of infant and adult chimpanzees (Plooij 1979; Waller and Dunbar 2005). Human infants tend to engage in smiling involving mouth opening while gazing at their mothers' faces. Smiles involving both eye constriction and mouth opening (duplay smiles) tend to occur when human infants are gazing at their smiling mothers, when infants are being tickled, and in other rough-and-tumble games (Carvajal and Iglesias 2002; Dickson et al. 1997; Fogel et al. 2000, 2006; Messinger et al. 2001).

Both smiles involving eye constriction and smiles involving mouth opening also involve stronger smiling actions than smiles without these features. In adults, children, and infants, stronger smiles—which involve greater zygomatic contraction—are more likely than weaker smiles to occur during positive events such as the climax of peekaboo and tickle games (Ekman and Friesen 1982; Fogel et al. 2006; Schneider and Uzner 1992).

The possibility that stronger smiling and smiling involving eye constriction are especially emotionally positive is borne out by rating studies. Naïve observers perceive static adult smiles with eye constriction (Duchenne smiles) as more emotionally positive than smiles without eye constriction (Frank et al. 1993). When static images are digitally edited to isolate the affective impact of specific facial actions, smiles with eye constriction are perceived as more emotionally positive by naïve raters than the same smiles without eye constriction (Bolzani-Dinehart et al. 2005; Messinger 2002). Digitally edited stronger smiles are also consistently rated as more emotionally positive than weaker smiles (Bolzani-Dinehart et al. 2005).

It is unclear whether smiles involving mouth opening are perceived as more positive than those involving less mouth opening. Bolzani-Dinehart et al. (2005) found that undergraduate raters did not perceive digitally edited smiles involving greater mouth opening as more emotionally positive than smiles involving less mouth opening. Intriguingly, (Beebe 1973a, b) found that both stronger smiling and greater mouth opening were associated with a single mother's perceptions of increasing positive affect in filmed records of her infant. Despite its limitations, this study suggests that mouth opening may be perceived positively when smiles are displayed dynamically and when smiles are rated by experienced observers such as parents.

Recent research on the temporal dimension of smiling tends to focus on the distinction between Duchenne and non-Duchenne smiles, and between spontaneous and deliberate smiles (Hess and Kleck 1994). Adult smiles involving the Duchenne marker, for example, are thought to have smoother more ballistic trajectories than smiles without the marker (Frank et al. 1993). Similarly, recent work using automated measurements of smile strength in adults indicates a variety of timing features that distinguish spontaneous and posed smiles (Schmidt et al. 2006). Spontaneous Duchenne smiles, for example, have slower onset times than posed Duchenne smiles (Schmidt et al. 2006), and raters use these parameters in determining the genuineness of synthetically created smile sequences (Krumhuber and Kappas 2005).

Despite innovative work on the dynamics of smile strength (Frank et al. 1993; Hess and Kleck 1994; Krumhuber and Kappas 2005; Schmidt et al. 2006), smiles are typically categorized based on the presence or absence of features such as eye constriction. These features may, however, wax and wane over the course of a smile. This raises questions about the association of these features in time and their impact on perceptions of positive emotion throughout the smile. It is not clear, for example, whether infants display greater mouth opening and more intense eye constriction when they smile more strongly. It is also unclear whether the intensity of these actions—in addition to their presence or absence—impacts the perception of positive emotion during the course of a smile. Addressing such issues requires fine-grained measurement of facial actions.

Computer-vision software can be used to measure the intensity of facial actions on a continuous scale. We used feature point tracking implemented through version 3 of the CMU/Pitt Automated Facial Analysis (AFA3) system to produce continuous measurements of the movement of facial features (Cohn and Kanade 2007; Moriyama et al. 2006). AFA3 measurements of smile strength and mouth opening were supplemented with the Facial Action Coding System (FACS) (Ekman and Friesen 1978; Ekman et al. 2002). FACS and its application to infants, BabyFACS (Oster 2006), remain a gold-standard for identifying anatomically based appearance changes in the form of facial Action Units (AU). In FACS, the action units that comprise smiles—lip-corner movement, mouth opening, and eye constriction—are coded as present or absent and a five-tier ordinal intensity categorization can then be applied to identified action units.

An ordinal categorization of smile intensity based on BabyFACS coded smile strength and mouth opening proposed by Oster (2006) is of particular interest. A dichotomous version of this system indicated that preterm infants spend less time than full-term infants engaging in relatively strong open-mouth smiles during face-to-face interactions, presumably because of their reduced ability to engage in highly arousing positive engagement (Segal et al. 1995). A version of this system that trifurcated smile expressions yielded strong associations with rated affective valence when used in conjunction with a parallel system for categorizing negative expressions (Oster 2003). The full nine-category ordering of smile intensity (Oster 2006) has not, however, been used to predict ratings of positive emotion intensity.

Our first goal was to explore the dynamics of smiling using continuous automated measurements, supplement these descriptions with manual measurements, and compare the two measurement techniques. This involved assessing the convergent validity of the different measurement approaches, and using the measurements to describe the covariation between smile strength, mouth opening, and eye constriction. The second goal was to examine the association between these facial parameters and perceptions of positive emotion. The focus here was using automated measurements of facial actions to predict ratings of positive emotional intensity. A secondary aim was the use of BabyFACS codes and, in particular, the nine-level categorization of infant smiling intensity recommended in BabyFACS, to predict these positive emotion ratings.

With respect to ratings, parents of infants may be more sensitive to subtleties of infant facial expression, even in unrelated infants, than would individuals who have never been parents (Papousek and Papousek 2002). Consequently, we complemented ratings of static images made by naïve observers (undergraduates) with those of more experienced observers (parents) (Peterson 2001; Waldinger et al. 2004). Previous research indicates that dynamically presented smiles may convey emotional information in a more salient fashion than static presentations of smiles (Ambadar et al. 2005; Biele and Grabowska 2006). To capitalize on this possibility, we collected observers' continuous ratings of dynamic presentations of smile sequences.

In brief, we investigated associations between facial actions involved in smiling (Study 1) and their influence on perceptions of emotion intensity (Studies 2–4). Both undergraduates who are likely to have relatively little experience with infant facial expressions (Study 2), and the parents of infants, who are likely to have more experience with infant facial expressions (Study 3), served as raters. To capture perceptions of the smiles as dynamic events, a separate undergraduate sample rated video clips of the infants' smile sequences (Study 4).

Study 1

Method

Participants

Five infants (infants A–E) between 5 and 6 months of age were videotaped as they participated in 3-min face-to-face interactions with their mothers. There were three female and two male infants. Infants were Caucasian Hispanic (4) and Southeast Asian (1).

Equipment

Infants were seated in a car seat attached to a table at mother's eye level. A digital video camera (PV-L859) was used to record a close-up of each infant's facial expressions.

Procedure

The longest sequence of continuous smiling was selected from each infant in which there was a clear frontal view of the infant's face, no occlusion of the face, and in which head movement was not excessive. We selected the longest sequence to maximize the available rating stimuli for each infant. The five smile sequences ranged from 5½ to 15 s in length (see Fig. 1). Based on FACS coding (see below), all smile sequences began before the onset of trace zygomatic action except that of Infant B, whose sequence began when trace levels of smiling were present. Infant A's smile sequence ended during extreme zygomatic action. Infants B, C, D, and E's smile sequences ended either when all zygomatic activity had ceased or when only a trace of zygomatic activity was visible on one side of the face.

