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Signal Characteristics of Spontaneous Facial Expressions: Automatic Movement in Solitary and Social Smiles

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Abstract

The assumption that the smile is an evolved facial display suggests that there may be universal features of smiling in addition to the basic facial configuration. We show that smiles include not only a stable configuration of features, but also temporally consistent movement patterns. In spontaneous smiles from two social contexts, duration of lip corner movement during the onset phase was independent of social context and the presence of other facial movements, including dampening. These additional movements produced variation in both peak and offset duration. Both onsets and offsets had dynamic properties similar to automatically controlled movements, with a consistent relation between maximum velocity and amplitude of lip corner movement in smiles from two distinct contexts. Despite the effects of individual and social factors on facial expression timing overall, consistency in onset and offset phases suggests that portions of the smile display are relatively stereotyped and may be automatically produced.

Keywords

facial expression; nonverbal communication; emotion

Facial expression researchers have stressed the role of facial expressions as signals, both of emotion and social intention (Ekman, 1992; Fridlund, 1994; Grammer, Schiefenhovel, Schleidt, Lorenz, & Eibl-Eibesfeldt, 1988; Schmidt & Cohn, 2001a). Smiles are one of the most important of human facial displays, appearing early in development, and frequently throughout the lifespan, in both solitary and social situations (Bavelas & Chovil, 1997; Cohn & Tronick, 1983; Messinger, Fogel, & Dickson, 1999; Owren & Bachorowski, 2001; Schmidt & Cohn, 2001b).

The literature describes a diversity of smiling patterns, and an exact description of what specific actions constitute the smile signal is unclear. Given the variation in appearance and temporal parameters of spontaneous smiles, it is necessary to define more clearly the portion or portions of a smile display that can be considered the primary signaling behavior, if the signaling role of smiling is to be investigated. The facial appearance of the smile with upturned lip corners as a result of *Zygomaticus major* activity, has been demonstrated to be a universal facial expression of joy across cultures (Ekman & Keltner, 1997). Ekman describes this emotional

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expression as “unbidden, quick, and short in duration” (Ekman, 1992). In contrast, reports of variable smiling displays including other associated movements emphasize variation in duration and onset and offset phases (Cheyne, 1976; Jones, 1984; Messinger et al., 1999; Otta, Abrosio, & Hoshino, 1996). In the present study, we hypothesized that a particular portion of the smile display, the smile onset, has highly consistent signaling characteristics. We demonstrated the consistency of *Zygomaticus major* activity in smile onsets originating from different contexts and we also found that offset phase, as well as the onset phase of smiles, showed consistent signaling characteristics.

Fridlund (1994) has advanced a behavioral ecological interpretation of facial expression and has argued for a central signaling role of smiles. If smiles are to be considered evolved social signals, however, it is expected that they will meet several criteria widely described in behavioral ecological descriptions of animal signaling (Schmidt and Cohn, 2001b). Evolved signaling displays are the result of selective pressures for conspicuous, stereotyped, and redundant communication (Hauser, 1996; Johnstone, 1997). These characteristics ensure the efficiency of the signal in communicating among members of a species. Stereotypy, for example, provides a reliable signal that is easily recognized across individuals and contexts, while redundancy and conspicuousness increase the likelihood of signal detection by intended recipients. These features have already been observed in the configuration of human smile displays. For example, stereotypy of facial configuration has been observed in the typical facial expressions of joy appearing across individuals and across cultures, (Ekman 1993).

In this study, we initially proposed that temporal patterning of movement in the onset of spontaneous smiles constitutes a characteristic signal within the human smile display. The smile onset provides the initial and most conspicuous change in appearance of the face as perceived by human observers (Leonard, Voeller, & Kuldau, 1991). In a study of response to facial expressions, viewers activated their own *Zygomaticus major* muscles as early as 0.30 - 0.40 seconds after viewing an image of a smile (Dimberg & Thunberg, 1998). These results suggest that observers have a propensity to respond rapidly to facial expressions. In spontaneous social contexts, this rapid reaction is most likely in response to the onset of expressions, rather than other phases of the display, since spontaneous smiles typically last for at an average of at least 3 - 4 seconds (Frank et al., 1993) and smile onsets have been reported to last at least 0.7 seconds on average (Bugental, 1986). For the purposes of producing a response in a receiver's facial muscles, therefore, the onset of expression seems likely to constitute an important facial signal. In addition, stereotypy is evident in that the upturned lip corners are found in all smile onsets (Ekman, 1993). As a display, smiling is also redundant (Bavelas & Chovil, 1997) with as many as three smiles per minute, on average, occurring in social interaction (Schmidt & Cohn, 2001b). Facial expression researchers have reported multi-peaked smiles, which can also be interpreted as multiple, redundant signals (Bugental, 1986).

In addition to *Zygomaticus major*, other facial muscles may also be active in producing variation during smiling, either by acting to suppress the movement of the lip corners or by changing the appearance of the mouth in general (Otta et al., 1996). Ekman (1985) and others have found that the activity of muscles that tend to pull the lip corners down, while they are simultaneously pulled upwards in a smile, produces a “miserable” or “masking” smile. The Duchenne marker, which is the addition of visible activity of the *Orbicularis oculi* muscle during a smile that produces wrinkling of the skin around the lateral edge of the orbit, has been identified as a marker of positive emotional experience, the “felt smile” (Ekman & Friesen, 1982; Frank & Ekman, 1997; Hess, Banse, and Kappas, 1995). In this study, potential temporal differences between smiles with and without dampening and *Orbicularis oculi* activity were investigated.

Most studies consider the components of the smile display over its entire course, or the length of phases of the smile relative to each other. They encompass both culturally variable aspects of facial motor control and universally observed facial expressions. From a perspective that considers facial expressions or displays as visible signals of emotion and intention, the characteristics that smiles have in common are a primary focus. The upward, oblique movement of the lip corners describes the core feature of the smile display, regardless of physical or emotional variation (Ekman & Friesen, 1978; Schmidt & Cohn, 2001a). We apply this type of approach to the timing of facial expressions by testing whether timing of lip corner movement is similar across different social contexts and in the presence of other facial movements. In this study, smiles from two distinct contexts, a laboratory elicited smiling condition and a smiling condition produced in a social context, were used in order to explore the level of variation in smile signals associated with differences in social context.

