**Smile (but only deliberately) though your heart is aching:
Loneliness is associated with impaired spontaneous smile mimicry**

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ABSTRACT

As social beings, humans harbor an evolved capacity for loneliness—perceived social isolation. Feelings of loneliness are associated with aberrant affective and social processing, as well as deleterious physiological dysregulation. We investigated how loneliness affects spontaneous facial mimicry (SFM), an interpersonal resonance mechanism involved in social connection and emotional contagion. We used facial electromyography (fEMG) to measure activity of the zygomaticus major (“smiling muscle”) and corrugator supercilii (“frowning muscle”) while participants viewed emotional stimuli, such as video clips of actors expressing anger, fear, sadness, or joy, and emotional IAPS images. We also measured self-reported loneliness, depression, and extraversion levels. Evidence for SFM was found in greater fEMG activity of the zygomaticus and corrugator to positive and negative emotions, respectively. However, individuals reporting higher levels of loneliness lacked SFM for expressions of joy. Loneliness did not affect deliberate mimicry activity to the same expressions, or spontaneous reactions to positive, negative, or neutral IAPS images. Depression and extraversion did not predict any differences in fEMG responses. We argue that impaired automaticity of “smiling back” at another—a faulty interpersonal resonance response—represents a pervasive behavioral mechanism that likely contributes to negative social and emotional consequences of loneliness and may facilitate loneliness contagion.

KEY WORDS

Loneliness, facial mimicry, mimicry, electromyography (EMG), fEMG, smile(s), social isolation, isolation, social connection.

INTRODUCTION

Loneliness: Mechanisms and Consequences

Humans are social beings with a fundamental need to belong (Baumeister & Leary, 1995). As such, they harbor an evolved capacity for loneliness (Cacioppo, Cacioppo, & Boomsma, 2014). Loneliness—*perceived* social isolation—is an aversive state designed to motivate social (re)integration (Cacioppo & Hawkley, 2009). Chronic loneliness, however, is associated with global affective and motivational impairments. Longitudinally, loneliness predicts lower subjective well-being (VanderWeele, Hawkley, & Cacioppo, 2012) and higher depression (Cacioppo, Hawkley, & Thisted, 2010). Loneliness is also associated with physiological impairments and carries strong mortality risk (Luo et al., 2012). Unfortunately, loneliness has proven relatively resistant to clinical reduction interventions (Masi et al., 2011), possibly because it is contagious within social networks (Cacioppo, Fowler, & Christakis, 2009). In short, loneliness seriously affects individual and public health, constituting what some have described as a social epidemic (Will, 2018).

Thus it is critical to better understand the *social mechanisms* that maintain—and spread—loneliness. An influential model proposes that loneliness is maintained by aberrant processing of social stimuli that underlie positive social interactions (Cacioppo & Hawkley, 2009). But what is the specific mechanism? One intriguing possibility is dysregulation of emotional contagion—the spreading of positive affective states amongst interaction partners (Hatfield, Cacioppo, & Rapson, 1993). So, inspired by the proposed model, we raise the novel possibility that loneliness is linked to impaired sharing of positive emotions that aid social connection and relatively spared sharing of negative emotions. This possibility fits with reports that loneliness is negatively correlated with empathy (Beadle et al., 2012), which requires a capacity to adaptively respond with positive emotion in social situations (Zaki & Ochsner, 2012). Similarly, loneliness is also associated with difficulties in positive emotional regulation (Kearns & Craven, 2016).

Because lonely people overtly express desire for camaraderie, the idea that loneliness involves reduced sharing of positive social emotions is not obvious. However, chronic loneliness implies failed attempts at constructive social interactions and maintained focus on negative interactions (Cacioppo & Hawkley, 2009). This suggests potential dysregulation of subtler, more implicit behavioral mechanisms that contribute to social connection. This possibility, which we investigate here, could involve a dissociation between spontaneous and deliberate emotion sharing mechanisms. Interestingly, such a dissociation has been found in two very different clinical populations with different tasks—psychopathic offenders during an empathy task (Meffert et al., 2013) and autistic individuals during a facial expression imitation task (McIntosh et al., 2006). Without instructions for deliberate engagement, both populations failed to recruit spontaneous emotion sharing mechanisms. Thus, it is possible that lonely people also show such atypical response patterns, particularly for positive emotions that facilitate social connection.

