UNIVERSITY OF CALIFORNIA SAN DIEGO

Some Body to Love: Intrapersonal and interoceptive components of social connection

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by

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The dissertation of Andrew J. Arnold is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

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DEDICATION

First, I dedicate this dissertation to my parents:

thanks to my mother for instilling within me a sense of emotional curiosity and motivated social awareness and compassion, and

thanks to my father for instilling within me a sense of intrapersonal discovery with nature, music, sports, and the overall craft of life.

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~ Thanks ~

EPIGRAPH

If you want to awaken all of humanity,
then awaken all of yourself.
If you want to eliminate the suffering in the world,
then eliminate all that is dark and negative in yourself.
Truly, the greatest gift you have to give is that
of your own self-transformation.

Lao Tzu

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ABSTRACT OF THE DISSERTATION

Some Body to Love: Intrapersonal and interoceptive components of social connection

by

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As inextricably social beings, humans harbor (perceptions of) quality social connection as a vital homeostatic need. Our evolved fundamental need to belong drives much of our emotion, perception, and cognition, since quality social connection is required for optimal physiological and psychological functioning. Research on loneliness—perceived social isolation—reveals widespread physiological degradation and increased mortality risk when loneliness persists, situating social connection as a core component of psychosocial health. Loneliness, pervasive and dangerous, is a growing public health concern, yet it has proven difficult to ameliorate. Loneliness underlies many illnesses and more research on its mechanisms and frailties is urgently needed. Research on interoception—perception, regulation, and appraisal of bodily states—has recently surged driven by recognition of interoceptive mechanisms supporting emotional clarity, with promise of improving clinical disorders and psychosocial health. The burgeoning field of "social interoception" has just begun to examine interoception in loneliness,

and our research represents some of the first studies on interoceptive mechanisms supporting social connection. However, what comprises perceptions of connection? Does quality social connection depend, in part, on a sense of intra-personal integration, clarity, or "connection"? This dissertation addresses these questions by focusing on a range of intra-personal and interoceptive mechanisms supporting social connection.

Chapter 1 assesses how different types of comparisons—intra-personal and social—impact perceptions of loneliness, using mixed methodology across diverse populations. Chapter 2 investigates physiological responses in loneliness using facial electromyography (fEMG) to assess spontaneous smiling and frowning activity during emotional perception. Chapter 3 addresses intra-personal affective correlates of loneliness using meta-analysis on 17 samples of cross-sectional survey data, highlighting the role of interoceptive body trust.

Altogether, this dissertation indicates that the common experience of loneliness is associated with maladaptive social cognition, behavior, and emotional processing. Interoception may represent "intra-personal connection" which impacts perceptions and fulfillment of quality social connection. Further investigations of interoception in affective social neuroscience, clinical psychology, and social connection will benefit from this research.

INTRODUCTION

On April 19th, 2022, the entire crowd at Liverpool's stadium applauded for an uninterrupted minute—not for the home team, but for an opposing player, Manchester United star Cristiano Ronaldo. Cristiano was not present for the game because just a day prior, his newborn baby son had died. Following Liverpool's 4-0 victory, Liverpool coach Jurgen Klopp explained the phenomenon of his entire stadium cheering for the bereaved opponent: "My moment of the game was the seventh minute when the whole stadium showed pure class, so many things are much more important in life than football. We feel for Cristiano and his family."

Imagine how Cristiano, worldwide sports icon and billionaire, must have felt from this unexpected show of support and compassion from his fierce rivals, following his tragic interpersonal loss so close to home. What was that feeling that permeated the Liverpool stadium to warm the hearts of Cristiano and his family, and millions around the world hearing of this story? To be sure, this soccer icon was not socially "connected" to the thousands of fans expressing support for his social loss, but that "heart-warming feeling" that is "much more important" than business, or professional rivalry, is a core aspect of humanity.

We all need to feel adequately socially connected, understood, and supported to thrive. And despite his elite status, Cristiano was enduring a universally tragic interpersonal tragedy, and the "mob" of humanity displayed compassion. This quality of social connection, and how we come to assess, define, and achieve it, is the core topic of this dissertation: "Some Body to Love: Intrapersonal and interoceptive components of social connection". Key themes throughout include subjective perception—a constructed model underpinned by unconscious processing and

appraisal mechanisms—and a singular organism with idiosyncratic needs, which may be more or less accurately perceived, and/or acted upon.

Intrapersonal Psychosocial Health Nested within a Social World

What do people need to be healthy and happy? The longest-running longitudinal study on health and well-being at Harvard suggests that after controlling for genetic and lifestyle factors, quality, lasting relationships are the strongest predictor for health and well-being throughout life (Waldinger, 2015). These robust empirical results align with Abraham Maslow's (1943) influential clinical observations and his "Hierarchy of Needs," which posits a pyramidal hierarchical structure upon which humans can strive for self-fulfillment and growth. At the base of the pyramid are simply physiological and safety needs—indeed "higher" needs often cannot be adequately fulfilled without these basic needs of the self as a foundation. The third largest tier of the pyramid then is social—belonging and love needs, which comes before personal esteem, cognitive, aesthetic, and spiritual needs. This framework situates the need for quality social connection as central for human motivation and self-fulfillment, which may operate with even more primacy than other needs such as for status and mastery. A more recent term—psychosocial health—neatly comprises four critical areas: mental, emotional, social, and spiritual. Also echoing Maslow, contemporary integrative health approaches in medicine and clinical science utilize this framework to define an individual as a necessarily dynamic being with multidimensional needs, embedded within a social environment. Many integrative health approaches then, for example, incorporate alternative health practices such as meditation or yoga, emotion-targeted therapeutic techniques, and a holistic view of the human as an embodied being situated in a (perceived or imagined) social context.