There have been few quantitative reports of continuous facial movement during smile onset or any other facial expression (Frank et al., 1993; Grammer, Filova, & Fieder, 1997). Leonard and her coworkers reported quantitative changes in facial movement during smile onset, but focused on the effects of rapid movement of the face on the subsequent perception of smiles (Leonard, Voeller, and Kuldau, 1991). A related group, using the same methods, assessed asymmetry of motion in smiles and other expressions, but restricted their analyses to a uniform period of 12 frames (0.40 s) during expression onset (Richardson, Bowers, Bauer, Heilman, & Leonard, 2000).

Recent advances in automated analysis of facial expression have made possible more detailed studies of particular facial movements in facial expression (Cohn, Zlochower, Lien, & Kanade, 1999; Leonard et al., 1991). With respect to timing of the phases of lip corner movement, spontaneous smile onsets (*Zygomaticus major*), are relatively rapid, and may exhibit the characteristics of automatic movement (Frank et al., 1993). Previous work on other automatic movements has shown a consistent, deterministic relationship between maximum velocity and amplitude characteristic of automatic movement (Baloh, Sills, Kumley, & Honrubia, 1975; Zuber, Stark, & Cook, 1965). These automatic motor routines are programmed and have the characteristic of reaching their goal without interruption, leading to a consistent relationship between maximum velocity of continuous movement and amplitude of movement (Brooks, 1986).

Conspicuous and stereotyped visual signals typically have consistent movement patterns, as well as a consistent configuration of features. Fridlund (1994) argued that smile displays do not belong in this category with other automatically generated signaling behaviors such as yawning, because they do not show stereotypy in intensity or time course. Although this may be true for entire smiling bouts, portions of the display may still meet the criteria for stereotyped visual signals. By focusing on the empirically defined phases of the spontaneous smile, it is possible to uncover stereotypy among smile displays that vary in other respects. We predicted that consistent movement patterns would be found in spontaneously occurring smile onsets, despite individual, configurational (presence of accompanying movements) and contextual (laboratory elicited solitary smiles vs. smiles produced in social context) variation in smiling displays. In this study, we also explored the possibility that smile onsets may also be produced stereotypically, by the action of automatically generated motor patterns. We tested the hypothesis that the onset of spontaneous smiles, as compared to other smile phases, would represent an automatically produced stereotyped signal within the smile display.

Method

Participants

Spontaneous smiles from two independent studies, a laboratory film-clip viewing context designed to elicit positive emotion (laboratory elicited or "solitary" *N* = 49; Miller, Fox, Cohn, Forbes, Sherrill, and Kovacs, 2002), and a face-to-face interview context ("social" *N* = 15; Frank & Ekman, 1997) were analyzed. Original videotaping and study procedures involving human participants were approved by the Institutional Review Boards of the University of Pittsburgh and the University of California, San Francisco.

Contexts for smiling were selected to maximize social differences between conditions in order to investigate the role of context in the diversity of smiling displays (Fridlund 1994). Participants in the laboratory elicited (solitary) smile condition were selected from a larger group of participants recruited for a study of risk for depression conducted at the University of Pittsburgh Affect Analysis Group Laboratory. These participants watched a film clip of a comedy routine while seated alone in a laboratory room during the course of a study designed to measure facial activity and other psychophysiological measures of emotional response. Solitary participants were videotaped in a session that included monitoring of facial muscle activity with sensors attached to the face (see Figure 1.) Care was taken to ensure that participants were as comfortable as possible with respect to sensor placement. Also, the right lip corner was used in analysis, minimizing the effects of the sensors for midfacial activity, as these were placed on the left of the participant's face.

Smiles elicited in a social context were obtained from participants interviewed and videotaped in an earlier study by Frank and Ekman (1997). Participants in the interview task (smiles elicited in a social context) were recruited from the community for a study of facial expression during deception (Frank and Ekman 1997). During the interview task, these participants were seated across from the interviewer, who asked them about their opinions regarding various political topics. All participants were instructed to convince the interviewer of their opinions, whether falsely held or not. There were incentives provided in this study for producing a credible account, heightening the normal demands of social interaction. The choice of the political interview as a source of naturalistic social smiling was made because this is a good example of the face-to-face context, which varies socially (following Fridlund 1994) from our laboratory elicited solitary smiles.

Videotaping procedures for these independent studies were quite similar. Resulting videotape images were of participants in similar, seated pose, with similar focal range and lighting. From these two groups, individual participant smiles were selected from the first analyzable image sequence, either following the first joke in the solitary context, or during conversation in the social context. Seventeen of 68 solitary participants originally considered for analysis did not smile following the first joke of the film clip, and four of 22 interview (social) participants considered for analysis did not smile at all during the interview period, and were therefore excluded. One of the solitary participants suffered from a neurological condition that affected facial movement and was excluded. An analyzable smile sequence was defined as one in which the person faced relatively straight forward during the sequence, smiled, and kept the mouth uncovered. One of the solitary participants was not analyzable because she covered the right lip corner with her hand during smiling. Three of 22 social participants were not analyzable because of excessive head movement, covering of the right lip corner, or positioning with the head turned to the side. The resulting smile sequences (*n* = 49 solitary and *n* = 15 social) were analyzed using computerized facial feature tracking (Cohn et al., 1999; Tian, Kanade, & Cohn, 2001) and included men (*n* = 23) and women (*n* =26) from the solitary (laboratory elicited) context (73% Euro-American, 16% African–American, 8% bi-racial or multi-racial, and 2%

Asian-American.) Social participants whose smiles were analyzed included only men (n = 15; 73% Euro-American, 13% African-American, and 13% Asian American).