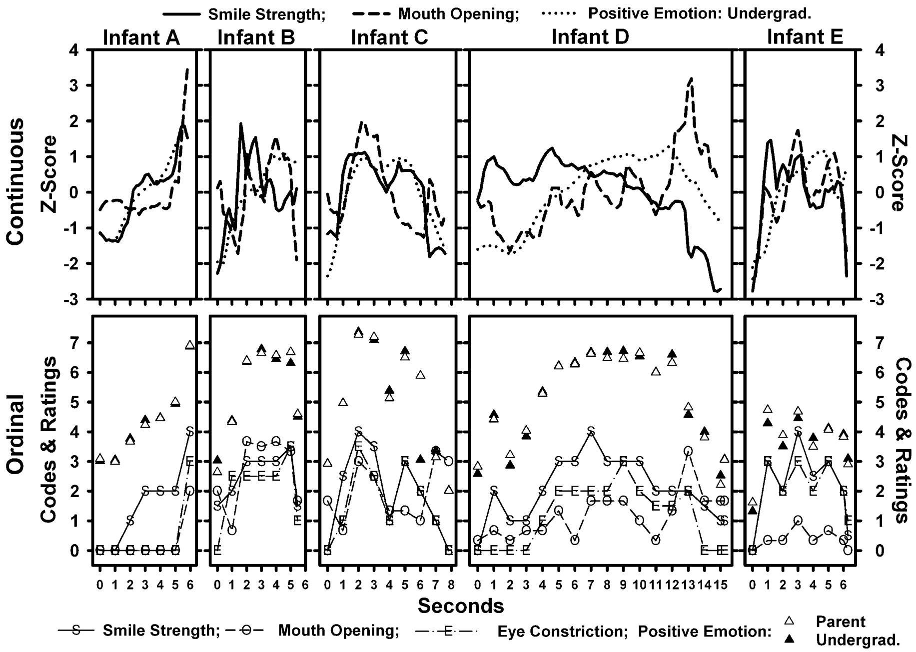

Fig. 1 Continuous measurements of smile descriptors and rated positive emotion in five infants' smile sequences are displayed on the top half of the figure. Ordinal measurements of these parameters are displayed on the bottom half of the figure (note the separate legends). In the top half of the figure, smile strength and mouth opening represent automated measurements (AFA3) of facial movement. Mean undergraduate positive emotion ratings (0–400) were collected continuously in real time and lagged seven fifths of a second (see text). All measures are displayed as infant-specific *Z* scores. A *Z* of zero for the positive emotion ratings (and the value of each single unit *Z* score deviation) for Infants A, B, C, D, and E are, respectively, 185 (33), 189 (32), 270 (44), 267 (45), and 209 (22). The bottom half of the figure contains FACS/BabyFACS (ordinal) coding of smile strength, mouth opening, and eye constriction. Smile strength and eye constriction are displayed on a 0–5 metric—from the absence (0) to a maximal (5) level of the Action Unit; mouth opening involved three action units and is also displayed on a 0–5, resulting from division of the original 0–15 metric by three (see text). The bottom half of the figure also contains mean positive emotion ratings of individual images from both an undergraduate and a parent sample displayed on their original 0–8 scale. These mean ratings frequently overlap

Measurement

Smile sequences were digitized into 720 × 480 pixel arrays and analyzed using the CMU/Pitt automated AFA3 system (Cohn and Kanade 2007; Moriyama et al. 2006). To ensure that rigid head motion did not confound measurement of nonrigid expressive facial actions, face images were registered by AFA3 using a cylindrical head model (Xiao et al. 2003). AFA3 produced continuous measurements of the movement of facial features. There was insufficient texture in infants' cheeks to measure eye constriction using AFA3. Measured facial features included the right and left lip corner, and the medial (center) point of the top and bottom lip. These were used calculate smile strength and mouth opening. Smile strength was defined as the diagonal displacement of the lip corners, $\Delta d = \sqrt{\Delta x^2 + \Delta y^2}$, where *x* and *y* represent, respectively, horizontal and vertical displacement (Cohn and Schmidt 2004; VanSwearingen et al. 1999) (see Fig. 2). Mouth opening was defined as the vertical distance between the upper and lower lips. Measurements were smoothed using a

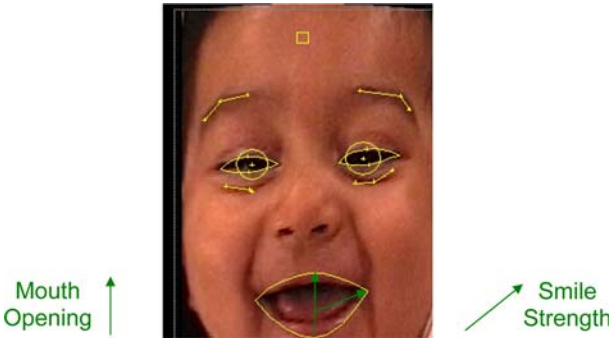

Fig. 2 Automated facial image analysis illustrating the measurement of mouth opening and smile strength

three frame moving average and normalized for each infant, producing individualized *Z*-scores, which were used in all analyses.

Three areas of action—eye constriction, smile strength, and mouth opening—were measured in static images sampled at 1-s intervals from the smile sequences. Using FACS/BabyFACS (referred to as FACS throughout), coders identified eye constriction (FACS AU6, cheek raising) and smiling (AU12, lip corner pulling) and assigned each Action Unit an ordinal intensity code (A = *trace*, B = *slight*, C = *pronounced*, D = *extreme*, E = *maximal*) that was converted to a number from 1 to 5 (Frank et al. 1993). Zero was assigned when action units were not present. Three FACS codes were used to quantify mouth opening (Ekman et al. 2002). Degree of lip parting (AU25) describes the space between the lips on a 1–5 (A–E) intensity scale and is coded independently of jaw movement. Jaw movement is described by two action units that cannot co-occur: Jaw dropping (AU26) is caused by the relaxation of muscles holding the lower mandible closed while mouth stretching (AU27) is caused by the active depression of the lower mandible. These scales were combined to create a 0–10 scale of in which AU26 contributed the 0–5 and AU27 the 6–10 scale points (e.g., AU26E = 5, AU27A = 6). We added the lips parting 0–5 scale to the jaw movement scale to produce a 0–15 scale of mouth opening (e.g., AU25C = 3, AU25C + AU26C = 6). As all instances of AU25 of a B level or lower occurred with levels of AU26 of a B level or lower, the procedure was identical to that proposed by Oster (2006) (see below).

Coding was conducted by four individuals certified in FACS (Ekman and Friesen 1978) and trained in BabyFACS (Oster 2006). The first three independent coding protocols obtained were compared, discussed, and united in a consensus FACS protocol. The reliability of this consensus protocol was determined by comparing it to that of an independent fourth coder. Comparison of the protocols over infants yielded reliable indices of inter-coder agreement expressed as mean percent agreement (%) and chance-corrected Cohen's Kappa (K). Differences of one point were treated as agreements. Mean agreement was 77% ($K = .72$) for smile strength, and 92% ($K = .89$) for eye constriction. Agreement was 96% ($K = .94$) for AU25, and 81% ($K = .75$) for AU26/AU27.

The BabyFACS matrix is an ordinal rating of smile intensity (Oster 2006), which was used in the prediction of positive emotion ratings. The matrix contains three levels of mouth opening: (1) lips closed, through all levels of lip parting (AU25), up to slight levels of jaw dropping (AU26A-B); (2) pronounced jaw dropping (AU26C); and (3) extreme/maximal jaw dropping (AU26D-E) through all levels of mouth stretching (AU27). These levels of mouth opening define, respectively, the 1–3, 4–6, and 7–9 levels of smile intensity. Within these levels of mouth opening, smile intensity is determined by three levels of smile strength (lip corner pulling): 1 = *trace/slight* (AU12A-B), 2 = *pronounced* (AU12C), and 3 = *extreme/maximal* (AU12 D-E). Mouth stretching (AU27) and low level smile strength (AU12B), for example, would yield a smile intensity level of seven. The inclusion of a zero level (*no smiling*) produced a 10-point BabyFACS smile intensity matrix.