Primacy of Social Connection and Evolved Capacity for Loneliness

The universal human proclivity to connect, express interest, understanding, and support for one another—to recognize and honor our shared human emotional experience in the midst of inevitable suffering, sickness, and death—is indispensable for individual and collective survival. Quality social connection is a vital, homeostatic need for humans, and while we vary in the amount (e.g., number of confidantes) or type (e.g., professional, romantic, familial) of connection required, no one of us can survive or make meaning alone. Importantly, assessing one's current quality of social connection is a necessarily subjective affair—it is the feeling of social connection that matters for health and psychological functioning more than any objective measures of connectedness (Cacioppo & Patrick, 2008). This is best demonstrated by studies showing that sustained loneliness—perceived social isolation—predicts physiological and psychological degradation over and beyond objective measures of social support like number of friends (Rico-Uribe et al., 2018; Luo et al., 2012, Holt-Lunstad, 2018). Research on loneliness was revolutionized by John Cacioppo and colleagues (2009), who reconceptualized loneliness as an adaptive capacity, a "social pain" that should motivate social (re)connection to resolve its aversive nature. This view helped reduce cultural and scientific stigma of loneliness as a moral or social failing, but greater public—and intrapersonal—education is needed to aid human health.

Compared to other organisms, humans are born fairly helpless, requiring substantial assistance from parents (or other conspecifics) to ensure survival. This formative biological interdependence, and the reflexive tendency to take on the goals and needs of another, may ground the social affiliation drive as early as infancy (Powell, 2021). This "fundamental need to belong" continues to predominantly direct perception, motivation, and behavior throughout life (Baumeister & Leary, 1995) and quality social connection is intrinsically rewarding and necessary (but not sufficient) for happiness (Diener & Seligman, 2002). While the instrumental

benefits of social connection—increased safety, food and resource security, division of labor, procreation—are evident, the pervasiveness of social processing can be seen in many studies in social psychology, as we will review here. Given that cues for social connection are particularly salient, how we perceive and navigate social environments are important components to consider for psychosocial health.

Interoception for Need Fulfillment

"I feel, therefore I am."

~ Bud Craig, 2015

Research on interoception has recently been revolutionized by convergent interest from neuroscience, clinical science, and psychology, due to its role in selfhood, emotion, and psychosocial health (Quigley et al., 2021). The term interoception has a unique conceptual historical development (Ceunen et al., 2016), and research interest was especially sparked by Craig's seminal work, defining interoception as: "the sense of the physiological condition of the body" (Craig, 2002; 2015). This account, rooted in neuroanatomical tract-tracing, substantiated the importance of afferent—body-to-brain—signals from all tissues of the body for physiological monitoring and regulation. Comparative neuroanatomical studies indicated a substantial afferent pathway for physiological signals to travel through spinal cord and vagus nerve to formulate an internal "body map" within the primary interoceptive cortex—posterior/mid-insula. This interoceptive image of the self propagates to the anterior insula, which is highly interconnected also with amygdala, cingulate, and prefrontal areas. Craig argued that interoception mediates myriad sensations from the body (including temperature and pain), to help regulate the organism with homeostatic balance across physiological systems, for optimal functioning. Interoceptive processing is distinct form exteroceptive processing—regarding stimuli outside of the body.

Craig emphasized that the purpose of interoceptive sentience is to maintain homeostasis—balance between physiological systems for optimal functioning.

Modern accounts of interoception emphasize it's iterative and predictive nature, with interoceptive sensation the result of dynamic interplay between afferent physiological signals and central "interoceptive predictions" (Barrett & Simmons, 2015). While the global, ontogenetic focus of interoception is homeostatic maintenance, allostasis directives also arise from certain situations. Allostasis represents shifting of ideal homeostatic "set points" for physiological function, to adapt to certain (perceived) stressors, such that sustained "allostatic load" represents the interoceptive system incurring extra metabolic cost. Within a Bayesian interoceptive predictive processing (IPP) framework, this metabolic processing cost is the result of prediction error—a mismatch between expected physiological state (prior) and real-time afferent physiological signaling. One such IPP model details how "interoceptive predictions" may arise and sustain maladaptive affective and physiological conditions, such as depression (Barrett & Simmons, 2015; Barrett et al., 2016). Interoceptive predictions represent ongoing, efferent visceromotor adjustments to the body in anticipation of expected demands, based on appraisal of the current situation and prior experience in similar contexts. One may surmise loneliness could often be a case of dour (social) interoceptive predictions, which do not adequately serve social connection needs. Interoception is a critical process by which an organism monitors its internal states to regulate levels of needed vital resources (e.g., food, water, and social connection) and motivate behavior to acquire those resources (Petzchner et al., 2021). How might interoception monitor and motivate fulfillment of social needs? This is a central question within this dissertation, but before we can address it we require better grounding of interoception.

Measures of Interoception

Garfinkel and colleagues (2015) proposed an influential tripartite operationalization framework for interoception. The most common measure—the Schandry heartbeat counting task—is a measure of interoceptive accuracy (IAcc) specifically in the cardiac domain, as participants try to engage interoceptive attention to sense their own heartbeat, with their guesses compared to objective cardiac measurement. This counting paradigm is the more traditional approach, but due to measurement confounds (Zamariola et al., 2018), more researchers are moving to the heartbeat discrimination (vs. counting) task for interoceptive accuracy, where participants are presented a stimulus (such as auditory tone) and asked if the tone is in synchrony with their heartbeat or out of sync. Trials vary in and out of sync and performance on this measure seems less reliant on lay beliefs about heartrate and additionally requires multisensory (and exteroceptive) cue integration, which could better reflect the dynamic nature of interoception in the wild. If participants are then asked to rate their confidence in each guess during interoceptive accuracy trials, the correlation between confidence and their interoceptive accuracy scores is a measure of interoceptive awareness (IAw)—the metacognitive awareness of interoceptive accuracy. Last but not least, self-reported interoception is considered interoceptive sensibility (IS), and questionnaires measure different aspects of maladaptive (i.e. anxiogenic) or adaptive attentional styles to interoceptive sensations. An increasingly popular measure is the MAIA (Mehling et al., 2012; 2018), which produces eight distinct subscales of IS: Noticing, Not Distracting, Not Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Body Trust. This questionnaire neatly captures dissociable dimensions of quantity and quality of interoceptive attention, and critically, how interoception is appraised and

integrated into decision-making and self-regulation, or not. We cover the MAIA and the Body Trust subscale in detail in Chapter 3.