Six of the solitary participants had either experienced diagnosed depression in adulthood, or depression or anxiety in childhood. An additional eight solitary participants were full or half siblings of probands with childhood onset depression or anxiety consistent with the original recruitment goals of the larger study of risk for depression (Miller et al., 2002). None of the solitary participants included in the present study reported significant current depressive or anxiety symptoms on the day of data collection, as measured by Beck Anxiety Inventory (Steer & Beck, 1997) and Beck Depression Inventory (Beck, Steer, & Garbin, 1988; Steer & Beck, 1997) scores below clinically significant cut off values. All solitary participants were therefore included in the analysis. The possible effects of a family or personal history of depressive illness on current smiling behavior were tested and results are reported in the results section below.

Social (interview) participants' data were obtained from an archive of coded videotape data, and did not include a description of psychological variables (these participants were not screened for depressive or other symptoms).

Materials

Videotaped Sequences—Videotape sequences were manually coded for activity of facial muscles affecting lip corner movement (Facial Action Coding System (Ekman and Friesen, 1978). Sequences considered for analysis included the first (if any) smile observed during the two minute clip of the interview context, and the smile (if any) following the solitary participant's exposure to the first joke in a film clip of a Chris Rock comedy routine. All sequences selected for analysis were coded for *Zygomaticus major* activity (action unit 12) by consensus of at least two certified FACS coders. Agreement between two certified FACS coders on a subset of 27 participants was 0.91 overall for visible muscle activity of *Orbicularis oculi* (action unit 6), *Zygomaticus major* (action unit 12), *Depressor anguli oris* (action unit 15), and *Mentalis* (action unit 17) (Ekman & Friesen, 1978). Sequences were then digitized at 30 frames per second, producing a set of sequential 640 × 480 pixel uncompressed images (custom software, Matrox Meteor II image capture board, Pentium II PC with 400 MHz processor and 384 MB RAM). It should be noted that video sequences were truncated in the interview condition within the first five seconds after the initial appearance of the smile display because of continued lip movement associated with talking following the end of *Zygomaticus major* activity. In the solitary condition, video sequences were truncated at the end of *Zygomaticus major* activity observed, or at the beginning of the second joke in the comedy routine (approximately 10 seconds after the initial joke stimulus). Although the length of these digitized sequences does not allow for analysis of extremely long smiling bouts during which *Zygomaticus major* activity is maintained to some degree, it does allow for the analysis of spontaneous smiles that are similar in length to the average 4 - 6 seconds reported for spontaneous smiles (Frank, Ekman, and Friesen, 1993). Lip corner movement data from each smile was then analyzed in these digitized image sequences using computerized facial feature tracking (Cohn et al., 1999).

Computerized facial feature tracking and face analysis

Lip and eye corners, as well as twelve other facial feature points, were hand marked in the initial digitized image frame of each sequence by the first author. Feature contours were generated by the feature tracking program, based on these initially marked feature points (see Fig. 1; Tian et al., 2001). Only measurements relying on lip and inner eye corner feature positions are described in this report. Pixel coordinates of the right lip corner in subsequent frames, relative to the initial center point of the lip corners in the initial frame, were automatically obtained using the Lucas-Kanade algorithm for feature tracking (Lien, Kanade, Cohn, & Li, 2000). This initial center point was recalculated automatically by the program in each frame relative to the stable inner eye corner feature points, allowing for accurate measure in the case of small head movements. Note that this calculated “initial center point” remains stable with respect to the image frame, not the current position of the lips, and thus is a suitable anchor point for the measurement of lip corner movement.

The right lip corner position, measured as r :

$$r=\sqrt{x^2+y^2}$$

was recorded for each frame of the sequence (see Fig 1.). A similar approach to facial feature measurement, using manually obtained feature point position values, was followed by VanSwearingen and colleagues (VanSwearingen, Cohn, & Bajaj-Luthra, 1999). Reliability for automated feature tracking was assessed using the values of r obtained from two independent observations, based on the initial placement of feature tracking points by two different researchers. Measurements of r produced from these independent trackings were highly correlated over a series of 200 - 300 frames in each of 5 image sequences, indicating that feature tracking recorded similar movement patterns, even when initial feature point placement varied. The correlation of r values ranged from r=0.94 to r=1.00, comparable to tracking reliability values obtained in other studies using the same automated system (Cohn et al., 1999;Wachtman, Cohn, VanSwearingen, & Manders, 2001).

For the sake of comparison among participants, individual participant's r values were standardized on the initial width of each participant's mouth in the initial image. This standardized value is hereafter referred to as “radius”. Standardization resulted in a starting frame radius value of 0.5 (half of the distance from center of mouth to right lip corner) for each participant. Radius values were collected for each frame in the video sequence, forming a time series of lip corner position. Results for time series data were smoothed, using the T4253H algorithm [1] (SPSS Inc., Chicago IL, 1999) (see Figures 2 and 3 for examples of automatically tracked smiles and smoothed radius values). The longest continuous increase in lip corner position (radius value) was obtained for each participant. This period of lip corner movement was defined as the smile onset (see Figures 2 and 3 for examples of beginning and ending frames of smile onsets and ending frame of smile offsets). Duration and amplitude of lip corner movement during this onset period were calculated, based on the smoothed data. The duration of lip corner movement was measured as the difference in time (s) between the last and first frames of the onset, and the amplitude of lip corner movement was measured as difference in values of lip corner movement between beginning and end of longest continuous increase. The longest continuous decrease in lip corner position (radius value) was also obtained for each participant. This period of lip corner change was defined as the smile offset, and the peak duration of the smile was defined as the distance between ending onset frame and beginning offset frame[2]. One female solitary participant was excluded at this point in the analysis, because there was no offset of lip movement within the ten second video sequence (no offset before subsequent joke viewed in the comedy routine).

[1]The T4253H smoother starts with a running median of 4, which is centered by a running median of 2. It then resmooths these values by applying a running median of 5, a running median of 3, and hanning (running weighted averages). Residuals are computed by subtracting the smoothed series from the original series. This whole process is then repeated on the computed residuals. Finally, the smoothed residuals are computed by subtracting the smoothed values obtained the first time through the process. This is sometimes referred to as T4253H smoothing (SPSS Inc., Chicago IL,1999).