Facial Mimicry and Social Connection

One classic way to study spontaneous emotion sharing is through mimicry. Mimicry is the process of copying, or “mirroring” the actions of a model, which contributes to social bonding and group formation (Chartrand & Lakin, 2013; Kavanagh & Winkielman, 2016). Facial mimicry, in particular, is a ubiquitous process through which emotions are shared and understood by interaction partners (Korb et al., 2014; Winkielman et al., 2016). Furthermore, emotional contagion *covertly* spreads from person to person through *spontaneous facial mimicry*

(SFM; Dezechache et al., 2013). In addition, socially-relevant personality traits positively correlate with lab-measured SFM, which predicts subsequent social interaction quality over 10 days (Mauersberger et al., 2015). Finally, people high in empathy show more spontaneous mimicry of smiles and frowns (Sonny-Borgstrom, 2016) and individual differences in such traits and states modulate SFM (Seibt et al., 2015).

Interestingly, recent reviews have emphasized that mimicry of *smiles* plays an especially important role in social interactions (Niedenthal et al., 2016.) Smiles are intrinsically rewarding (Shore & Heerey, 2011), signaling affiliative intent, and *smile mimicry* is a component of social reciprocity (Hess & Bourgeois, 2010). In fact, mimicry of smiles is facilitated by conditioned anticipation of social rewards (Heerey & Crossley, 2013) and inhibited by lower trust in the interaction partner (Fujimura & Okanoya, 2016). Weaker smile mimicry was also shown to predict lower authenticity judgments of smiles themselves (Korb et al., 2014), which could undermine positive social interaction. Since poor expectation of social reward is a suggested mechanism of loneliness (Cacioppo & Hawkley, 2009), one could expect such individuals to have reduced smile mimicry.

In sum, research demonstrates that facial mimicry—especially spontaneous smile mimicry—influences the tone of social interactions, emotion perception, empathy, and represents an avenue for positive emotional contagion (or lack thereof). Therefore, it is critical to understand how this fundamental social process is related to loneliness.

Present Study

In the present study, we tested if loneliness is characterized by a dissociation between spontaneous and deliberate facial mimicry. We used a standard paradigm in the mimicry literature where participants view facial expressions and their reactions are recorded with facial electromyography (fEMG). These reactions are recorded while participants simply observe these expressions (spontaneous mimicry) and next, when they intentionally imitate the face (deliberate mimicry). This design allows for testing if any mimicry differences are due to more general motoric, motivational, or attentional issues (McIntosh et al., 2006). We also assessed participants' spontaneous reactions to standard affective stimuli – specifically negative, neutral, and positive IAPS images that have been shown to elicit spontaneous smiling and frowning (Larsen et al., 2003). The reactions to IAPS images (which are mostly non-social) offer a control for whether any mimicry impairments are unique, or reflect more general affective processing (a distinction highlighted in the autism literature, see Hsu et al., 2017). Thus, we assessed i) spontaneous mimicry, ii) deliberate mimicry, and iii) spontaneous facial responding across three distinct experimental sessions, within all participants.

METHOD

Participants

Thirty-five undergraduate students—30 female and 5 male—at the University of California, San Diego received partial course credit for study participation (Age: $M = 21.22$; $SD = 1.57$). They had normal or corrected-to-normal vision and a clean face without makeup or facial hair (for fEMG measurement). All participants were included in all analyses, unless otherwise specified. The research protocol was reviewed and approved by the University of California, San Diego Institutional Review Board. Written informed consent was obtained from all participants.