Recently Murphy and colleagues have developed self-report scales for perceived interoceptive accuracy (Murphy et al., 2020) and interoceptive attention (Gabriele et al., 2021), which are promising additions to IS methodology. While new scales are still being developed, a recent systematic review and factorial analysis of interrelations between IS scales showed considerable spread in underlying constructs assessed (Desmedt et al., in press). The tripartite operationalization framework has provided greater consistency and common dialogue for interoception researchers, and studies have begun to examine dissociations between different dimensions of interoception. Garfinkel and colleagues (2016) assessed interoceptive accuracy for respiration as well as heartbeat perception, and found no relationship between these accuracy measures, but a positive correlation between respective measures of metacognitive awareness (IAw). More recently, additional measures of interoception have been developed for respiration (Harrison et al., 2021) and gastric sensations (van Dyck et al., 2016). There are also efforts being made to develop smartphone-based mobile assessments of interoceptive accuracy (Plans et al., 2021; Tsakiris, personal communication).

There is precedence for investigating interoception for social conditions such as loneliness. For a comprehensive review on interoceptive mechanisms associated with mental health, see the review of Khalsa and colleagues (2018). We also note that an emerging area of research is of interoceptive dysregulation from trauma, which is often inherently interpersonal (Van der Kolk, 2015), and that interoceptive improvement may be a mechanism of post-traumatic growth (Peterson et al., 2008). Outside of specific trauma, one may often find oneself feeling lonely.

Loneliness: Definition and measurement

Loneliness is best defined as perceived social isolation, and it is this subjective perception of social disconnection that matters for health much more than objective measures of social isolation (Cacioppo & Patrick, 2008). Individuals, moreover, have idiosyncratic "set points" of optimal social connectedness, but mismatch of perceived and needed social connectedness is what loneliness represents. The most common measure of loneliness is the UCLA Loneliness scale (Russell, 1996), which does not mention loneliness explicitly, but asks participants the extent they agree with statements such as, "How often do you feel that people are around you, but not with you?" Loneliness scores range from 20-80, with > 44 representing high loneliness (Cacioppo & Patrick, 2008, p. 271). (See more methodological detail in Chapters 1-3.)

All the Lonely People: Loneliness prevalence and risk factors

Research tracking the growing prevalence of loneliness was already alarming before the recent global pandemic, which dramatically increased social distancing and reduced in-person interaction. While some studies suggest that the pandemic increased loneliness (van Tilburg et al., 2020), and particularly for young adults (Lee et al., 2020), social connection was already under siege with increasing rates of social atomization within modern cultures, family ties loosening as more people move away for (sometimes remote) work, and the rise of living alone. Loneliness was traditionally more of a concern for older individuals, but recent research highlights it's causes psychological and physiological suffering across the lifespan. A meta-analysis of 75 longitudinal studies from diverse populations examined variability of loneliness across age, indicating that loneliness rates remain relatively stable from adolescence to old age (Mund et al., 2020), but this large-scale analysis may miss interactions of culture and life stage that impact loneliness. Another recent cross-temporal meta-analysis examined the subgroup of

"emerging adults" aged 18-29 years old and found increasing rates of loneliness since the 1970s, but especially since the turn of the century (Buecker et al., 2021). Focus on this age group is notable because it is usually when individuals leave the family home to pursue higher education or other job and social opportunities, often inducing social challenges and opportunities for (mal)adaptation.

And prior social experience can bias later social (and otherwise) success, as one longitudinal study of Norwegians aged 13 to 31 years old has demonstrated. von Soest & colleagues (2020) tracked increases in loneliness from early adolescence to mid-20s, which then plateaued. Social risk factors (e.g., leaving home before 18) predicted later loneliness, and women generally reported higher loneliness than men. Finally, these intriguing results indicated that adolescent and young adult loneliness can increase prospective risk for disability, mental health, and lower midlife income. Further investigations should examine what mechanisms at what life stages can confer better social adaptation and facilitate social connection. Adolescence is naturally a stage of physiological—and often social—upheaval, and when vulnerability to alienation and loneliness is heightened. Loneliness increases in adolescence were most affected by differential social needs (Gallardo et al., 2018)—which suggests the importance of recognizing and understanding one's own needs, particularly during socioemotional challenges of adolescence. These results also suggest that loneliness may be mitigated by engagement of emotional regulation, a maturing process with benefits for psychosocial health. Leading up to adolescence, behavioral problems often shift from motor to emotional control issues, with increasing social consequences, as indicators for later mental health risk (Bathelt et al., 2021). One intriguing intrapersonal mechanism increasing risk for loneliness could be diminishing interoceptive body trust, as found in a longitudinal sample from ages 7-17 (Jones et al., 2020).

This may represent a potential sensitive period for interoceptive intervention for psychosocial health, as we explore body trust in Chapter 3. It is well known that adverse childhood experiences such as trauma can often dysregulate socioemotional development and increase health risks later in life. Childhood and adult trauma reliably predict worse later loneliness (Hyland et al., 2019). Childhood experiences also contribute to adult attachment styles, which have been associated with dysregulated interoception, with avoidant individuals demonstrating diminished body trust (Oldroyd et al., 2019).