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Results

Preliminary Analyses

The inclusion of individuals with a history (although no current diagnosis) of depression or anxiety in the solitary sample introduced the possibility that some variation in smiling parameters may be attributable to a history of psychiatric diagnosis, or familial relationship with someone previously diagnosed. Potential effects were compared by assessing the relation between previously diagnosed (n = 6), sibling of individual previously diagnosed (n = 8), or control participant status (n = 35) on the following temporal parameters within the solitary sample: onset, peak, and offset duration, and onset and offset amplitude. None of these parameters were significantly affected by psychiatric status (all p values > 0.05), and data from all solitary participants was considered in further analyses.

Characteristics of Smile Onsets, Peaks, and Offsets

Smile onset duration averaged less than one second in both social ($\bar{X}$ = 0.67s, SD = 0.24) and solitary contexts ($\bar{X}$ = 0.52s, SD = 0.31) and was not significantly different in length in these two contexts ($t(61) = -1.75$, $p = 0.09$). The amplitude of lip corner movement, measured as change in values of radius (lip corner movement) between beginning and end of longest continuous increase, was significantly different between contexts ($\bar{X}$ = 0.050, SD = 0.07 in the solitary context and $\bar{X}$ = 0.150, SD = 0.09 in the social context; $t(62) = -3.97$, $p = 0.001$).

Smile peak duration also differed between solitary and social smiles, with the peaks of laboratory solitary smiles lasting significantly longer ($t(61) = 3.80$, $p = 0.001$). Offset duration did not differ between contexts ($t(61) = -.0002$, $p = 0.99$). Offset amplitude also did not differ significantly between contexts ($t(61) = -2.78$, $p = 0.02$). Significance was set at $p<0.01$, using the Bonferroni correction for multiple tests (N = 5) of context effects on smile parameters. This result, however, represents a strong trend toward larger amplitude offsets in the social context ($\bar{X}$ = 0.04, SD = 0.05 in the solitary context; $\bar{X}$ =0.10, SD = 0.08 in the social context).

Effects of Other Facial Movements—Visually observable *Orbicularis oculi* activity, previously associated with spontaneous smiles of enjoyment (Frank et al., 1993) occurred in 23 smiles (n =18 (37%) solitary condition, n =5 (33%) social condition). There was not a significant difference in the presence of this marker in the two different contexts ($\chi^2(1) = .058$, $p = .81$), therefore spontaneous smiles from the two contexts were analyzed together for effects of *Orbicularis oculi*. The presence of *Orbicularis oculi* activity was not significantly related to either amplitude or duration of smile onset ($t(61) = 1.10$, $p = 0.28$ for amplitude; $t(61) = 1.21$, $p = 0.23$ for duration). *Orbicularis oculi* activity also did not significantly affect duration of smile peak or amplitude of smile offset. The duration of smile offset, however, was related to the presence of *Orbicularis oculi* activity, with longer offsets in these smiles ($\bar{X}$ = 0.67s, SD = 0.38s for smiles with *Orbicularis oculi* activity; $\bar{X}$ = 0.39s, SD = 0.19s for smiles without *Orbicularis oculi* activity; $t(61) = 3.30$ $p=0.003$). The Bonferroni correction was applied for multiple tests of significance, with significance set at $p<0.01$.

Dampening movements that have been described as potential modifiers of *Zygomaticus major* activity (and lip corner appearance during smiles) were relatively rare and began following the initial frame of smile onset. Only seven participants displayed *Mentalis* (n = 4 solitary), or *Depressor anguli oris* (n =3 solitary) activity during the smile onset. Of those

[2]Note that the peak and offset phases of the smiles in Figures 2. and 3. may not necessarily represent smile phases that have previously been described schematically (Ekman and Friesen 1978). This is a direct consequence of the way that the terms onset, peak, and offset have been operationalized in this study. Because peak is defined as the *period* between quantitatively determined onset and offset, its duration varies in length and may last no longer than one frame (see Figure 2.). Additionally, there may be small increases or decreases in lip corner radius during the peak phase (see Figure 3.).

seven participants with dampened smiles, five were control participants with no history of depressive symptoms. Furthermore, the percentage of control participants with dampened smiles (14%, or five of 35 participants) was similar to the percentage of participants with either a history of psychiatric illness or siblings of those with a history of psychiatric illness (15%, or two of thirteen participants). These dampening actions appeared after the visually coded onset of *Zygomaticus major* activity, and had no apparent effect on amplitude or on duration of onset ($t(61)$ =-1.78, p = 0.08 for amplitude, $t(61)$ = 0.17, p = 0.87 for duration). Effects of dampening movements approached significance for duration of peak, where peaks of smiles with dampening movements lasted 1.87 s on average and peaks of smiles without dampening movements lasted 0.86 s on average ($t(61)$ = 2.54, p = 0.01) and were significant for duration of offset, where offsets of smiles with dampening movements lasted 0.79 s on average, while offsets of smiles without dampening movements lasted 0.45 s on average ($t(61)$ = 2.9, p = 0.005). There was no significant effect of dampening movements, however, on amplitude of smile offset ($t(61)$ = 0.73, p = 0.47). The Bonferroni correction applied for multiple tests of significance, with significance set at $p<0.01$.

Relation between velocity and amplitude of lip corner movement

Despite differences in smile onset amplitude across contexts (solitary smiles showed less lip movement on average), maximum velocity of lip corner movement was closely related to the amplitude of the movement (see Figure 4). For smile onsets, this relation was best fit by the power curve $y = 50.5\ x^{1.4}$ ($R^2 = 0.87$). Individual regression analyses of social and solitary smile onset data sets showed similar fit, with curves $Y = 79.3x^{1.5}$ ($R^2 = 0.82$) and $y = 26.5x^{1.3}$ ($R^2 = 0.82$) as the best fit curves for solitary (laboratory elicited) and social (interview) smile onsets, respectively.

Amplitude of lip corner movement was also related to maximum velocity of lip corner movement during smile offsets. The relation between maximum velocity and offset amplitude was best fit by the power curve $y = 11.8\ x^{1.1}$ ($R^2 = 0.82$). Individual regression analyses of offsets in solitary and social smile offsets were best fit by curves $y = 22.8\ x^{1.3}$ ($R^2 = 0.77$) and $y = 7.4\ x^{1.0}$ ($R^2 = 0.83$), respectively.