Before the fEMG sessions, participants completed a survey. The survey collected basic demographic information as well as three scales measuring loneliness, depression, and

personality. Loneliness was assessed with the R-UCLA Loneliness scale (Russell, 1996), a 20-item measure that assesses feelings of social connectedness (e.g., “How often do you feel that your relationships with others are not meaningful?”). Participants respond on a 4-point Likert scale from 1 (never) to 4 (often), indicating the frequency with which they feel this way. Total scores range from 20-80, with higher values reflecting greater loneliness. Depression was measured using Beck Depression Inventory (Beck et al., 1996), with scores ranging from 0-60. One item about suicide was removed. Personality variables were gauged with the Ten-Item Personality Inventory (Gosling et al., 2003), as we were interested in extraversion. High scores on this measure indicate high extraversion (range = 2-14).

We conduct analyses treating loneliness as a continuous factor, which replicate with treating loneliness as a categorical factor, which we also use for results presentation. For this, we conducted a median split to form into two groups: “Lonely” ($n = 17$; $M = 49.2$; $SD = 5.2$) with values of 43 and above, and “Connected” ($n = 18$; $M = 36.0$; $SD = 5.6$) with scores of 42 and below.

Procedure and Design

Participants first completed informed consent and the survey. Next, they were prepared for fEMG measurement (details below). Once electrodes were successfully attached, participants were asked to “remain still, but relaxed” while completing tasks on the computer. The experiment progressed in three consecutive sessions: 1) spontaneous mimicry, 2) deliberate mimicry, and 3) affective images. In all sessions, trial progression was self-paced, as participants were required to press the ‘c’ key to continue and encouraged to rest briefly between trials, if desired. During Sessions 1 and 2, participants were presented the same stimuli: 5000ms video clips of four individuals (two female, two male) each making facial expressions of anger, fear, joy, and sadness. The videos began with a neutral face and ended with full emotional expression. Stimuli were preceded by a fixation cross for 1500ms, and followed by 2000ms of blank screen. These 16 video clips were presented in two consecutive randomized blocks (32 trials) for both sessions. Clips were from the Amsterdam Dynamic Facial Expression Set (Van der Schalk et al., 2013).

Figure 1. Task Design.

During the spontaneous mimicry session, participants were instructed to 1) press the spacebar as soon as each video began, as their response time (RT) would be measured, and 2) pay attention to the videos since they would be asked about them later. During the deliberate mimicry session, participants were instructed to try to make the same expression as the person in the video, hold it as long as they do, and then relax.

Following Sessions 1 and 2, the experimenter entered the testing room and gave instructions that Session 3 would involve viewing images and making ratings about the perceived negativity and positivity in the image. They were given printed instructions and verbal examples of how to use the affect matrix scale (provided in supplementary materials), which allows for ratings of both negative and positive valence (Figure 1). Stimuli for Session 3 were static images from the IAPS database of positive (9), negative (9), and neutral (6) affective valence. Images were each presented once (24 trials) for 6000ms, after a fixation cross for 3000ms and followed by a blank screen for 3000ms. Immediately after viewing each image, participants made ratings of its perceived positivity and negativity on the affect matrix. In addition, they made a ratings of perceived arousal of the images. For Session 3, specific images, presentation parameters, and rating scales were identical to a previous study that reliably elicited spontaneous positive and negative fEMG affect (Larsen et al., 2003). See supplementary materials for further detail and IAPS image codes. Stimuli were presented on a 17-inch monitor. The survey was administered online via Qualtrics (Qualtrics, Utah, USA). All experimental tasks were presented using E-Prime 2.0 (Psychology Software Tools, Pennsylvania, USA).

Following Session 3, participants made affect matrix ratings of each expression video from Sessions 1 and 2, also on its perceived positivity and negativity. After all sessions, participants were given an exit survey that included inquiries about our purpose/hypothesis of the study. No one accurately identified the link between loneliness and facial mimicry.