Two physiological mechanisms associated with social connection are heart-rate variability (HRV), which indexes adaptive autonomic cardiac control, and oxytocin, a parochial social bonding neurohormone. Higher HRV may allow for greater psychophysiological resolution in response to the environment, as well as social sensitivity—higher HRV was found in participants forming more accurate first impressions of others (Human & Mendes, 2018). One review suggests that HRV influences prosocial behavior and (both self-report and observed) traits in a quadratic, inverted U-shape relationship (Kogan et al., 2014). A longitudinal study examined HRV and social integration of international college students—the extent to which they affiliated more with i) primarily their own cultural group in a foreign land, ii) the local cultural group, or iii) a mix of both. Participants were tested at three timepoints: a) when they arrived at host university, b) two months after, and c) five months after. Resting HRV was measured at each timepoint, along with subjective measures of social integration and loneliness. HRV decreased across the 5 months overall, but increased at Time 3 only for individuals who reported high social integration (Gouin et al., 2015). This study suggests that HRV may be an index of greater overall psychosocial adjustment—a notion supported by a study on HRV in loneliness. Norman and colleagues (2011) demonstrated that intranasal oxytocin administration acutely

increased HRV, but that this effect was dampened as loneliness increased, and independent of circulating immune or stress hormone levels. This study suggests loneliness may reflect relative physiological intransigence, which should also manifest in interoception and cognition. Although not many studies have jointly examined HRV and interoception, one recent investigation showed a positive correlation between HRV and heartbeat counting interoceptive accuracy (Lishke et al., 2021). More research should examine HRV and interoception and their interaction in psychosocial health conditions, since both reflect adaptive physiological regulation. A recent review on this topic suggests that both processes are associated with greater emotion regulation—HRV with greater reappraisal and acceptance of emotions, and interoception with resilience to negative emotions and social uncertainty (Pinna & Edwards, 2020). What are our models of the lonely mind and body?

As Above, So Below: Lonely Minds and Bodies

Cacioppo and colleagues (2009; 2015) proposed the leading Evolutionary Theory of Loneliness, which conceptualizes loneliness as an evolved human capacity for social pain that should motivate social (re)connection but causes physiological dysregulation when social needs go unmet for too long. This theory outlines a common "lonely mindset" which is marked by hypervigilance for social threat (HST), an attentional bias for processing social negative stimuli, which can maladaptively maintain loneliness. This cognitive bias instigates negative social predictions for oneself in loneliness, and memory and social behavioral biases that contribute to the defeatist lonely mindset becoming a self-fulfilling prophecy. In Chapter 2, our impaired smile mimicry results represent fulfillment of a node in this process model (Arnold & Winkielman, 2020). Negative beliefs about the self in loneliness may manifest in different ways, including greater self-disgust (Ypsilanti, 2018), and reflect the social stigma often surrounding

loneliness, especially promoted by young adults (Kerr & Stanley, 2021). Another finding that reflects the paradoxically self-defeating nature of the lonely mindset is that loneliness is associated with fear of compassion (Best et al., 2021). While other-compassion and self-compassion are positively correlated (Neff & Pomier, 2013), loneliness showed a weak correlation with compassion for others, but strong negative correlations with (receiving) compassion *from* others and self-compassion. Changing beliefs about oneself, and particularly increasing empathic and compassionate understanding of loneliness as a core, common human condition reflecting genuine need for social connection, could be a promising route for improving loneliness. In Chapter 3, we examine intrapersonal correlates of loneliness and explore how diminished interoceptive body trust could reflect poor self-beliefs as well. Although loneliness can affect everyone, a recent meta-analysis (Buecker et al., 2020) suggests that it is moderately associated with specific personality variables: lower extraversion, agreeableness, conscientiousness, and openness (in descending magnitude) and higher neuroticism.

Emotionally, loneliness is often comorbid with depressive symptomatology, and has been shown to increase depression over time, without depression impacting loneliness (Cacioppo et al., 2010; for a meta-analysis, see Erzen & Cikrikci, 2018). These results suggest loneliness be a more central component of psychosocial health than depression, perhaps a more modern disorder. In addition to depression, loneliness has been associated with higher alexithymia—inability to identify and describe one's own emotion (Qualter et al., 2009).

Lonely Brains, Physiology, and Health

Since incidence of loneliness is an idiosyncratic perception, how we perceive other aspects of ourselves may also reliably covary with loneliness. For example, loneliness shows a reciprocal relationship with subjective self-reported health (SRH). Over a 24-year longitudinal

study, loneliness initially predicted worse SRH, but then at timepoints 2, 3, and 4, poor SRH contributed to maintaining loneliness (Tsur et al., 2019). Objectively, loneliness is associated with a host of physiological consequences, which increase morbidity and mortality risk (Rico-Uribe et al., 2018). One major physiological system impacted is cardiovascular, with loneliness predicting elevated blood pressure both cross-sectionally and longitudinally (Hawkley et al., 2010). In addition, sleep is dysregulated in loneliness (for a meta-analysis, see Hom et al., 2020). Loneliness is associated with differential genetic expression of immune markers, which causes immunosuppression, called conserved transcriptional response to adversity (CTRA). While loneliness was the strongest psychological risk factor for CTRA, eudaimonia—purpose and meaning in life—was shown to be the strongest psychological protective factor (Cole et al., 2015). These results suggest the intriguing notion of a conceptual path to improving loneliness.

Recently, larger studies have begun to delineate consistent neural differences associated with loneliness. 776 healthy young adults (18-27yo) completed the UCLA loneliness scale and underwent scanning for white matter density—greater loneliness was associated with reduced density in eight regions, including right anterior insula and dmPFC (Nakagawa et al., 2015) Examining scanning data from 40,000 middle-aged brains, higher loneliness was linked to grey matter differentiation and stronger functional communication within the default network—circuits supporting mentalizing, reminiscence, and imagination "to fill the social void" (Spreng et al., 2020). Using the same dataset, Zajner and colleagues (2021) also showed that default network aberrations associated with loneliness were linked systematically to subregional alterations in hippocampal function, which could reflect memory biases associated with the "socially-defeated" lonely mindset. More specifically, researchers have begun to link

neurocognitive mechanisms underlying loneliness within models involving interoceptive dysregulation, which we review later. But first, we review basics of emotional processing.