Discussion

We found that the onset phase of spontaneous smiles reported here has consistent temporal characteristics, despite many differences in the contexts and conditions under which these smiles were elicited (see Figures 2 and 3). With respect to social context, a similar duration of onset was found in both solitary (laboratory elicited) and social (interview) contexts, and average smile onset duration overall ($\bar{X}$=0.56s) was similar to that found in other studies using manual and computerized facial feature tracking methods (Frank et al., 1993; Leonard et al., 1991; Richardson et al., 2000). Onset amplitude did vary with social context, with larger amplitude in onsets in the social condition.

Also consistent with an interpretation of smiles as stereotyped signals, was the high degree of temporal consistency found in offsets of social and solitary smiles. Offset characteristics were temporally consistent across social contexts, with no significant difference in offset duration or amplitude between social and solitary contexts. Context had an effect on the duration of peak phase, with peaks of solitary smiles lasting significantly longer than those of social smiles.

The presence of other facial movements during smiling had no significant effect on the duration or amplitude of smile onsets, suggesting that this phase of *Zygomaticus major* activity represents a consistently produced signal across conditions in which smiling occurs. The presence of *Orbicularis oculi* activity was not related either to amplitude or duration of smile onset across contexts. Amplitude of smile offsets was also unrelated to *Orbicularis oculi* activity, although the duration of offset was longer in smiles with *Orbicularis oculi* activity. Duration of peak phase was unaffected by the presence of *Orbicularis oculi* activity. The relative lack of suppressing movements in the smiles investigated was similar to reported characteristics of spontaneous smiles (Frank et al., 1993; Richardson et al., 2000). Where smiles were found to have dampening or suppressing movements, this also did not affect either duration or amplitude of smile onsets, although dampening movements significantly affected other phases of the smile display (particularly by lengthening smile offset duration). Overall, lip corner movement in both onsets and offsets was relatively stable despite contextual variation in social context and other facial movements.

In this study, we also explored the possibility that smile onsets would show evidence of production by automatically generated motor patterns. The strength of the curvilinear relation between amplitude and maximum velocity of lip corner movement during smile onset (see Figure 4.) supported the hypothesis of smile onsets as automatically produced facial movements resulting from the initiation of automatic motor programs in the central nervous system. An unexpected finding was that the maximum velocity and amplitude of smile offset also fit this "automatic movement" pattern (Figure 5.). Because downward movement of the lip corners in offset is the result of both gravity and the action of other muscles besides *Zygomaticus major*, as well as the relaxation of that muscle, this pattern does not result primarily from the action of a single muscle. Consistency of movement in the offset phase, although probably not the result of an automatically generated motor program, indicates the likelihood of a signaling role for this phase of the smile as well. If automatic movement cannot explain the similarity of the velocity/amplitude relation in onsets and offset, then this may be due instead to an adaptation of these signals to the perceptual constraints of receivers.

It is important to note that the variation reported in other studies of spontaneous smiles was not absent here, yet this variation did not affect the velocity/amplitude relation in the lip corner movement during smile onset. Spontaneous smile onsets in the social condition (interview) were larger on average than smiles during the solitary context, consistent with earlier reports of social effects on smiling (Fridlund, 1994; Kraut & Johnson, 1979). Thirty-six percent of smiles (n = 18 solitary and n = 5 social) were also accompanied by the movement of the skin around the eye. Interestingly, there was not a higher degree of visible *Orbicularis oculi* activity in the laboratory elicited smiles, even though this procedure was designed to elicit amusement. Possible restriction of movement due to the placement of facial sensors in these participants could explain this result, although it is also possible that participants simply lacked truly felt amusement/joy for responses to this particular joke in the comedy routine[3]. Because the peak duration of smiles in the solitary sample was significantly longer than that in the social sample where no sensors were used, restriction of movement in this context seems unlikely. Additionally, this was only the first joke of the comedy routine, and there is the possibility that smiles not involving *Orbicularis oculi* activity were followed by a change over time to include such activity, in a conversion from non-Duchenne to Duchenne smiling (Messinger et al., 1999).

The presence of smile dampening movements during spontaneous smiles was also observed, but only in a relatively low proportion of smiles, and only in the laboratory elicited solitary context, contrary to expectations that social expressions might be more likely to be suppressed or dampened than are expressions produced in private. One possible explanation for this result is that certain individuals may adopt individualized patterns of smiling that regularly include these movements (Cohn et al., 2002; Schmidt and Cohn, 2001a). A history of psychiatric illness in some of the laboratory elicited solitary participants or their siblings is unlikely to be an

[3]In the solitary (laboratory elicited) context, only overall participant response, rather responses to individual jokes in the comedy video clip were assessed. This procedure, though standard, precludes the identification of brief moments of truly felt amusement/joy.

explanation for dampening, as dampening was just as likely to appear in smiles of control participants with no history of psychiatric illness.

Limitations of the present study include the absence of cross-cultural data, although the participants are multi-ethnic, and include both sexes. Also, the right lip corner only is sampled in these data. The literature reports mixed findings on the question of spontaneous smile laterality, but generally smiles are thought to be either symmetric (Frank et al., 1993) or slightly stronger on the left (Kowner, 1995; Skinner & Mullen, 1991). It could be that the data from the right lip corner support hypotheses investigated here, while data from the left corner would not. The similarity between the duration of smiles in the present study, however, and that in other studies using different methods, automated or manual, suggests that these results might generalize to a variety of contexts (Ekman and Friesen, 1982; Frank, et al. 1993).

Overall, the results support the conceptualization of the spontaneous smile as a facial expression with multiple temporal components including relatively stable movement patterns during both onset and offset. The data support the interpretation of the spontaneous smile onset as a signal, possessing consistent timing even in the presence of other facial movements. In Leonard and colleagues' work on perception of spontaneous smiles, it was suggested that the signal phase of the smile is defined as the period of rapid upward lip movement, rather than the absolute position of the lip corners, since the perceptions of the smile changed the most between frames in which the largest facial changes were observed quantitatively (Leonard et al., 1991). Dimberg and Thunberg's work also suggests that perceptual mechanisms are specialized for rapid response, less than one second after viewing a facial expression (Dimberg & Thunberg, 1998). If the typical spontaneous smile in a social situation lasts approximately 3-4 seconds (Frank et al., 1993), this means that observers begin to smile in response before the initial observed smile has completed its offset, implying that the first part of the expression is the leading signal. The consistency of the amplitude/velocity relation across social contexts, however, also points to a signaling role for the offset of the display, although offset duration varied with the inclusion of other facial movements in the display.