Results

Smile sequences are graphed using AFA3 continuous movement parameters and FACS codes in Fig. 1. The duration of smiling within the sequences (the first to the last coded image in which FACS lip corner pulling was present) ranged from 4 to 14 s. All smile sequences involved the activation of orbicularis oculi, pars lateralis, the Duchenne marker. Mean correlations between smile parameters were hypothesized to be positive. The significance of the mean correlations over infants was, consequently, assessed by one-tailed *t*-tests.

Table 1 contains the range, mean, and standard deviation of correlations over infants, with associated significance tests. Correlations between FACS and automated (AFA3) measurements of mouth opening and of smile strength were moderate to high, an index of method convergence. Substantively, FACS measured eye constriction (AU6, cheek raising) intensity showed high mean correlations with FACS and AFA3 measurements of smile strength. Eye constriction intensity showed moderate and variable associations with FACS and AFA3 measures of mouth opening. Both FACS and AFA3 measurements indicated substantial variability in the correlations between smile strength and mouth opening. The FACS-measured association of these parameters was significant although the AFA3-measured association was not.

Discussion

Our sampling strategy was oriented toward long smiles in order to maximize the contiguous stimuli available for rating studies. Automated measurement of the full extent of two infants' smile sequences was precluded by rapid head movement and occlusion. Smile durations were nevertheless typically between 5 and 6 s with one smile of 14 s. These smiles often involved multiple peaks in smile strength, and of mouth opening and/or eye constriction. Results, then, are most applicable to smiles of long duration.

Moderate to high levels of association between FACS and automated measurements of mouth opening and smile strength over different infants suggest their convergent validity (see Table 1). This convergence is noteworthy as AFA3 produces continuous measurements of facial movement while FACS produces ordinal measurements of appearance changes based on muscle contractions (see Fig. 1).

Changes in smiles strength were linked tightly to changes in eye constriction over the course of smiles. This suggests that eye constriction (orbicularis oculi, pars lateralis) is not simply a dichotomous signal of whether a smile involves the Duchenne marker, but an ordinally graded index of smile intensity. In keeping with this interpretation, eye constriction intensity was also associated with mouth opening, although inter-infant variability was evident in these associations (see Table 1).

Manual FACS measurements, but not automated AFA3 measurements, showed a significant association between smile strength and mouth opening. In part this is due to the different measurement approaches afforded by the two techniques. Greater mouth opening

Table 1 Correlations between smile parameters over infants (study 1)

Correlations	FACS smile strength & AFA3 smile strength	FACS mouth opening & AFA3 mouth opening	FACS eye constriction & AFA3 smile strength	FACS eye constriction & FACS smile strength	FACS eye constriction & AFA3 mouth opening	FACS eye constriction & FACS mouth opening	AFA3 smile strength & AFA3 mouth opening	FACS smile strength & FACS mouth opening	FACS eye constriction & BabyFACS matrix
Min–Max	.54–.96	.53–.96	.39–.87	.80–.96	.29–.98	−.03–.81	−.57–.58	−.05–.91	.10–.99
Mean	.76	.83	.68	.88	.58	.51	.21	.51	.61
(*SD*)	(.19)	(.18)	(.20)	(.07)	(.33)	(.40)	(.51)	(.42)	(.34)
$t(4)$	8.80***	10.23***	7.73***	30.18***	3.94**	2.81*	0.93	2.72*	3.94**

Notes. Min–Max refers to the lowest and highest correlation in the set of five infants. FACS—Facial Action Coding System, AU—Action Unit, AFA3—Automated Facial Analysis. * $p \leq .05$, ** $p < .01$, *** $p \leq .001$

can reduce the diagonal lip corner movement measured by AFA3, an effect for which a FACS coder would likely counterbalance. The different sampling frequency of AFA3 (every fifth of a second) and FACS measurements (every second) may have also played a role in this difference. More generally, both approaches documented substantial variation between infants in the association of smile strength and mouth opening. Fogel et al. (2006) have demonstrated that, overall, open mouth smiles involve a stronger smiling action than closed mouth smiles. The current results suggest that associations obtained by summing over an epoch of smiling do not reveal subtle variations in how facial expressions are organized in real time.

Having examined measurement reliability and the dynamics of infant smiling, we next investigated how infant smiles are perceived. We asked whether eye constriction, smile strength, and mouth opening predict perceived positive emotion during smiling. This involved a series of rating studies incorporating variations in type of rater and type of stimulus presentation. We were primarily interested in the association of automated measurements of facial movement with human ratings of positive emotional intensity. Our secondary interest was in the association of these ratings with manual FACS measurements, particularly the BabyFACS smile matrix composite.

Overview of Rating Studies and Analysis Procedures

Studies 2, 3, and 4 investigate whether variation in the intensity of facial actions predict ratings of positive emotional intensity. In Study 2, undergraduates rated positive emotion in static images sampled at 1 s intervals from the five infant smile sequences. In Study 3, parents rated these images to evaluate the influence of experience with infants in the perception of positive emotions. In Study 4, an additional sample of naïve observers provided continuous ratings of positive emotion in the smile sequence videos to evaluate the impact of dynamic stimulus presentation on ratings.

Regression Approaches

The rating studies examine the impact of smile parameters such as smile strength, mouth opening, and eye constriction on perceptions of positive emotion while controlling for the possible impact of demographic factors such as the ethnicity and gender of the rater. The impact of these parameters on ratings of each individual infant could not be accomplished with a single 'group' regression (Pedhazur 1997). Consequently, individual regression analyses were conducted for each infant to determine the impact of smiling parameters and rater characteristics on perceptions of positive emotion (Lavelli et al. 2005). In this replicated single subject design, beta weights from the individual regression analyses were treated as descriptive measures of association that were subject to inferential *t*-tests to ascertain their significance over infants (Bakeman and Gottman 1986; Lavelli et al. 2005). This design is similar to Hierarchical Linear Modeling (HLM) of associations within infants (Bryk and Raudenbush 2002), and the two techniques produced comparable results.

Practically, we first examined the univariate association of each predictor with the outcome rating variable for each infant in separate regression analyses. We expected positive associations between facial parameters and ratings. Consequently, one-tailed *t*-tests of the resulting beta weights were used to determine whether each predictor showed univariate associations with ratings over the five infants. Predictors that were significantly different than zero ($p < .05$)—and did not show multicollinearity (see below)—were then used in forced entry multiple regression analyses for each infant. These regressions produced a beta for each predictor for each infant. They were followed up with one-tailed *t*-tests of the beta weights for each coefficient over infants. Because there are five infants in the sample, *t*-tests for all parameters had four degrees of freedom. These final *t*-tests indicated the impact of a given predictor on perceptions of positive emotion across infants while controlling for other predictors.

Multicollinearity

Some of the pairs of smiling measurements examined in Study 1 showed very high correlations overall that approached unity (1.0) for some infants (see Table 1). Substantively, this suggests that the smiling parameters reflect a common process. Statistically, these correlations produce multicolllinearity. This occurs when one predictor is essentially a linear transformation of other predictor(s), e.g., when correlations reach or exceed .9 (Tabachnick and Fidell 1989), producing a variance inflation factor of 10 or above (Pedhazur 1997). The presence of multicollinearity between smiling parameters measured in one or more infants biases all regression-based techniques (Bryk and Raudenbush 2002). These biases can produce spurious results because of non-meaningful division of the common variance between the multicollinear predictors. After selecting univariate predictors of rated positive emotion in Studies 2, 3, and 4, we eliminated variables that produced multicollinearity.