Emotion as Adaptive Homeostatic Processing

Since William James's seminal essay on emotion (1884), proposing that "our feeling of [bodily] changes as they occur is the emotion"—scientists have pondered and produced experiments to test the role of bodily signals in emotion. Research on emotion since has not debunked James's assertion that bodily signals associated with emotion are not merely epiphenomenal, but also constitutive of emotion. Importantly, this account of emotion highlights its indispensable role in motivating behavior—that emotion is functional rather than fluff. Although appraisal theories of emotion sometimes disagreed with James about the causal links between bodily signals and emotion, they highlighted an important perceptual process that assesses the personal relevance of the emotion eliciting situation and the emotion itself: namely, appraisal. Decades later, models of emotion regulation (Gross, 2018) would highlight cognitive reappraisal as a common and helpful emotion regulation strategy—since after all, perhaps our implicit "sizing up" so quick in the moment isn't always right. These accounts suggested it is not (just) the feeling itself, but our cognitive perception (appraisal)—which accounts for basic positive or negative affect and even perceptions of available resources/energy to deal with the situation. This elaborated account highlights the background role of previous experiences, expectations, we well as by-the-moment monitoring of the body, which we return to later.

In total, the James-Lange theory of emotion (1884) and others in the following century deepened scientific understanding of the role of emotion in decision-making, (social) behavior, and perception. Prominent theories of emotion followed which highlighted the constitutive role of the bodily signals for emotion, most notably the Somatic Marker Hypothesis (Damasio, 1994)

and the Theory of Constructed Emotion, which was later expanded into a model for interoceptive processing (Barrett et al., 2016). These theories also reflect an increasing understanding of the embodiment of emotion, which developed independently from, but then joined with, interoception research (Herbert & Pollatos, 2012). While some subjective aspects of emotion can only be captured by self-report, psychophysiological measures have also been used to capture arousal and affect. Most notably, facial electromyography (fEMG) can capture facial muscle activity that is specific to certain valences of emotion—the zygomaticus major being activated for smiling and the corrugator supercilii being activated for frowning (Tassinary & Cacioppo, 2000). While fEMG is commonly used to measure facial mimicry (for a review, see Arnold & Winkielman, 2019), facial muscle activity can also reflect cognitive-affective processes such as the facilitated processing of fluency conducive to positive affect (Winkielman & Cacioppo, 2002). We cover fEMG methodology and results in detail in Chapter 2.

Emotion, Semantic Representation, and Well-being

Vine and colleagues (2020) found, by analyzing naturalistic language in essays and blogs, that emotion vocabulary richness correlates with well-being based on valence—larger negative emotion categories were associated with worse mental and physical health, while larger positive emotion categories were associated with greater mental and physical health. On the flipside, loss of emotion concepts for meaning-making from distress may portend disease and decrements in well-being following emotional challenge (Munch-Jurisic, 2021). As we explore later, low emotional clarity may be the result of interoceptive dysregulation and emotion regulation under low emotional clarity is a persistent challenge (Shalev, 2020).

Where you end and I begin: Development of Social Interoception

How do we come to know ourselves in the world? It has been suggested that, even prior to birth, experience of "co-embodiment" within the mother in utero forms the basis for a necessarily interdependent minimal self (Ciaunica et al., 2021a) and that consciousness first forms from these bodily roots (Ciaunica et al., 2021b). These considerations, interestingly, situate rudimentary self/other distinction and social processing as the basis on which consciousness develops, with one's own body manifesting as the boundary between self and other. Evidence for interoceptive sensitivity has been shown as early as 5 months old (Maister et al., 2017). A twin study examined the genetic vs. environmental factors contributing to interoceptive accuracy, and suggested some heritability for the ability in 8-10 year old twins, but with considerable plasticity (Murphy et al., 2019). Another study suggested that the level of a mother's interoceptive knowledge predicts teacher ratings of her children's ability for emotion regulation, social initiative, cooperation, and self-control (MacCormack et al., 2019), suggesting interoceptive sensitivity and its link to socioemotional learning can be modeled across generations. As interoception develops to regulate the increasingly complex biological and social human, these informative internal signals can be incorporated into higher-order processing. Interoception may be critical for the process of self/other distinction (Palmer & Tsakiris, 2018), with important social consequences.

Recent research on interoception—the processing, regulation, and appraisal of bodily states—highlights its formative role in selfhood, requiring multisensory integration to infer boundaries between self and other (Tsakiris, 2017). Interoceptive impact on self-processing has been shown a number of ways. The canonical method is the rubber hand illusion, which involves an individual having the sensation of "owning" a rubber hand they are viewing being touched in the same way their real hand (which is out of view) is being touched. Tsakiris and colleagues

have shown that greater interoceptive accuracy reduces the psychological susceptibility to this illusion, implying a "stronger" body ownership and self-representation. Importantly, this body ownership illusion occurs because the brain matches the feeling of the touch to its visual input of the other hand being touched, but only when the touches are in synchrony. Another method that demonstrates interoceptive impact on self-processing takes advantage of timing visual signals with one's real-time heartbeat. Aspell and colleagues (2013) had participants use a virtual reality headset that projected their virtual body in front of themselves. When a flashing bodily silhouette was in synchrony with the participant's heartbeat, they exhibited greater self-identification with the virtual body. These studies suggest that internal, online interoceptive monitoring of signals, and particularly the internal signature of the heartbeat, can act as self-rooted anchoring mechanism for processing outside (social) stimuli.

The heartbeat—a frequent, vital, and discrete interoceptive signal—gets special representation in the brain. This neural signature—the heartbeat-evoked potential (HEP)—can be non-invasively recorded using EEG/ERP methods and its strength reflects interoceptive processing (for a review, see Coll et al., 2021). Although more research is needed to understand the importance of the HEP in social-emotional processing, it appears to be a relatively clean measure of interoceptive attention (Petzschner et al., 2019), which may play a key role in interoceptive regulation and ensuing (mal)adaptive behavior (Joshi et al., 2021). Future studies should integrate HEP measures during social interaction to index whether interoceptive/exteroceptive attentional switching can facilitate adaptive social learning (e.g. trust decision), as proposed by Arnold and colleagues (2019). Better interoception not only substantiates a stronger sense of self, but enhances emotional processing, since interoceptive dysregulation can result in alexithymia—relative inability to identify and describe one's

emotions (Brewer et al., 2016; Murphy et al., 2018). Additionally, some studies have indicated that higher interoception scores are associated with anxiety—but Palser & colleagues (2018) demonstrated this relationship is partially mediated by alexithymia—i.e., when one knows what one is feeling, awareness of interoceptive signals is less likely to be labeled anxiety.