There are important implications of these results for further studies of facial expressions, and smiles in particular. There has been some apparent disagreement over the primary signaling function of facial expressions, and smiles in particular, as to whether or not they have a primarily social or emotional function (Fridlund, 1994; Jakobs, Manstead, & Fischer, 1999). These two perspectives represent complementary, rather than alternative approaches to smiling and facial expression in general, with results reported here addressing primarily the signaling characteristics of facial expressions produced in both social and laboratory elicited contexts.

Based on the results of the present study, we suggest a new approach to the analysis of smiling displays with particular emphasis on empirically defined onset and offset phases as units of analysis. Other signals that co-occur with *Zygomaticus major* activity can be considered separately, depending on the hypotheses to be tested. For example, tracking lip corner movement automatically will no doubt reveal the presence of multiple consecutive lip corner raises during many continuous smile displays. Although the presence of such multiple peaked smiles has long been acknowledged, these displays may be better conceived of as multiple smile signals occurring in a bout of smiling, rather than as a single, multi-peaked smile (Bugental, 1986). This approach to smiling could also be employed, for example, to understand the finding that both small and large intensity smiles produce positive affiliative responses. In this case, the timing or frequency of smile onsets or offsets may have been the key factor in producing affiliation, not the overall intensity (Hess, Blairy, & Kleck, 2000).

If the timing of smiles is consistent across contexts, then smile onset duration, as well as the relation between maximum velocity and amplitude of smile onsets and offsets could function as an indicator of the spontaneity and naturalness of smiling (Ekman, 1992). Disturbances in this pattern of automatic movement could be important in distinguishing pathological facial movement from normal variation in smiling (Gray & Tonge, 2001; Pedersen & Schelde, 1997; Wachtman et al., 2001), or to suggest that involuntary facial expression is unaffected in the presence of conditions such as congenital blindness (Galati et al., 1997). Clearly, further work establishing the role of this relation in the offset phase, as well as in onset is needed, given our results for the consistency of this relation in smile offsets.

In contrast to the suggestion that most facial expressions do not fit the criteria for stereotyped conventional signals, we suggest that a focus on the onset and offset phases of smiles, and other facial expressions as well, will reveal a set of facial signals with stereotyped timing (Fridlund, 1994). We predict that the timing of these signals as well as the basic movements will be constant across cultures, consistent with evolutionary hypotheses of facial signaling (Grammer et al., 1988; Owren & Bachorowski, 2001; Schmidt & Cohn, 2001b). Elaborations on the smile itself, either through additional movements (addition of *Orbicularis oculi* activity), or by suppression of *Zygomaticus major* movement (due to the activity of opposing muscles) between onset and offset, are likely characteristic of different human groups, according to their cultural display rules, and a multitude of other social and emotional factors.

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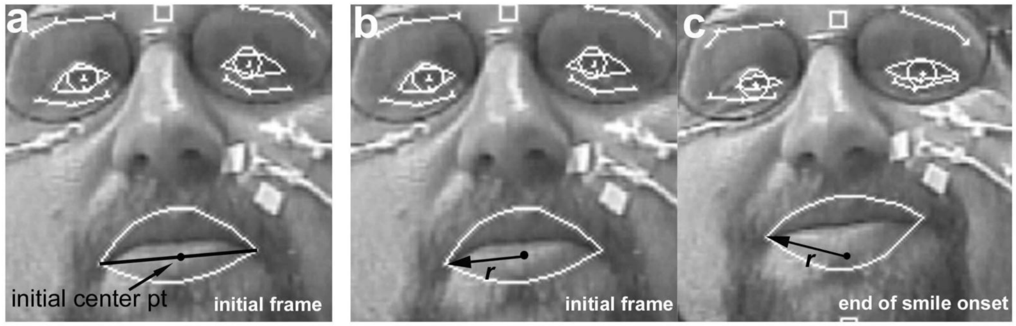

Figure 1.
Measurement of Right Lip Corner Movement (r)
a. Initial center point, located midway between lip corners in the initial frame, is used to anchor the radius (r). This initial center point is recalculated automatically in each frame, relative to the stable inner eye corner feature points, allowing for accurate measure in the case of small head movements.
b-c. r is the distance (in pixels) between the initial center point and the right lip corner in each frame