Study 2

Method

Participants

To investigate how raters perceived static images of smiles, 191 undergraduates were recruited from an introductory psychology course at a major university. They were 71% female with a mean age of 19.1 years ($SD = 4.07$). The undergraduates were White (55%), Hispanic (20.9%), African American (12.6%), Asian (3.1%), and Bi-racial/Other (8.4%). These categories were recoded into White and Other categories for data analysis.

Stimuli

Undergraduates viewed 48 images corresponding to the first frame, every subsequent thirtieth frame (every 1 s), and the last frame of the smile sequences. As infant smile sequences had different durations, the number of images differed across infants. Infant A contributed 7 images, infant B 7 images, infant C 9 images, infant D 17 images, and infant E 8 images. Image size was held constant across stimuli ($4 \times 4.5''$).

Procedures

A Microsoft Access database was used to present all the infants' images in random order and to obtain rating data. Raters were asked to rate the joy, happiness, positive feeling, arousal, and excitement in each image/video on a nine-point scale (0 = *not at all*, 8 = *very strong*). The ratings of arousal and excitement were not part of this study. Completion of the rating of a given image triggered presentation of the next so that raters determined the pace of their own rating.

Results

Preliminary Analyses

Correlations among rated joy, happiness, and positive feeling ranged from .80–.94, and a positive emotion composite rating was created by averaging these variables. We next examined the univariate association of individual predictors with the outcome rating variable for each infant in separate regression analyses. *T*-tests of beta weights produced by individual regressions of each automated smiling measurement indicated that the positive emotion rating composite was separately associated with AFA3 smile strength, $t(4) = 8.40$, $p < .001$ and mouth opening, $t(4) = 4.25$, $p < .01$. The positive emotion rating composite was also predicted by individual FACS measurements of smile strength, $t(4) = 10.56$, $p < .001$, mouth opening, $t(4) = 2.40$, $p < .05$, eye constriction, $t(4) = 12.21$, $p < .001$, and by the BabyFACS smile intensity composite, $t(4) = 5.16$, $p < .01$. Undergraduate gender $t(4) = -.26$, $p = .40$ and ethnicity (White vs. Other), $t(4) = 1.67$, $p = .085$, were not associated with the positive emotion composite and were not included in the multivariate regressions.

Correlations between FACS measurements of smile strength, mouth opening, the BabyFACS smiling composite, and eye constriction approached unity (>.9) in one or more infants (see Table 1). Utilizing any pair of these variables as predictors would have led to multicollinearity with variance inflation factors >10 (Pedhazur 1997). Multicollinearity was not present in the automated measurements of smile strength and mouth opening.

Final Analyses

Two sets of regression analyses were performed, one for the automated measurements and one for the manual measurements of facial parameters (see Table 2). With respect to the automated measurements, forced entry regression analyses were conducted for each infant individually to assess the combined influence of smile strength and mouth opening on the ratings of positive emotion (see Table 3). Beta weights from each infant's regression indicate how well each predictor was associated with rated positive emotion after accounting for variance related to the other predictor. One-tailed *t*-tests indicated that the mean beta weights for smile strength and mouth opening were significantly higher than zero. That is, automated measurements of greater smile strength and greater mouth opening were uniquely associated with higher ratings of positive emotion.

With respect to the manual measurements of facial parameters, multicollinearity precluded multiple regression analyses utilizing more than one FACS variable. We focused on the BabyFACS smile intensity composite because it unites smile strength and mouth opening measurements in a single parameter (see Table 2). This smile intensity composite was a significant predictor of positive emotion ratings.

Discussion

In study 2, undergraduates rated static images from infant smile sequences. Neither rater ethnicity nor gender impacted ratings. Overall, images with greater smile strength and mouth opening were perceived as more emotionally positive than images with lower levels

Table 2 Two sets of regression equations predicting undergraduate ratings of positive emotion in static images (study 2)

Automated measurements							Manual measurements		
Infant	AFA3 smile strength			AFA3 mouth opening			BabyFACS smile intensity matrix		
	B	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
A	0.75	.06	.36	.44	.04	.32	0.37	0.02	0.56
B	1.13	.05	.52	.51	.03	.32	0.26	0.02	0.32
C	1.35	.04	.59	.69	.05	.27	0.44	0.01	0.65
D	1.18	.03	.66	.93	.04	.44	0.17	0.01	0.25
E	0.25	.05	.17	.42	.06	.23	0.36	0.03	0.28
Mean (*SD*)			.46 (.20)			.31 (.08)	0.32 (.11)	0.02 (.01)	0.41 (.18)
t-value			5.20**			8.99***			5.16**

Note. The regression equations using automated measurements of smile sequence images to predict ratings are on the left. The equations using the BabyFACS Smile Intensity Matrix to predict ratings are on the right. One tailed significance levels for the significance of the mean predictor over infants: ** $p \leq .01$, *** $p \leq .001$. The significance levels of beta weights for individual infants are not presented

Table 3 Two sets of regression equations predicting parent ratings of positive emotion in static images (study 3)

Automated measurements										Manual measurements					
Infant	Rater gender			AFA3 smile strength			AFA3 mouth opening			Rater gender			BabyFACS smile intensity matrix		
	B	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
A	.73	.32	.12	.74	.16	.32	.46	.11	.31	.37	.30	.06	.39	.04	.52
B	.13	.29	.02	1.26	.11	.56	.53	.08	.32	.13	.36	.02	.29	.05	.34
C	.20	.26	.03	1.60	.09	.70	.22	.10	.09	.20	.31	.03	.40	.03	.58
D	.75	.23	.11	1.19	.08	.62	.91	.09	.40	.75	.26	.11	.14	.03	.20
E	.63	.39	.09	.21	.16	.13	.18	.18	.10	.58	.39	.09	.36	.08	.26
Mean			.07			.46			.24			.06			.38
(*SD*)			(.05)			(.24)			(.14)			(.04)			(.17)
t-value			3.65*			4.39**			3.85**			3.64**			5.13**

Note. The regression equations using automated measurements of smile sequence images to predict ratings are on the left. The equations using the BabyFACS Smile Intensity Matrix to predict ratings are on the right. One tailed significance levels for the significance of the mean predictor over infants: * $p \leq .05$, ** $p \leq .01$. Male raters produced higher ratings of positive emotion. The significance levels of beta weights for individual infants are not presented

of smile strength and mouth opening. This was evident in a multivariate analysis of automated parameters, as well as univariate analyses of automated and manually measured parameters. Greater levels of manually coded eye constriction (AU6, cheek raising) were also associated with higher positive emotion ratings in a univariate context. Substantively, very high levels of association between manually coded parameters of smile strength, mouth opening, and eye constriction indicated that, in some smile sequences, these were redundant indices of positive emotion.

Our next concern was parental perceptions of infant smiles. Parents of infants are likely to have more experience interpreting infant facial expressions than undergraduates. In Study 3, we investigate whether automated and manual measurements of smiling parameters predict parent perceptions of positive emotion in infant smiles. This also allowed us to examine potential differences between more (parent) and less (undergraduate) experienced raters.

Study 3

Method

Participants

To investigate how parents perceived infant smiles, 32 mothers and 5 fathers who had infants between the ages of 1 and 36 months (mean age = 9.86 months, $SD = 6.64$) were recruited as raters. The 37 parents had a mean age of 33.8 years ($SD = 4.8$), and they were White (45.9%), Hispanic (45.9%), African American (2.7%), Asian (2.7%), and Bi-racial/Other (2.7%). These categories were recoded into White and Other categories for data analysis. Two of the parents rated their own infants.