Data Acquisition and Reduction

Facial EMG was measured by pairs of 1-cm (2.5 cm square) electrodes on the left side of the face, over the regions of zygomaticus major (cheek) and corrugator supercillii (brow), according to fEMG processing standards (Tassinari and Cacioppo, 2000). For the zygomaticus major muscle, the first electrode was placed in the middle of an imaginary line between the lip corner at rest, and the point where the jaws meet (approximately near the ear lobe), the second electrode a collar width (approximately 1 cm) posterior to the first. For the corrugator supercillii muscle, the first electrode was placed right above the left eyebrow, on an invisible vertical line from the inner corner of the eye up, the second a collar width posterior to the first (following the eyebrow arch). AcqKnowledge software along with Biopac hardware (Version 4, Biopac Systems, Goleta, CA) was used to acquire the EMG signal. The amplified EMG signals were filtered online with a low-pass of 500 Hz and a high-pass of 10 Hz, sampled at a rate of 2000 Hz, and then integrated and rectified using Mindware EMG software (version 2.52, MindWare Technologies Ltd., Ohio, USA). Data were analyzed using Matlab (version R2012b, Mathworks, Natick, MA) and R (version 1.1.442, R Core Team, Boston, MA). Data were first averaged within 500ms epochs across a trial (i.e., 10 data points for a 5 second trial). Outliers greater than 3 standard deviations from the participant mean were filtered out from Session 1 (2.48% of 11200 observations) and 3 (3.05% of 10080 observations) data. Next, data were standardized within participant and within each muscle, using as baseline averaged activity for 1000ms before each trial. Thus, we calculated baseline-corrected activity for each participant and each muscle to each stimulus by subtracting baseline activity from each data point.

Finally, we averaged baseline-corrected EMG activity (i.e., a z-score) within 500 ms epochs across trials for each participant, muscle, and stimulus. For each participant, we analyzed 320 (32*10) trials each for SFM and IMI, 288 (24*12) trials for IAPS. The above procedure was conducted separately on data from each session, but for Session 2 data we did not remove outliers (since we expected extreme activations for deliberate mimicry).

Manipulation Check Results

For Session 1, we analyzed response times (RTs; i.e., latency to press the spacebar to indicate the start of each video) for each emotion in order assess attentional engagement with the stimuli. Overall, participants responded to 95.5% of all video presentations. We tested the likelihood of making a response using a logistic regression model with predictors of emotion (categorical) and loneliness (continuous). There were no significant effects (all $ps > .250$). Similarly, we tested RTs using a repeated measures ANOVA with predictors of emotion and loneliness. There was a marginal effect of emotion: $F(3,96) = 2.365, p = .076$, which reflected slightly longer RTs to Anger. There was no interaction with or main effect of loneliness ($ps > .250$). These results suggest that all participants were sufficiently attentive to expression videos during Session 1.

Participants were highly accurate in identifying the target emotion in the expression videos: 98.4% correct. In addition, they reliably rated Anger, Fear, and Sadness as highly negative, and Joy as highly positive on the affect matrix. Loneliness scores did not predict significant differences in valence ratings on expression videos. They did predict lower arousal ratings, but this was not specific to any particular emotion (i.e., no interaction). Participants rated the affective images with expected valence (Negative, Neutral, Positive). Loneliness did interact with image type, predicting less extreme ratings for Negative and Positive images. Loneliness did not predict significant differences in arousal ratings for affective images. Valence and arousal ratings and statistics are presented in supplementary materials.

In summary, all participants, regardless of loneliness level, evaluated the affective specificity (emotion type) and intensity (valence, arousal) of all stimuli similarly. Though loneliness did predict subtle differences in ratings, these findings do not track with fEMG results. As these manipulation checks suggest little impact of loneliness on overt emotional perception of all stimuli, we next test if spontaneous or deliberate affective facial reactions to these stimuli are altered by (higher) loneliness.

RESULTS

fEMG Data

For each muscle, we conducted repeated measures ANOVA with emotion (anger, fear, joy, sadness) as a within-subjects categorical factor and loneliness as a between-subjects continuous factor. As outlined above, we also treated loneliness as a categorical factor (based on a median split) in some cases for ease of presentation and interpretation. Importantly, we replicated key analyses using linear mixed effects modelling (see supplementary materials).