Interoception and Social Sensitivity

Arnold and colleagues' (2019) theoretical review of interoception and social connection, the first to address interoceptive components in loneliness, posited that the exteroceptive HST bias operates in social situations at detrimental cost to interoceptive attention, though this has not yet been adequately tested. Specifically, they suggest that poor online interoception during social interaction may undermine adaptive learning from socially-induced affect, and that accurate social sensitivity may depend on flexible switching between exteroceptive and interoceptive attention, to best read another's signals and own's own signals in reaction. They also summarized findings of greater interoceptive accuracy buffering against negative affective consequences of social exclusion and social stress, suggesting stronger interoception may confer a sense of social resilience. However, it is not that stronger interoception makes one less responsive to others—the opposite was found for physiological response in social proximity. Ferri and colleagues (2013) showed that individuals with greater interoceptive accuracy exhibited more pronounced HRV reaction to a hand (vs. non-social stimulus) at the boundary of their peripersonal space (~20cm away from one's own hand). The interaction of trust and interoception is particularly salient, especially given our results in Chapter 3. One recent study examined how interoceptive accuracy might relate to being "suggestible" enough to change one's judgments based on social feedback. Participants were asked to rate perceived trustworthiness of faces, then given ostensible feedback that most people gave a different rating,

and were given the chance to change their own trustworthiness rating. The feedback was bogus and not related to any real trustworthiness judgments, but did sway participants' ratings as a function of interoceptive accuracy: those with less interoceptive accuracy were more suggestible (von Mohr et al., 2022). While Arnold and colleagues (2019) were the first to review the potential interactions and importance of loneliness and interoception, a model of social allostatic load was brilliantly elaborated by Quadt and colleagues (2020) which incorporates interoceptive predictions, Barrett and colleagues' (2015) "locked-in brain"), and other fertile ground for new research.

Intrapersonal and Interoceptive Components of Connection

What does it mean to connect? Two separate entities make contact. The primary entity we are grounded within our consciousness is our own body, distinct from the bodies of others. Our own self perception is necessary for our perception of the outside world, and may have a complex impact on how we perceive others. How we conceive ourselves imprints upon how we conceive others. Clearly, loneliness relies on perception of inadequate social connection—but what comprises perceptions of connection?

Intrapersonal Representation and Connection

Extensive evidence has shown that individuals who exhibit greater interoceptive accuracy are less susceptible to the rubber hand illusion (Tsakiris, 2017), implying a strengthened sense of self. In addition to interoceptive accuracy, which integrates perception of the bodily self-boundary and confers greater emotional clarity (i.e. less alexithymia; Brewer et al., 2016) how can we conceive of intrapersonal connection? One prominent construct that carries psychosocial health benefits and can represent interpersonal connection is self-compassion. Self-compassion represents an intimate relationship with one's self and a desire to reduce the self's suffering in

the face of inevitable challenges—self-compassion is considered more beneficial for psychosocial health than self-esteem, which depends on social comparison (Neff, 2011). But what are some mechanisms through which self-compassion might improve self-clarity and/or social connection? Wong and colleagues (2019) propose that self-compassion is key for reducing stigma (of the self), through self-acceptance and dissolving putative concerns from others based on an identity (i.e. social stigma). This is particularly notable given the negative social stigma of loneliness purveyed particularly by young adults, but not as much among older adults (Kerr & Stanley, 2021), and our results in Chapter 3. As it entails recognition of common humanity between self and other, greater self-compassion also predicts greater concern for others, which can increase social connection (Neff & Pommier, 2013).

Yours or mine? Self—other processing

One classic finding in social psychology is the self-serving bias—the tendency of an individual to attribute successes or credit to oneself, but blame negative events on external circumstances. And from an evolutionary perspective, awareness of the self is adaptive for decision-making within a social context (Baumeister, 2011). Do we need a self to socially connect? How might self-processing interact with social processing? What is social connection? One clever study showed that trustworthy, compared to untrustworthy, investment partners were perceived with greater facial similarity to the participants (Farmer et al., 2014). Trustworthy partners were also rated with greater felt closeness (IOS scale), so this study highlights the reciprocal relationship between trust and self/other similarity as components of social connection. This study raises an additional empirical question—does the accuracy or "resolution" of one's self concept, bodily or facial appearance play a role in the outcome of comparison processes? That is, if the (self) standard to which another is compared is skewed,

how much does this skew social perception and behavior? Finally, might quality, stable, healthy social connection require mutual allowance for dynamic self and other representations, outside of idealized (and unattainable) "union"? This idea could explain the effects a "perfect unity" metaphor for love—two separate halves complete each other—on relationship perception. Lee & Schwarz (2014) found that activating this static, unity metaphor (vs. a dynamic, journey metaphor) caused couples to report lower relationship satisfaction after considering a recent argument. Applying more fluid (and hopefully accurate) self and other representations could improve relationship satisfaction and perhaps engagement, in a joint effort to adjust to the dynamic seas of connection.

How is social connection represented in the brain? Two recent neuroimaging studies address this question. Hyon and colleagues (2020) examined resting state functional connectivity amongst members of a small South Korean village and found that similar "functional connectome" activity—particularly in default mode areas—predicted social network proximity and closer social connection. This effect was weakened by geographical distance between people, suggesting that localized micro-cultures may facilitate social connection through similar neural activity patterns. Courtney & Meyer (2020) scanned participants in fMRI while they engaged in self-other processing, then made closeness ratings and completed the UCLA loneliness scale. Participants were asked to compare and contrast themselves on personality traits during a self-other reflection task including five close friends, five acquaintances, and five celebrities, creating similarity indices. Neural activity in the mPFC was especially associated with self-representation, and both this activity and that in other areas appeared to cluster targets into three categories: self, social network members (including close others and acquaintances), and celebrities. This representational activity positively correlated with self-other closeness

ratings, suggesting that closeness is related to stronger similarity-based neural representation of a relationship. Perceived self-other similarity was not measured in this study, but the more socially connected (less lonely) people were, the more similar was neural representation of self and other. These authors conclude loneliness may be underpinned by a "lonelier" neural self-representation—and so if this representation can be further elaborated, could it provide greater chance for representational similarity with others, on the road to more quality social connection?