Stimuli

Stimuli—48 images from the smile sequences of five infants—were identical to those rated by the undergraduates in Study 2.

Procedures

Procedures were identical to those employed in Study 2. In brief, the Microsoft Access database was used to present all the infants' images in random order and to obtain ratings of joy, happiness, positive feeling, arousal, and excitement on a nine-point scale (0 = *not at all*, 8 = *very strong*). The ratings of arousal and excitement were not part of this study. Raters determined the pace of their own rating.

Results

Preliminary Analyses

Correlations among joy, happiness, and positive feeling ranged from .86 to .96. A mean positive emotion composite was created from these variables as in Study 2. Trial exclusion of the two parents who rated their own infants did not affect results and they were included in subsequent analyses.

Univariate regressions were used in preliminary analyses to determine which facial parameters and rater characteristics were associated with ratings of positive emotion. One-tailed t-tests indicated that automated measurements of smile strength, $t(4) = 5.62, p < .01$ and mouth opening, $t(4) = 3.60$, $p < .05$, were each associated with positive emotion ratings. FACS measurements of smile strength, $t(4) = 10.29$, $p < .001$, eye constriction, $t(4) = 5.99$, $p < .01$, the BabyFACS smile intensity matrix, $t(4) = 5.13$, $p < .01$, were associated with positive emotion ratings, but FACS measurements of mouth opening were

Table 4 Regressions equation predicting undergraduate continuous ratings of positive emotion in smile sequences (study 4)

Infant	Rater gender			AFA3 smile strength			AFA3 mouth opening		
	B	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
A	−0.23	0.04	−0.12	0.42	0.03	0.43	0.02	0.03	0.02
B	−0.06	0.05	−0.03	0.22	0.02	0.23	0.21	0.02	0.21
C	−0.18	0.04	−0.10	0.42	0.02	0.46	0.04	0.02	0.04
D	−0.26	0.03	−0.13	0.21	0.02	0.23	0.41	0.02	0.43
E	−0.46	0.04	−0.25	−0.08	0.03	−0.09	0.21	0.03	0.23
Mean			−0.13			0.25			0.19
(*SD*)			(0.08)			(0.22)			(.17)
t-value			−3.62*			2.54*			2.50*

Note. One tailed significance levels for the significance of the mean predictor over infants: * $p \leq .05$. Female raters produced higher ratings of positive emotion. The significance levels of beta weights for individual infants are not presented

not, $t(4) = 1.79$, $p = .07$. Parent rater gender was associated with positive emotion ratings, $t(4) = 3.65$, $p < .05$, but parent ethnicity (White vs. Other) was not, $t(4) = 1.88$, $p(4) = .07$.

Multicollinearity paralleled that in Study 2. That is, all pairs of manual FACS measurements were multicollinear, with variance inflation factors >10 (Pedhazur 1997), but automated measurements of smile strength and mouth opening were not multicollinear.

Final Analyses

Regression analyses were performed first for the automated measurements of facial parameters, and then for the manual measurements (see Table 4). With respect to the automated measurements, forced entry regression analyses were conducted for each infant in order to assess the simultaneous influence of rater gender, smile strength, and mouth opening on parent perceptions of positive emotion. One-tailed *t*-tests of the resulting beta weights for gender, smile strength and mouth opening were significantly higher than zero, indicating that male gender, greater smile strength, and mouth opening were uniquely associated with higher ratings of positive emotion.

With respect to manually measured facial actions, multicollinearity precluded multiple regression analyses with more than one FACS variables. Consequently, we examined the simultaneous influence of rater gender and the BabyFACS smile intensity composite, which united smile strength and mouth opening measurements. One-tailed *t*-tests of the resulting beta weights indicated that male gender and higher levels of the BabyFACS smile intensity variable were significantly associated with higher parent positive emotion ratings (see Table 3).

Supplementary Analyses

We next compared the undergraduate ratings of static smile sequence image from Study 2 and the parent ratings of the same images from the current study. There were impressive similarities between the mean undergraduate and parent ratings (see Fig. 1). The mean correlation between ratings, .96 ($SD = .05$), $t(4) = 4.92$, $p < .01$, indicated almost exact agreement on the relative rating of images within infants. Likewise *t*-tests conducted for each infant indicated no differences in the absolute level of undergraduate and parent ratings, *p*s $\geq$ .40.

Discussion

Parental ethnicity was roughly comparable (Caucasian and/or Hispanic) to the ethnicities of the rated infants and was not associated with ratings of positive emotion. Moreover, parents' ratings of their own (ethnicity-matched) infants appeared to reflect the ratings of parents as a whole. This is a striking finding because an infant's parent is the quintessential expert interpreter of the infant's facial expressions. Equally striking was the almost exact correspondence between mean undergraduate and parent ratings. This finding suggests different infant smiles elicit very similar reactions from more and less experienced observers, and suggests the validity of using undergraduates as raters of emotional expressions. Given the small number of fathers in the sample, we are cautious in interpreting the finding that fathers rated infants as expressing higher levels of positive emotion than mothers. Supplemental analyses that excluded fathers, yielded results identical to those found in the full parent sample.

Automated measurements of greater mouth opening and smile strength were uniquely associated with parent ratings of positive emotion. A composite a priori measure of FACS smile strength and mouth opening was also associated with positive emotion ratings. Both of these associations involved controls for rater gender (see Table 3). In univariate analyses, FACS measurements of smile strength and eye constriction (AU6, cheek raising) were associated with parent positive emotion ratings, and FACS-measured mouth opening showed a similar association with a *p* value of .07.

Study 3 indicated that automated measurements of smile strength and mouth opening uniquely predict parental ratings of positive emotion. Infants, however, do not produce static images of smiles. They smile dynamically in time. We investigated the predictors of undergraduate perceptions of dynamically presented smiles in Study 4.

Study 4

Method

Participants

As in Study 2, participants were 52 undergraduates recruited from an introductory psychology course at a major university. The sample was 54% female with a mean age of 20 years (*SD* = 4.0). Undergraduates were White (61.5%), Hispanic (23.1%), African American (5.8%), Asian (7.7%) and Multiracial/Other (1.9%). These categories were recoded into White and Other for data analysis.

Procedure

Using a joystick interface, raters moved a cursor over a continuous color-coded rating scale. They indicated in one rating pass the degree of "positive emotion, joy, and happiness" they perceived in each smile sequence. The scale ranged from "*none*" (which yielded a rating of 0) to "*maximum*" (which yielded a rating of 400). The joystick interface and associated software—the Continuous Rating System (CRS)—recorded the rater's perception of dynamic facial configurations in real time. The CRS also randomized the order in which the five smile sequences were presented to raters.[1]

Stimuli

Stimuli were digitally edited versions of the smile sequences described in Study 1. Digital editing was undertaken because we expected continuous ratings to lag behind changes in facial action. To avoid "losing" the ratings of the end of smile sequences to this lag, we used AVID software to edit the smile sequences so that they played forward and then seamlessly played backward. This allowed us to capture the ratings of the end of the smile sequences as the smile sequence began to play backward.

Results

Preliminary Analyses

Data were aggregated over intervals of one-fifth of a second. Inspection of cross-correlations indicated that a forward lag (a lead) of seven fifths of a second captured the highest degree of correspondence between positive emotion ratings on the one hand and smile strength and mouth opening on the other. In other words, ratings were most highly associated with facial actions that had occurred seven fifths of a second prior.