Deliberate Mimicry

Deliberate mimicry was assessed in Session 2, after spontaneous mimicry, but we present these results first to demonstrate the validity of the fEMG measurements and effectiveness of video stimuli in the mimicry protocol. We analyzed zygomaticus activity during deliberate mimicry with the repeated measures ANOVA described above. There was a main effect of emotion: $F(3,99) = 233.01, p < .001, \eta^2_{\text{partial}} = .876$. As shown in Figure 2, zygomaticus activity to joy was higher than to any other emotion (all simple contrasts of joy and other emotions: $ps < .001$). There was no main effect of loneliness ($p = .121$) and no interaction of emotion and loneliness ($p > .250$).

Identical analysis on corrugator activity found a main effect of emotion: $F(3,99) = 143.87, p < .001, \eta^2_{\text{partial}} = .813$. As shown in Figure 2, corrugator activity to negative emotions was higher than to joy (all simple contrasts of joy and other emotions: $ps < .001$). There was no main effect of loneliness ($p > .250$) but there was an interaction of emotion and loneliness: $F(3,99) = 3.87, p = .012, \eta^2_{\text{partial}} = .105$. As shown in Figure 2, this interaction reflects that higher loneliness is associated with relatively reduced (compared to the connected group) activity to anger and relatively enhanced activity to fear.

These effects demonstrate that participants robustly mimicked, with their smiles and frowns, different emotional expressions. We show that 1) emotion-related zygomaticus and corrugator activity was accurately measured, and 2) loneliness is not strongly associated with differences in deliberate facial muscle engagement for expressing emotion.

Figure 2. Average Deliberate Mimicry Activity to Facial Expressions. Significant emotion differences are noted by brackets and error bars represent SEM.

Spontaneous Mimicry

Spontaneous mimicry was assessed in Session 1, when participants first observed emotional expression videos. Using the above repeated measures ANOVA, we analyzed zygomaticus activity and there was no main effect of emotion ($p > .250$) or loneliness ($p > .250$). There was, however, an interaction of emotion and loneliness: $F(3,99) = 3.46$, $p = .019$, $\eta^2_{\text{partial}} = .095$. Simple effect tests to diagnose this interaction revealed a significant difference in group responses to joy ($p = .05$). As shown in Figure 3, lonely people did not spontaneously mimic smiles, while connected people did; higher loneliness is associated with impaired smile mimicry.

Next, we analyzed corrugator activity and found a main effect of emotion: $F(3,99) = 3.51$, $p = .018$, $\eta^2_{\text{partial}} = .096$. As shown in Figure 3, corrugator activity decreased (i.e., relaxed from baseline level) in response to joy, and was sustained in response to negative emotions. This resulted in significant differences between joy and anger ($p < .001$), sadness ($p < .001$), and fear ($p = .001$). There was no main effect of loneliness on corrugator reactivity ($p > .250$) and no interaction of emotion and loneliness ($p > .250$).

Figure 3. Average Spontaneous Mimicry Activity to Facial Expressions. Significant group differences are noted by * and error bars represent SEM.

Since we found evidence of differential responses to emotion in both muscles, we combined the datasets for zygomaticus and corrugator activity. We ran the same repeated measures ANOVA as above and added muscle (zygomaticus, corrugator) as a within-subjects categorical factor. There were no main effects of emotion ($p > .250$), loneliness ($p > .250$), muscle ($p > .250$), or significant 2-way interactions (all $ps > .250$), besides a marginal interaction of emotion and muscle ($p = .070$). However, we found a 3-way interaction of emotion, loneliness, and muscle: $F(3,99) = 3.29$, $p = .024$, $\eta^2_{\text{partial}} = .091$. This reflects the pattern of activity in both muscles in response to at least one emotion varying as a function of loneliness.