What would a more differentiated, or "fleshed-out" self-representation look like in the brain, behaviorally, and within social networks? Since interoception appears critical for a strengthened sense of self (Tsakiris, 2017), what role could interoception play in social connection, through self-representation? Interoceptive accuracy—heartbeat counting—can be dynamically increased by self-relevant exteroceptive stimuli, like a picture of one's face and more abstract narrative aspects of the self (Ainley et al., 2013). This suggests that even incidental self-relevant stimuli may activate self-representations that in turn interact with interoceptive processing. The implications for increased interoceptive processing during social interaction could be substantial for improving social connection and health.

Converging lines of research suggest that perception of others' emotions, and acting upon those perceptions as in empathic or prosocial behavior, depends in part on one's own "emotional map". One compelling line supporting this comes from a systematic review that shows, perhaps unsurprisingly, when we struggle to know our own emotions in alexithymia, we also have more difficulty recognizing (labeling) other's emotional facial expressions (Grynberg et al., 2012). This perceptual deficiency for emotions in self and others likely entails reduced semantic representation as well. And obviously, alexithymia carries social consequences, since emotions are currency for social connection. Alexithymia—an impoverished "emotional self"—is

associated with loneliness, while lower interpersonal trust partially mediates this relationship (Qualter et al., 2009).

Interpersonal Connection & Empathy

The relationship between empathy, self-other processing, and interoception appears complex, with some studies indicating shared neural insular activity between interoception and emotional experience (Zaki et al., 2012). But, insular computation is complex, reflecting a host functions such as interoceptive attention, salience monitoring, and managing interoceptive prediction error. One study utilized the HEP to index interoceptive processing during an empathy task, and found positive correlation between task-related HEP strength and self-reported empathy beliefs (Fukushima et al., 2011), but interoceptive accuracy scores were not directly related to empathic accuracy across four different laboratory tasks (Ainley et al., 2015). Using a different approach to modulate interoceptive processing during a perspective-taking empathy task, a more recent study showed that perspective-taking performance was facilitated by presenting key social stimuli in synchrony with one's real heartbeat particularly for people reporting high self-reported empathy, suggesting interoceptive embodiment in the moment may aid empathy (Heydrich et al., 2021). More research is needed to tease apart the functional relationships between interoception and empathy, since they are likely underpinned by self-other processing and individual differences such as basal loneliness.

We show in Chapter 1 that comparison processes play a role in perception of loneliness, with downward (intrapersonal/temporal and interpersonal/social) comparisons resulting in reduced loneliness compared to upward comparisons (Arnold et al., 2021). Regardless if the comparison target was one's self in the past or an imagined peer, participants reported less loneliness when they considered their current social connection as better than the target. One

obvious construct with important implications for social connection is interpersonal trust. Unsurprisingly, loneliness is associated with lower trust in other people (Qualter et al., 2009)—but could impaired interpersonal trust also reflect interoceptive dysregulation in loneliness?

A comprehensive study by Lieberz & colleagues (2021) addressed this. Researchers first pre-screened a group of high-loneliness individuals to compare to controls using psychophysiological, hormonal, and neuroimaging data. Otherwise-healthy lonely participants showed reduced oxytocin and affect boost following a positive conversation and reported less interpersonal trust and larger social distances than controls. Social behavior of the lonely individuals was later blind-coded, revealing that observers could significantly guess their lonely-group membership and they were rated as less trustworthy than controls.

Morr & colleagues (2021) examined college first-years at the beginning of the school year and six months later, once some social adjustments have taken place. Participants underwent fMRI scanning during a simple facial emotion matching task at Time 1, and completed baseline and monthly reports of alexithymia, perceived psychosocial stress, and loneliness. Over the six months, psychosocial stress increased and initial alexithymia predicted its increase via higher loneliness. Apparently, the stressful impact of loneliness got worse when combined with introductory alexithymia. At Time 1, alexithymia was associated with reduced amygdala reactivity to emotional faces, and loneliness was associated with diminished reactivity in the anterior insular and cingulate cortices. Most interestingly, (diminished) insular activity to emotional faces prospectively mediated the association between alexithymia and loneliness that predicted greater psychosocial stress over the entire six months. This means that relative emotional disclarity is associated with lower emotion-specific insular processing, which exacerbates feelings of loneliness and stress over time.

In an effort to move beyond the passive observer model often tested in lab experiments, Grezes and Dezecache (2014) argue that social situations, and the emotional signals embedded therein, constitute enacted social cognition beyond mere detection of another's states—which requires balancing of dynamic action affordances and emotional appraisal between self and other. They suggest social success therefore requires dynamic attentional shifting between self, other, and shared representations, and hypothetically explore this model in the face of social threat signals. This framework, whilst focusing on more on (potential) motor activity, complements the notion of dynamic switching between interoceptive and exteroceptive (social) attention for adaptive social learning and ultimately social connection (Arnold et al., 2019). Interoceptive processing offers a unique window to examine self-related processing in social situations, which often intrinsically attract so much attention.

Chapter 1:

The role of comparisons in judgments of loneliness

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Abstract

Loneliness—perceived social isolation—is defined as a discrepancy between existing social relationships and desired quality of relationships. Whereas most research has focused on existing relationships, we consider the standards against which people compare them. Participants who made downward social or temporal comparisons that depicted their contact with others as better (compared to other people's contact or compared to the past) reported less loneliness than participants who made upward comparisons that depicted their contact with others as worse (Study 1-3). Extending these causal results, in a survey of British adults, upward social comparisons predicted current loneliness, even when controlling for loneliness at a previous point in time (Study 4). Finally, content analyses of interviews with American adults who lived alone showed that social and temporal comparisons about contact with others were both prevalent and linked to expressed loneliness (Study 5). These findings contribute to understanding the social cognition of loneliness, extend the effects of comparisons about social connection to the important public health problem of loneliness, and provide a novel tool for acutely manipulating loneliness.