Only automated measurements of smile sequences produced continuous measurements appropriate for predicting continuous measurements. As in studies 2 and 3, we used univariate regression analyses to determine the individual associations of facial measurements and demographic factors on perceived positive emotion. *T*-tests of the resulting beta weights indicated that smile strength, $t(4) = 5.52$, $p < .01$, mouth opening, $t(4) = 5.69$, $p < .01$, and rater gender, $t(4) = -3.41$, $p < .05$ were each associated with rated positive emotion. There was no impact of ethnicity (White vs. Other) on ratings, $t(4) = .70$, $p = .25$, and this variable was not included in the multiple regressions.

Final Analyses

Forced entry regression analyses were conducted individually for each infant in order to assess the unique influence of the selected predictors—AFA3 smile strength, AFA3 mouth opening, and rater gender—on perceptions of positive emotion. This forced entry procedure allowed us to obtain a beta weight for each predictor across infants. Follow-up *t*-tests of the beta weights over infants indicated that female rater gender, greater smile strength, and greater mouth opening each were uniquely associated with higher ratings of positive emotion (see Table 4). The top panel of Fig. 1 illustrates the association of the mean continuous positive emotion rating with smile strength and mouth opening for each infant.

Discussion

Undergraduates provided continuous ratings of smile sequences in time. This allowed us to assess whether continuous automated measurement of smile parameters predicted dynamic ratings of smiles. Greater smile strength and greater mouth opening during smile sequences yielded ratings of higher positive emotion. Unlike in ratings of static images, female raters

[1] The CRS is available at http://www.psy.miami.edu/faculty/dmessinger/dv/index.html

perceived dynamic smile displays more positively than male raters, an effect previously documented by Biele and Grabowska (2006). Overall, Study 4 indicates the capacity of automated measurements of continuous smiling to predict real-time ratings of positive emotion perceived in those smiles.

General Discussion

To better understand how infants smile and the impact of those smiles on others, we conducted an encoding study and a series of rating studies. In Study 1, we demonstrated the reliability of automated measurements of infant smiles with respect to anatomically based coding and used both sets of measurements to investigate the dynamics of infant smiling. In Studies 2 and 3, rating studies indicated that automated measures of infant smile strength and mouth opening—and, separately, an anatomically-based coding composite—were unique predictors of naïve raters and parents' perceptions of positive emotion intensity in still images. In Study 4, continuous automated measurements predicted continuous undergraduate ratings of smile sequences, suggesting the real time impact of facial movement on perceptions of positive emotion expression. The findings are discussed with respect to the reliability of new measurement approaches, facial dynamics, and predicting perceived positive emotion.

Reliability and Convergent Validity

While automated approaches produce continuous measurements of the movement of facial features, FACS produces ordinal measurements based on constellations of appearance changes that are linked to specific muscle contractions. AFA3 measurements of smile strength and of mouth opening nevertheless showed moderately high correlations with ordinal FACS coding of images conducted at 1-s intervals in the smile sequences. The results suggest the convergent validity of the two different measurement systems. They complement similar correspondences between automated AFA3 and facial EMG and between AFA3 and FACS coding that have been documented in adults (Cohn and Kanade 2007; Cohn and Schmidt 2004; Cohn et al. 2003; Cohn et al. 1999; Tian et al. 2002). Variability between infants in the strength of association of automated and manual measurements suggests, however, the importance of attending to individual differences in the level of agreement between measurement approaches.

Limitations remain in applying automated facial measurement systems to infants. Abrupt head movements and occlusion curtailed the measurement of two of the smiles in this sample. Automated measurements of eye constriction (AU6, cheek raising) were not available because of the lack of texture in the cheek region and absence of wrinkling lateral to the eye region in infant faces. In addition, AFA3 measurements of smile strength and mouth opening use number of pixels as a metric and, consequently, are specific to a given infant. Thus, automated measurements do not have an a priori meaning analogous to the intensity measurements of a given FACS/BabyFACS Action Unit. Nevertheless, the promise of automated techniques for documenting continuous changes in facial expressivity—either alone or in concert with manual coding—is clear.

Facial Dynamics

Our sampling strategy was oriented toward long smiles and all these smiles involved the Duchenne marker. The prediction (Ekman and Friesen 1982) that the durations of

Duchenne smiles would typically range from one-half to four seconds has been born out by research on mean smile length in adults (Frank et al. 1993) and infants (Messinger et al. 2001). FACS coding of the current sample of long-running smiles revealed typical durations of five to six seconds with one smile of fourteen seconds duration. Although lengthy Duchenne smiles are occasionally observed among adults (Frank et al. 1993) and infants of this age (Messinger et al. 2001), these durations likely also reflect an a priori decision to capture smiling based on the presence of even trace (A) levels of zygomatic activity (see Fig. 2). The facial dynamics documented here are most generalizable to lengthy infant smiles, although they appear to reflect processes that have been observed among infant smiles sampled without regard to duration (Fogel et al. 2006; Messinger et al. 1999).

Adult Duchenne smiles are thought to be tightly organized, ballistic expressions of positive emotion (Ekman and Friesen 1982; Frank et al. 1993). Yet the spontaneous Duchenne smiles in this sample frequently involved multiple peaks and long apexes of smile strength. Similar temporal patterns characterized degree of mouth opening and eye constriction. This suggests the infants were engaged in oscillating levels of positive affect within a smile (Stern 1990). It remains to be determined whether such multi-peak variability is also evident among briefer infant smiles than those sampled here and among spontaneous adult Duchenne smiles.

Fogel et al. (2006) recently reported that epochs of infant smiling with eye constriction involved stronger smiling than epochs of smiling without eye constriction. We found that the intensity of FACS coded infant eye constriction had strikingly high correlations with measures of smile strength over the course of a smile. It appears, then, that smiling and eye constriction covary both within and over smiles. One source of this association may be muscular synergies. As the zygomatic pulls the lip corners laterally upward, it raises the cheeks toward the muscle body of orbicualris oculi, pars lateralis, whose contraction raises the cheeks toward the eyes (Williams et al. 1989). Smile strength and eye constriction may also both reflect continuously changing infant positive emotional intensity.

Previous studies have indicated that epochs of infant smiling involving eye constriction also tend to involve mouth opening (jaw dropping) (Fogel et al. 2006; Messinger et al. 2001). Going beyond this dichotomous association, we found that level of eye constriction intensity was associated with mouth opening over the course of smiles, suggesting that both actions are indices of positive emotion intensity. These correlations varied noticeably between infants perhaps, in part, because the actions are anatomical antagonists. While orbicularis oculi raises the cheeks toward the eyes, mouth opening pulls downward on the cheeks and tissue in the mid-face (Williams et al. 1989).

Fogel et al. (2006) found that infant smiles involving mouth opening involved greater FACS-coded smiling intensity than closed mouth smiles. Although automated continuous measurements of these parameters were not associated over the course of smiling, manual FACS measurements of smile strength and mouth opening were associated. One possibility is that automated measurements may be more sensitive than FACS coding to the anatomical antagonism between smiling (which pulls the lip corners laterally and upward) and mouth opening (which pulls the mouth open against the force of this lateral upward pull). It is also possible that the difference reflects the greater sampling frequency of the automated measurements and that the two approaches would both yield significant associations in a larger sample of smile sequences. Both automated and manual approaches ultimately indicated substantial variation in the association of smile strength and mouth opening with some smile sequences showing negative associations between these parameters.

In summary, automated and manual approaches to smile measurement were strongly associated and yielded similar but not identical results. Substantively, smile strength was associated with the intensity of eye constriction over the course of infant smiling and eye constriction intensity was, in turn, associated with degree of mouth opening (Messinger et al. 1999). We now examine the results of the rating studies in which both automated and manual measurements of these smiling parameters were used to predict perceived positive emotion.