Dissociation of Spontaneous and Deliberate Smile Mimicry and Temporal Dynamics

The above analyses revealed differences in spontaneous mimicry to smiles as a function of loneliness. To gain insight into the temporal dynamics of these facial reactions, we plotted average activity during 500ms periods in reaction to smiles using a categorical between-subjects factor for lonely and connected groups. Figure 4 shows that the connected group demonstrated a standard smile mimicry pattern over time, with zygomaticus activity gradually increasing and corrugator activity gradually decreasing. However, in the lonely group the activity of both muscles remain relatively flat. Statistically, this pattern resulted in an interaction between muscle (zygomaticus, corrugator) and group (lonely, connected): $F(1,33) = 7.22$, $p = .011$, $\eta^2_{\text{partial}} = .180$. For more specific time points, simple contrasts showed that for the connected group

there are statistical differences between muscles at timepoints of 2500ms ($p = .001$), 3000ms ($p = .007$), 3500ms ($p = .003$), 4000ms ($p = .009$), and 4500ms ($p = .002$), and 5000ms ($p = .006$). But in the lonely group, both responses are blunted; loneliness is associated with impaired spontaneous smile mimicry in both the zygomaticus and the corrugator, even at time points where they diverge (all $ps > .23$).

This pattern of differences in spontaneous reactions diverges strikingly from the dynamics of deliberate smile mimicry, also shown in Figure 4. Here, both groups intentionally mimicked smiles with identical magnitude and timing, with both muscles. This comparison emphasizes that impaired smiling activity in the lonely group occurs only for *spontaneous* mimicry, instantiating the dissociation from deliberate responses. Thus we added mimicry type as a categorical predictor to the above ANOVA, resulting in a 3-way interaction of group, muscle, and mimicry type: $F(1,33) = 4.80$, $p < .036$, $\eta^2_{\text{partial}} = .127$.

Figure 4. Loneliness is associated with impaired spontaneous, but intact deliberate, mimicry of smiles. In both plots, we plotted average muscle activity for both Zygomaticus and Corrugator during 500ms periods. Loneliness is associated with reduced activity of both muscles during spontaneous smile mimicry but not differences in temporal dynamics or intensity of deliberate smile mimicry.

Combined Spontaneous/Deliberate Response to Smiles

A useful way to illustrate the dissociation in connected versus lonely group reactions to smiling videos is to compute a ratio of the deliberate to the spontaneous response. This ratio, which we call “spontaneous mimicry potential” (SMP), represents the proportion of one’s possible smiling response is recruited spontaneously. We computed a SMP score for each participant by dividing the average spontaneous response by the average deliberate response to each specific smile video, and then averaged those within-subject. A score of 1.0 represents spontaneous responses that equals a participant’s deliberate response, and values closer to 0 indicate relatively weak spontaneous smile mimicry. This methodological approach, analogous to normalization via Maximum Voluntary Contraction, is often favored in psychophysiology because it gives more meaning to EMG values (Tassinari & Cacioppo, 2000). Furthermore, it provides another way to control for individual differences in electrode placement, muscle size and tone, and idiosyncratic preferential differences for specific stimuli (e.g., smiling more to a particular male or female model than others). We plotted SMP computed for each participant against their loneliness score. As depicted in Figure 5, as loneliness increases, spontaneous smiling mimicry potential decreases, $r(33) = -.42, p = .012, CI: [-0.66— -0.10]$.

Figure 5. Loneliness is negatively correlated with Spontaneous Mimicry Potential (SMP).

Spontaneous Reactions to Emotional IAPS Images

We analyzed muscle activity to valenced negative, neutral, and positive images. Similar to the analyses for spontaneous and deliberate mimicry sessions, we conducted a repeated measures ANOVA with a within-subjects categorical factor of valence (negative, neutral, positive) and a between-subjects continuous factor of loneliness.

For zygomaticus activity, there was a main effect of valence: $F(2,66) = 5.07, p = .009, \eta^2_{\text{partial}} = .133$. As shown in Figure 6, participants smiled to positive images more than neutral and negative ones. The differences between smiling to positive versus negative pictures were significant at the following timepoints: 1000ms, $p = .007$; 1500ms, $p = .005$; 2000ms, $p = .021$; 2500ms, $p = .049$; 3000ms, $p = .029$; 3500ms, $p = .232$; 4000ms, $p = .169$; 4500ms, $p = .106$; 5000ms, $p = .077$; 5500ms, $p = .077$; 6000ms = .052. Importantly, there was no main effect of

loneliness ($p > .250$), or an interaction of valence and loneliness ($p > .250$). This suggests that spontaneous smiling to differently-valenced images is not affected by loneliness level.