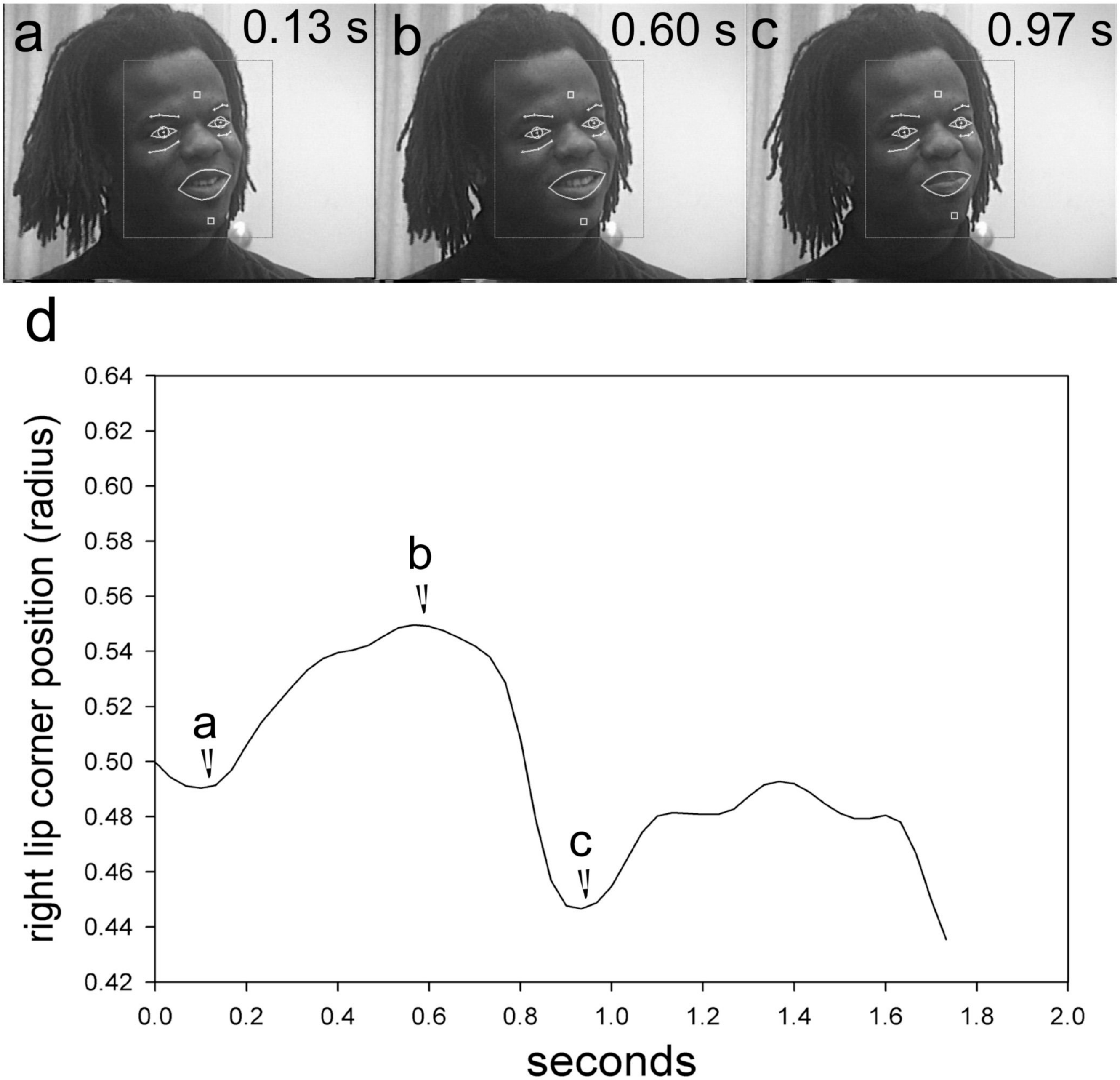

Figure 2.
Computerized facial feature tracking of lip corner movement in the Social (Interview) Context
a. beginning of smile onset
b. end of smile onset, beginning of smile offset
c. end of smile offset (see definition of offset phase in methods section)
d. Right lip corner movement during smile (change in radius)

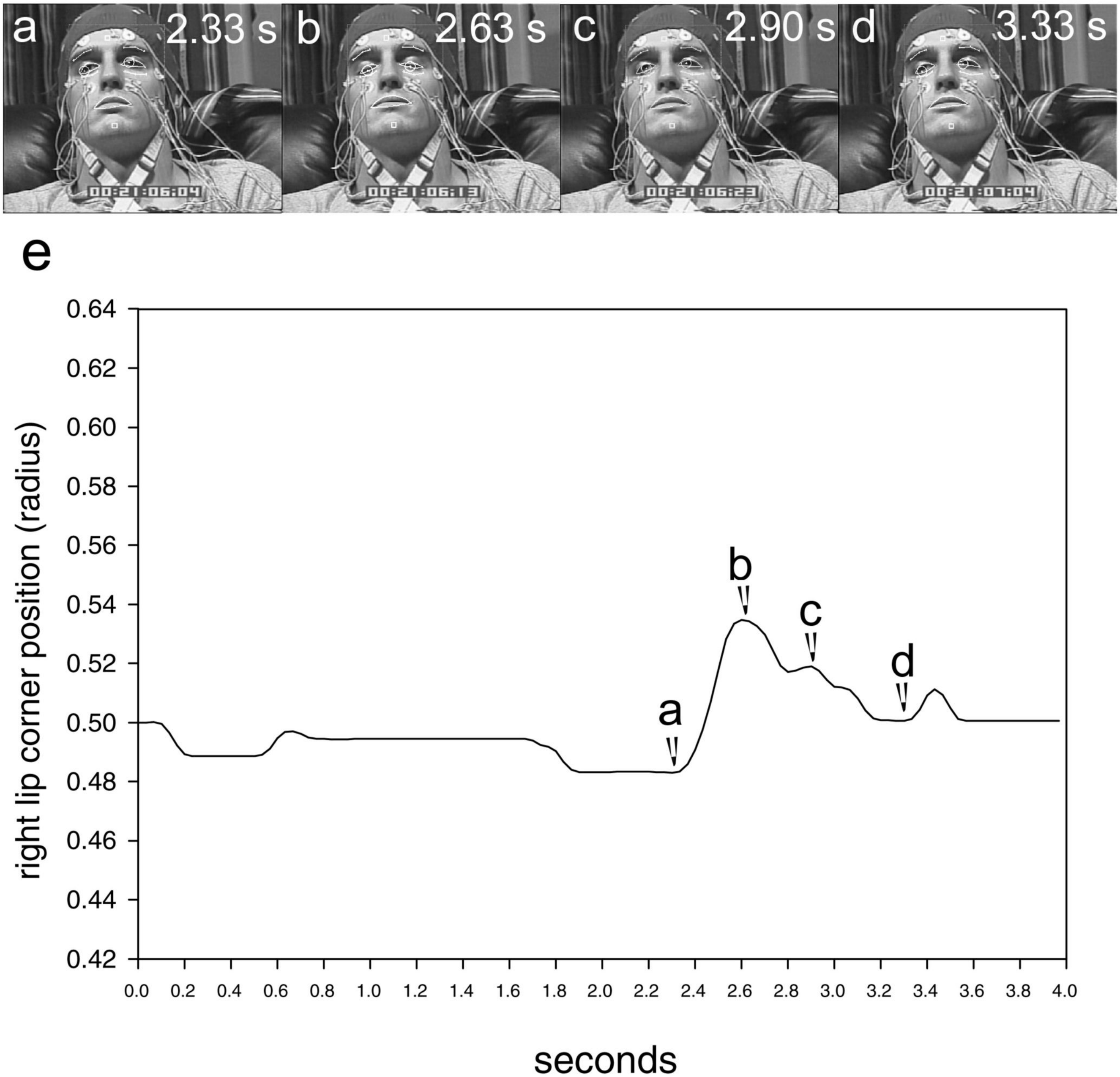

Figure 3.
Computerized facial feature tracking of lip corner movement in the Solitary (Laboratory elicited) context
a. beginning of smile onset
b. end of smile onset
c. beginning of smile offset (see definition of offset phase in methods section)
d. end of smile offset
e. right lip corner movement during smile (change in radius)