Predicting Perceived Positive Emotion

A series of rating studies demonstrated that eye constriction, smile strength, and mouth opening were associated with perceived positive emotion. We discuss each of these facial actions in turn, note similarities between the ratings of undergraduates and parents, and examine the use of dynamic ratings.

Eye Constriction (the Duchenne Marker)

Among infants and adults, Duchenne smiles, which involve eye constriction produced by orbicularis oculi, pars lateralis, are more emotionally positive than other smiles (Frank et al. 1993). Infants display smiles with eye constriction to greet mother and to reciprocate her smile but not when smiling at an unfamiliar stranger (Fox and Davidson 1988; Messinger et al. 2001). Adult Duchenne smiles are perceived as more positive than smiles without eye constriction of identical strength (Frank et al. 1993). Naïve observers (undergraduates) rate experimentally manipulated images of infant smiles involving eye constriction as more positive than the same smiles without eye constriction (Bolzani-Dinehart et al. 2005; Messinger 2002). The Duchenne marker has typically, however, been measured dichotomously as present or absent.

In the first two rating studies, undergraduates and parents rated static images selected at 1-s intervals from the smile sequences. In these studies, eye constriction's high correlations with smile strength and with mouth opening prevented us from assessing its *unique* association with ratings. Eye constriction intensity was, however, a consistent univariate predictor of positive emotion rated by both undergraduates and parents. This suggests that eye constriction functions as a graded signal which impacts the degree to which naturally occurring smiles are perceived as emotionally positive. Additional evidence that eye constriction can function as a graded signal of emotional positivity was found using a sample of women's yearbook photos. Strength of smiling and extent of eye constriction were jointly related to optimal outcomes (e.g., marital satisfaction) decades into adulthood (Harker and Keltner 2001).

Smile Strength and Mouth Opening

The rating studies utilized repeated multiple regressions to determine that smile strength uniquely predicted rated positive emotion. Greater smile strength was perceived as more emotionally positive by parents rating static images and by undergraduates rating static and dynamic stimuli. These ratings of naturally occurring smiles parallel those from a previous study of digitally altered static images (Bolzani-Dinehart et al. 2005). Stronger smiles are produced in conjunction with or in reaction to positive events among infants (Fogel et al. 2006), children (Schneider and Unzner 1992), and adults (Ekman et al. 1980). This suggests that stronger zygomatic contraction indexed by stronger smiling is a central index of the intensity of infant positive emotion.

In a previous study of digitally altered static images, automated measurements of mouth opening predicted undergraduate ratings of positive emotion in the smile sets of only one of two infants (Bolzani-Dinehart et al. 2005). In the current study, automated measurements of mouth opening were associated with more positive ratings of naturalistic (unedited) smiles among more and less experienced observers and among ratings of different types of stimuli (static images and video clips). The findings were somewhat less strong for FACS-coded measurements of mouth opening which, among parent raters, were only marginally associated with ratings of positive emotion. The results suggest that mouth opening may be a less potent predictor of positive emotion ratings than smile strength.

The BabyFACS smile intensity composite was proposed to simplify the manual measurement of infant smiles based on a priori formula uniting degree of mouth opening and smile strength (Oster 2006). This composite was consistently associated with rated positive emotion of static images. Together with similar findings from an encoding study (Segal et al. 1995) and an additional rating study (Oster 2003), this finding suggests the utility of this matrix for manual measurement of infant smiling.

Type of Rater and Type of Rating

We compared parent raters, whose experience interacting with infants might make them especially sensitive to subtle changes in infant facial expressions, with undergraduate raters (Papousek and Papousek 2002; Peterson 2001). Undergraduates and parents had similar mean ratings, and these ratings were highly associated (Mean $r > .95$, see Fig. 1). Substantively, the two types of raters produced similar results over two studies. These results support the validity of undergraduate ratings in this type of study, based on their similarity to the ratings of parents, the evolutionarily adapted recipients of infant expressions. It appears that stimuli as salient as infant smiles evoke similar responses from both more and less experienced observers.

Raters are more accurate in identifying dynamic than static adult smiles (Ambadar et al. 2005) and differences in the dynamic features of smiling affect ratings of genuineness (Krumhuber and Kappas 2005). With few exceptions (Beebe 1973a, b), however, rating studies investigating infant emotion have used static stimuli (Bolzani-Dinehart et al. 2005; Oster 2003). To capture dynamic expressive actions, we used a novel joystick interface similar to the affect dial (Gottman and Levenson 1985; Ruef and Levenson 2007) to obtain dynamic ratings perceived over the course of a smile. This procedure indicated that continuous changes in smiling influence dynamic perceptions of positive emotional intensity. Female raters rated these dynamic smile sequences more positively than male raters. The presence of this gender effect in the ratings of dynamic but not static images parallels Biele and Grabowska's (2006) finding that female students rated dynamic smiles as more emotionally intense than static smiles.

Conclusion

Infant smiles are compelling signals of positive emotion that are associated with later functional patterns of social interaction (Cohn et al. 1991; Henderson and Fox 1998; Moore et al. 2001). In this study we documented the ebb and flow of facial actions over the course of smiles. Linked changes in smile strength, eye constriction (the Duchenne marker), and mouth opening, were associated with perceptions of positive emotion. The findings suggest the potential of both automated and anatomically based measurement to illuminate how facial actions occur and express positive emotion in time.

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References

Ambadar, Z., Schooler, J. W., & Cohn, J. F. (2005). Deciphering the enigmatic face: The importance of facial dynamics in interpreting subtle facial expressions. *Psychological Science, 16*, 403–410.

Bakeman, R., & Gottman, J. (1986). *Observing interaction: An introduction to sequential analysis*. New York, NY: Cambridge University Press.

Beebe, B. (1973a). Ontongeny of positive affect in the third and fourth months of life of one infant. *Dissertation Abstracts International, 35*(2), 1014B.

Beebe, B. (1973b). *Ontogeny of positive affect in the third and fourth months of the life of one infant*. Doctoral dissertation, Columbia University.

Biele, C., & Grabowska, A. (2006). Sex differences in perception of emotion intensity in dynamic and static facial expressions. *Experimental Brain Research, 171*, 1–6.

Bolzani-Dinehart, L., Messinger, D. S., Acosta, S., Cassel, T., Ambadar, Z., & Cohn, J. (2005). Adult perceptions of positive and negative infant emotional expressions. *Infancy, 8*, 279–303.

Bowlby, J. (1982). *Attachment and loss* (Vol. 1). New York: Basic Books.

Bryk, A. S., & Raudenbush, S. W. (2002). *Hierarchical linear models: Applications and data analysis methods* (2nd ed.). London: Sage.

Carvajal, F., & Iglesias, J. (2002). The Duchenne smile with open mouth in infants with Down syndrome. *Infant Behavior & Development, 24*, 341–346.

Cohn, J., Campbell, S. B., & Ross, S. (1991). Infant response in the still-face paradigm at 6 months predicts avoidant and secure attachment at 12 months. *Development and Psychopathology, 3*, 367–376.

Cohn, J., & Kanade, T. (2007). Automated facial image analysis for measurement of emotion expression. In J. A. Coan & J. B. Allen (Eds.), *The handbook of emotion elicitation and assessment* (pp. 222–238). New York: Oxford.

Cohn, J. F., & Schmidt, K. L. (2004). The timing of facial motion in posed and spontaneous smiles. *International Journal of Wavelets, Multiresolution and Information Processing, 2*, 1–12.

Cohn, J. F., Xiao, J., Moriyama, T., Ambadar, Z., & Kanade, T. (2003). Automatic recognition of eye blinking in spontaneously occurring behavior. *Behavior Research Methods, Instruments, and Computers, 35*, 420–428.