For corrugator activity, we found a main effect of valence: $F(2,66) = 18.28, p < .001, \eta^2_{\text{partial}} = .356$. As shown in Figure 6, participants frowned more to negative images than neutral or positive ones. There was no main effect of loneliness ($p > .250$), and no interaction of valence and loneliness ($p > .250$). The differences between frowning to negative versus positive pictures were significant at these meaningful timepoints: 1000-3500ms, all $ps < .001$; 4000ms, $p = .002$; 4500ms, $p = .001$; 5000-5500ms, $p < .001$; 6000ms = .001.

These results replicate those of Larsen et al. (2003), demonstrating similar spontaneous smiling and frowning reactions to the same subset of IAPS images. Importantly, our results indicate that loneliness is not associated with differences in spontaneous smiling and frowning responses to the images. It is also worth noting that these images were selected for valence content. As such, many of them are non-social (contain no humans) and those containing humans depict them without direct eye gaze, compared to the direct emotional expression videos used in Sessions 1 and 2.

Figure 6. Affective Images Reliably Cause Smiling and Frowning Reactions. Loneliness was not associated with differences in reaction to Negative, Neutral, or Positive images.

Depression and Extraversion Not Associated with SFM Differences

Loneliness is often related with other constructs, such as depression and extraversion. As expected, loneliness was correlated with depression ($r(33) = .44, p = .008, 95\% \text{ CI: } [0.12—0.67]$) and extraversion ($r(33) = -.60, p < .001, 95\% \text{ CI: } [-0.33—-0.78]$). Therefore, we conducted the same repeated measures analyses as above with adding depression or extraversion as a between-subjects continuous factor, instead of loneliness. These analyses revealed no differences in spontaneous zygomaticus mimicry as a function of depression or extraversion, or interactions with emotion (all $ps > .250$). Similarly, we found no differences in deliberate zygomaticus mimicry as a function of either construct (all $ps > .250$), or interactions between emotion and depression ($p = .122$) or extraversion ($p > .250$).

Data posted:

https://osf.io/wv7gu/?view_only=c289e618970943f4876afc08c3472c7d

DISCUSSION

The primary finding of our study is that higher loneliness is associated with selective impairment of spontaneous, but not deliberate, mimicry of smiles. This association was not found in mimicry of negative emotions (anger, fear, sadness) and loneliness was also not associated with different spontaneous smiling or frowning reactions to affective images.

Additional data from our manipulation checks address the level at which spontaneous smile mimicry breaks down—attentional, perceptual, or motor. We found that response times to the expression videos during the spontaneous session did not differ as a function of loneliness, suggesting that attentional engagement was not an issue. In addition, our findings cannot be explained by differential perception of the stimuli, since loneliness did not predict any differences in valence ratings of the smile videos. Arousal ratings were reduced by higher loneliness, but this was the case for all of the expression videos. Finally, since temporal dynamics and intensity of deliberate smile mimicry were not affected by loneliness (Figure 4), simple motor production cannot explain our results. See online supplementary materials for more details.

These findings suggest that, at least at a gross level, attentional, perceptual, and explicit evaluative processes did not differ as a function of loneliness; the smile videos appear adequately perceived by all participants to enable spontaneous smile mimicry. However, this response was not generated in lonely individuals—suggesting atypical implicit affective processes underlying empathy and imitation, as have been associated with two very different clinical groups—individuals with psychopathy (Meffert et al., 2013) and autism (McIntosh et al., 2006).

To our knowledge, this is the first study presenting differences in facial mimicry associated with loneliness. It is useful to speculate on the larger implications of these findings. Given the salubrious social value of smiles (Niedenthal et al., 2016), and particularly returning a smile, lack of mimicry may send an asocial—or even antisocial—signal and undermine social connection. Indeed, this could be one behavioral mechanism that maintains chronic loneliness, fulfilling the proposed “behavioral confirmation processes” (Cacioppo & Hawkley, 2009). It may also reflect a physiological instantiation of the reduced positive emotional regulation tendencies recently linked to loneliness (Kearns & Creaven, 2016)—i.e., impaired social smiling could negatively impact positive reappraisal of social situations. It is also possible that impaired spontaneous smile mimicry and intact mimicry of negative emotions may jointly contribute to lower empathy present in loneliness (Beadle et al., 2012). That is, reduced automatic smile mimicry could undermine positive emotion recognition, contagion, and appraisal.