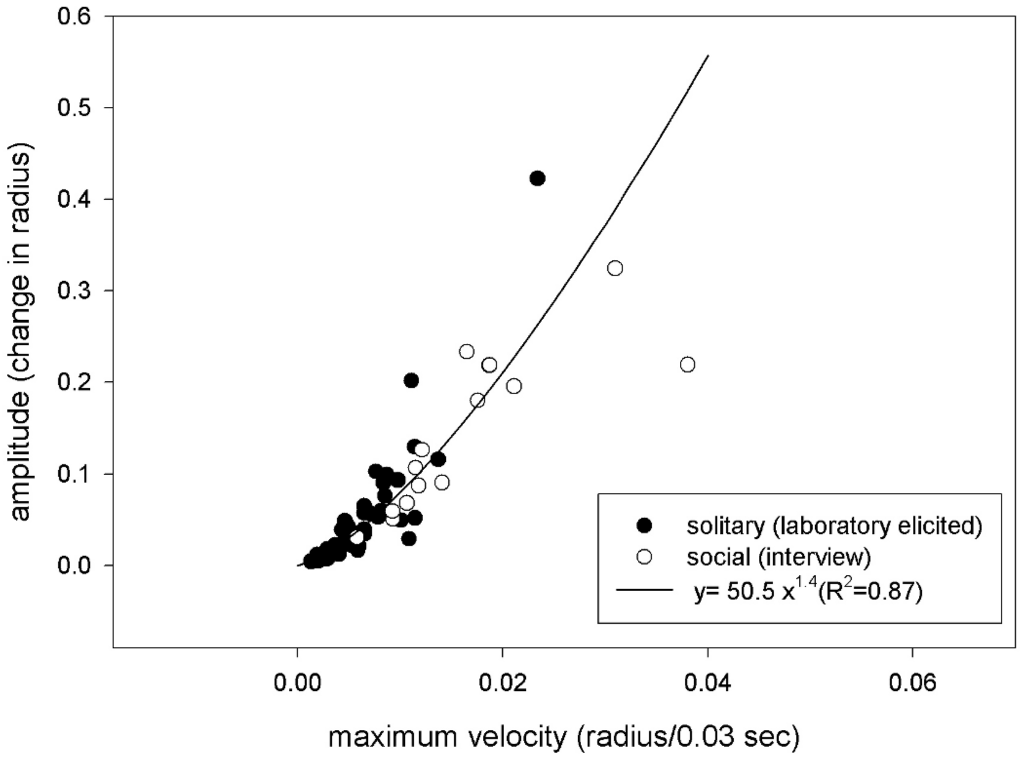

Figure 4.
Relation Between Maximum Velocity and Amplitude of Spontaneous Smile Onsets

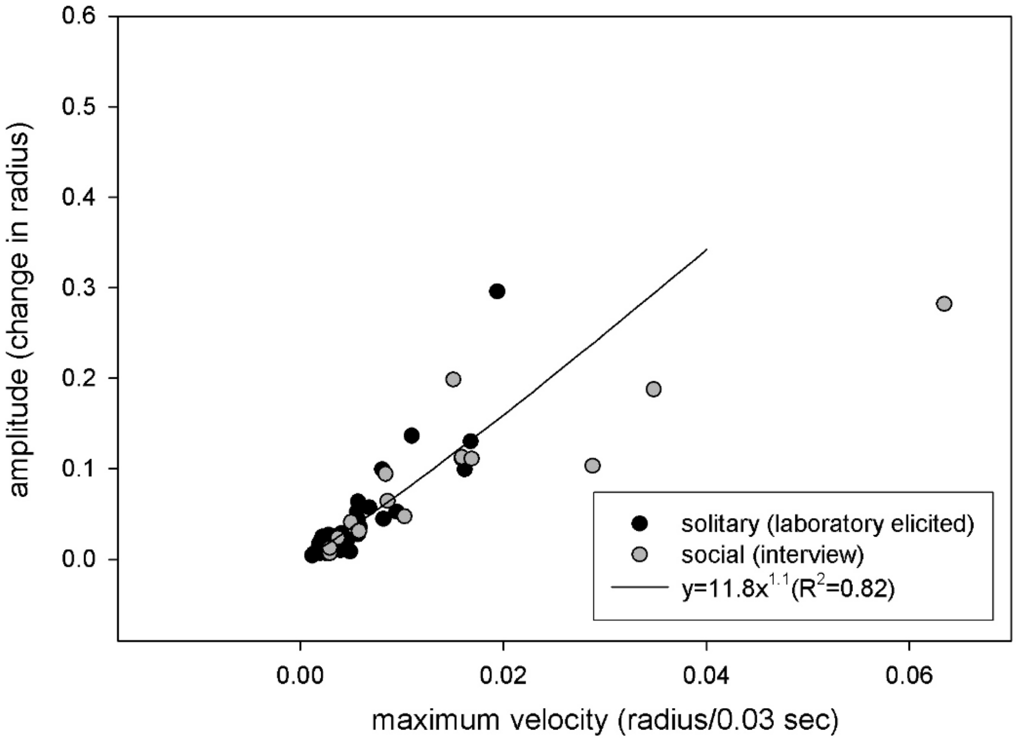

Figure 5.
Relation Between Maximum Velocity and Amplitude of Spontaneous Smile Offsets