Cohn, J. F., Zlochower, A., Lien, J., & Kanade, T. (1999). Automated face analysis by feature point tracking has high concurrent validity with manual FACS coding. *Psychophysiology, 36*, 35–43.

Dickson, K. L., Walker, H., & Fogel, A. (1997). The relationship between smile-type and play-type during parent-infant play. *Developmental Psychology, 33*, 925–933.

Ekman, P., & Friesen, W. (1978). *The facial action coding system*. Palo Alto: Consulting Psychologists Press.

Ekman, P., & Friesen, W. V. (1982). Felt, false, and miserable smiles. *Journal of Nonverbal Behavior, 6*, 238–252.

Ekman, P., Friesen, W. V., & Ancoli, S. (1980). Facial signs and emotional experience. *Journal of Personality and Social Psychology, 39*, 1125–1134.

Ekman, P., Friesen, W. V., & Hager, J. C. (2002). *Facial action coding system investigator's guide*. Salt Lake City, UT: A Human Face.

Fogel, A., Hsu, H.-C., Shapiro, A. F., Nelson-Goens, G. C., & Secrist, C. (2006). Effects of normal and perturbed social play on the duration and amplitude of different types of infant smiles. *Developmental Psychology, 42*, 459–473.

Fogel, A., Nelson-Goens, G. C., Hsu, H.-C., & Shapiro, A. F. (2000). Do different infant smiles reflect different positive emotions? *Social Development, 9*, 497–520.

Fox, N. A., & Davidson, R. J. (1988). Patterns of brain electrical activity during facial signs of emotion in 10 month old infants. *Developmental Psychology, 24*, 230–236.

Frank, M. G., Ekman, P., & Friesen, W. V. (1993). Behavioral markers and the recognizability of the smile of enjoyment. *Journal of Personality and Social Psychology, 64*, 83–93.

Gottman, J., & Levenson, R. W. (1985). A valid measure for obtaining self-report of affect. *Journal of Consulting and Clinical Psychology, 53*, 151–160.

Harker, L., & Keltner, D. (2001). Expressions of positive emotion in women's college yearbook pictures and their relationship to personality and life outcomes across adulthood. *Journal of Personality and Social Psychology, 80*, 112–124.

Henderson, H. A., & Fox, N. A. (1998). Inhibited and uninhibited children: Challenges in school settings. *School Psychology Review, 27*, 492–505.

Hess, U., & Kleck, R. E. (1994). The cues decoders use in attempting to differentiate emotion-elicited and posed facial expressions. *European Journal of Social Psychology, 24*, 367–381.

Krumhuber, E., & Kappas, A. (2005). Moving smiles: The role of dynamic components for the perception of the genuineness of smiles. *Journal of Nonverbal Behavior, 29*, 3–24.

Lavelli, M., Pantoja, P. F., Hsu, H., Messinger, D., & Fogel, A. (2005). Using microgenetic designs to study change processes. In D. G. Teti (Ed.), *Handbook of research methods in developmental psychology* (pp. 41–65). Blackwell.

Messinger, D. (2002). Positive and negative: Infant facial expressions and emotions. *Current Directions in Psychological Science, 11*, 1–6.

Messinger, D., Fogel, A., & Dickson, K. (1999). What's in a smile? *Developmental Psychology, 35*, 701–708.

Messinger, D., Fogel, A., & Dickson, K. (2001). All smiles are positive, but some smiles are more positive than others. *Developmental Psychology, 37*, 642–653.

Moore, G. A., Cohn, J. F., & Campbell, S. B. (2001). Infant affective responses to mother's still face at 6 months differentially predict externalizing and internalizing behaviors at 18 months. *Developmental Psychology, 37*, 706–714.

Moriyama, T., Kanade, T., Xiao, J., & Cohn, J. F. (2006). Meticulously detailed eye region model and its application to analysis of facial images. *IEEE Transactions Pattern Analysis and Machine Intelligence, 28*, 738–752.

Oster, H. (2003). Emotion in the infant's face insights from the study of infants with facial anomalies. *Annals of the New York Academy of Sciences, 1000*, 197–204.

Oster, H. (2006). Baby FACS: Facial action coding system for infants and young children. Unpublished monograph and coding manual. New York University.

Papousek, H., & Papousek, M. (2002). Intuitive parenting. In M. H. Bornstein (Ed.), *Handbook of parenting. Vol. 2: Biology and ecology of parenting* (pp. 183–203). Mahwah, NJ: Lawrence Erlbaum Associates.

Pedhazur, E. J. (1997). *Multiple regression in behavioral research* (3rd ed.). Wadsworth.

Peterson, R. A. (2001). College students in social science research. *Journal of Consumer Research, 28*, 450–461.

Plooij, F. (1979). How wild chimpanzee babies trigger the onset of mother–infant play – and what the mother makes of it. In M. Bullowa (Ed.), *Before speech: The beginning of interpersonal communication* (pp. 223–243). London: Cambridge University Press.

Ruef, A., & Levenson, R. (2007). Studying the time course of affective episodes using the Affect Rating Dial. In J. A. Coan & J. J. B. Allen (Eds.), *The handbook of emotion elicitation and assessment*.

Schmidt, K. L., Ambadar, Z., Cohn, J. F., & Reed, L. (2006). Movement differences between deliberate and spontaneous facial expressions: Zygomaticus major action in smiling. *Journal of Nonverbal Behavior, 30*, 37–52.

Schneider, K., & Unzner, L. (1992). Preschoolers' attention and emotion in an achievement and an effect game: A longitudinal study. *Cognition and Emotion, 6*, 37–63.

Segal, L., Oster, H., Cohen, M., Caspi, B., Myers, M., & Brown, D. (1995). Smiling and fussing in seven-month-old preterm and full-term black infants in the still-face situation. *Child Development, 66*, 1829–1843.

Stern, D. N. (1990). Joy and satisfaction in infancy. In R. A. Glick & S. Bone (Eds.), *Pleasure beyond the pleasure principle* (pp. 13–25). New Haven: Yale University Press.

Tabachnick, B. G., & Fidell, L. S. (1989). *Using multivariate statistics*. New York: Harper, Row.

Tian, Y. L., Kanade, T., & Cohn, J. F. (2002). *Evaluation of Gabor-wavelet-based facial action unit recognition in image sequences of increasing complexity*. Paper presented at the Proceedings of the Fifth IEEE International Conference on Automatic Face and Gesture Recognition, Washington, DC.

VanSwearingen, J. M., Cohn, J. F., & Bajaj-Luthra, A. (1999). Specific impairment of smiling increases the severity of depressive symptoms in patients with facial neuromuscular disorders. *Aesthetic and Plastic Surgery, 23*, 416–423.

Waldinger, R. J., Schulz, M. S., Hauser, S. T., Allen, J. P., & Crowell, J. A. (2004). Reading others' emotions: The role of intuitive judgments in predicting marital satisfaction, quality, and stability. *Journal of Family Psychology, 18*, 58–71.

Waller, B. M., & Dunbar, R. I. M. (2005). Differential behavioural effects of silent bared teeth display and relaxed open mouth display in chimpanzees (Pan troglodytes). *Ethology, 111*, 129–142.

Williams, P. L., Warick, R., Dyson, M., & Bannister, L. H. (1989). *Gray's anatomy*. Edinburgh: Churchill Livingstone.

Xiao, J., Kanade, T., & Cohn, J. F. (2003). Robust full motion recovery of head by dynamics templates and re-registration techniques. *International Journal of Imaging Systems and Technology, 13*, 85–94.