Within an interacting social network, impaired spontaneous smiling in social situations may inhibit the spread of positive emotions and contribute to the process of loneliness contagion (Cacioppo, Fowler, & Christakis, 2009). Smiles are spontaneously mimicked even when consciously unseen (Dezecache et al., 2013), which suggests implicit mechanisms for monitoring and mimicking social signals. If the transmission mechanism—mimicry—becomes impaired, as in loneliness, social *disconnection* may follow—ultimately fueling loneliness contagion. Given the rewarding nature of smiles (Shore & Heerey, 2011), the relative *lack* of smile transmission could undermine social connection in pervasive ways. For example, 1st person (“was I awkward?”) and 2nd person (“they were awkward”) appraisals of a dissatisfactory interaction may facilitate alienation and ostracism of the lonely person, potentially increasing loneliness within and across individuals. Lower smile mimicry has been found for interaction partners proven to be untrustworthy (Fujimura & Okanoya, 2016), and the cognitive maintenance model

for chronic loneliness suggests implicit hypervigilance of social threat, and essentially, a sense of social mistrust Cacioppo & Hawkley, 2009).

Converging evidence that dysregulation of these processes can undermine social connection may come from empathy, given its partial reliance on emotional contagion for facilitating constructive social responses (Zaki & Ochsner, 2012). Interestingly, self-reported empathy has been found to moderate the rewarding effect of facial mimicry—we tend to like people who mimic us, but higher empathy makes this effect stronger (Hsu et al., 2017). Since loneliness is negatively correlated with empathy (Beadle et al., 2012), it may also degrade felt social benefits of being mimicked. If lonely people aren't mimicking smiles and aren't adequately benefiting from others mimicking their expressions, they are both not 1) promoting social connection, and 2) not feeling connected. This work also converges with reports of reduced SFM associated with low empathy (Sonny-Borgstrom, 2016) and expands on individual differences that modulate SFM (Seibt et al., 2015).

Considerations and Conclusion

Our fEMG measure of spontaneous smile mimicry has been associated with quality of real-world interactions outside of the lab. For example, fEMG smile mimicry predicts social judgments like authenticity (Korb et al., 2014) and indices of actual subsequent social interactions (Mauersberger et al., 2015). Future studies could improve the ecological validity of our paradigm using dyadic interactions, and it is also important to assess causation—does loneliness cause impaired smile mimicry, or vice versa?

To our knowledge, this is the first study to demonstrate a relationship between loneliness and (spontaneous) facial mimicry. Our discovery of an impaired social “resonance” response builds on the maintenance model of chronic loneliness (Cacioppo & Hawkley, 2009), filling in a hypothesized, but never tested, node of behavioral confirmation that sustains social disconnection. In addition to implicit hypervigilance for social threat, loneliness may incorporate implicit *hypovigilance* for enacting social reward. Since the most effective loneliness reduction interventions address maladaptive social cognition (Masi et al., 2011), impaired smile mimicry may represent a new target. Further, increasing social awareness of this association may encourage greater empathy for people who don't return smiles (and may be lonely), helping to strengthen social networks. Taken together, our results suggest that lonely people are more likely to be *happy for you* (intact spontaneous smiling to positive social scenes) than *happy with you* (impaired spontaneous smiling to another's direct smile). Given the serious problem of loneliness in society (Will, 2018) and its danger to health (Luo et al., 2012), more research on how it presents in everyday social interactions is useful for greater understanding and treatment of the condition, ourselves and each other.

AUTHOR CONTRIBUTIONS

All authors contributed equally to the study concept and design. Testing, data collection, and data analysis was performed by AJA under the supervision of PW. AJA drafted the manuscript and PW provided critical revisions. All authors approved the final version of the manuscript.

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