The Role of Comparisons in Judgments of Loneliness

Loneliness, the emotional distress stemming from social connections that are perceived to be inadequate (Cacioppo & Patrick, 2008), is generally defined in terms of a discrepancy between perception of existing relationships and the idiosyncratic standards desired for those relationships. Nevertheless, most research on loneliness has focused on existing relationships, and surprisingly little attention has been given to the standards against which people compare them. The present line of research addresses this gap by examining how differences in comparison standards influence loneliness.

Loneliness can stem from dissatisfaction with the quantity *or* quality of relationships. For instance, loneliness is referred to as "a situation experienced by the individual as one where there is an unpleasant or inadmissible lack of (quality of) certain relationships. This includes situations in which the number of existing relationships is smaller than is considered desirable or admissible, as well as situations where the intimacy one wishes for has not been realized" (de Jong Gierveld, 1987, p. 120). Although an objectively low quantity (few hours in the week spent with others) or quality (lack of close supportive friends) of contact with others is a risk factor for loneliness, the causal direction of this relation is unclear (Klinenberg, 2012), and a large body of research has shown that objective social contact and subjective loneliness are distinct constructs (e.g., Cutrona, 1982; Dykstra & Fokkema, 2007; Peplau & Perlman, 1982; Pressman, Cohen, Miller, Barkin, & Rabin, 2005; Russell et al., 1996).

Objective social contact and subjective loneliness are imperfectly related because of differences in the way people think about their contact with others—that is, because of intervening social cognition (Cacioppo & Patrick, 2008). Social cognition, therefore, is a promising route for understanding and influencing loneliness. There are three options for people

who feel, or are at risk of feeling, lonely: increase the achieved level (quantity or quality) of social contact, decrease the desired level of social contact, or reduce the importance of the gap between the two (Perlman & Peplau, 1981). The latter two options, which are cognitive rather than behavioral strategies, appear to be both ubiquitous and potentially effective. Older adults indicated they would recommend to other lonely adults coping strategies that lower expectations about, or the importance of, social contact (Schoenmakers, van Tilburg, & Fokkema, 2012). Related research has shown that manipulating cognition, such as the salience of social connections, changes how people respond to social exclusion (Twenge, et al., 2007). A meta-analysis of attempts to reduce loneliness found that the most successful interventions tested with randomized controlled trials (RCTs) were those that targeted maladaptive social cognition rather than actual social contact (Masi, Chen, Hawkley, & Cacioppo, 2011). However, these interventions were generally weeks- or months-long individual or group cognitive behavioral therapy sessions, in which many aspects of cognition were addressed (e.g., jealousy, communication, stress), so they do not clearly identify effects on loneliness of adjusting the desired level of social contact.

One influence on people's *desired* levels of social contact is likely to be the perceived contact achieved by similar others: that is, social comparisons (Festinger, 1954; Hyman, 1942; Mussweiler, 2003; Suls, Martin, & Wheeler, 2002; Wills, 1981). People are uncertain about their abilities and opinions, and reduce uncertainty by comparing themselves to others; these others provide a standard against which one's own qualities—like intelligence or athleticism—may be evaluated (Festinger, 1954). People can be uncertain about loneliness too (e.g., Perlman & Peplau, 1981), so others' quality and quantity of social contact may provide a standard against which one's own social contact can be measured. Indeed, previous work on loneliness alludes to

an effect of such comparisons. Dykstra, van Tilburg, and De Jong Gierveld (2005) pointed to: "…the possible role of *social comparison* processes (Festinger, 1954) in late life loneliness. Older adults might be less lonely because they feel their social circumstances compare favourably in terms of earlier expectations or relative to peers" (p. 728). However, we are aware of little work that has directly tested the role of comparisons in loneliness.

Just as people feel worse about themselves in the presence of a highly competent other, and better about themselves in the presence of an incompetent other (Morse & Gergen, 1970), people should feel more lonely when comparing themselves to an individual with a better quality or quantity of social contact (upward comparison, Suls, et al., 2002), and less lonely when comparing to an individual whose social contact is worse than their own (downward comparison). Indeed, Schoenmakers et al. (2012) describe a form of coping with loneliness that involves lowering expectations, which "…can be done by, for example, not expecting one's children to visit as often, realizing that breaking down barriers to improve relationships is too costly, **or comparing oneself with someone who is worse off**." (emphasis added; p. 354).

Similar others are not the only potential reference point for a comparison standard—oneself at other points in time also provides such a standard (Wilson & Ross, 2000). People feel better about themselves when they believe they have improved over time, and worse if they believe they have declined. If people evaluate loneliness using temporal comparisons of the present self to a past self, they should feel lonelier when comparing the present to a past with a better quality or quantity of social contact (upward comparison), and less lonely when comparing to a time in the past when social contact was worse (downward comparison). As with social comparisons, there is some evidence that people make temporal comparisons about their contact with others (Suls, 1986). In a longitudinal study of new students at college, loneliness was

predicted by satisfaction with one's social relationships, which in turn was related to comparisons with previous relationships as well as comparisons with one's peers (Cutrona, 1982).

In sum, people should feel less lonely when they recognize their achieved (present) quantity or quality of social contact as surpassing a comparison standard, and lonelier when they see it as falling short of a comparison standard, whether these standards are social or temporal. Note that comparisons can focus on how the target and the self are similar as well as on how they differ (Mussweiler, 2003). However, because we consider comparisons in which one party is *better* and one is *worse*, our examination is confined to the comparisons that identify dissimilarities, referred to as contrasts. We first tested the effect of contrasts with three experiments in which people were instructed to make downward or upward social or temporal contrasts, and their feelings of loneliness were measured (Studies 1, 2, 3). We then used a large-scale secondary survey dataset to see how contrasts were linked to loneliness over time (Study 4). Finally, we content-analyzed a sample of interviews with American adults living alone, to observe whether people spontaneously made social and temporal contrasts when they talked about their contact with other people, and whether these contrasts were linked to their feelings of loneliness (Study 5). We report how we determined our sample sizes, all data exclusions (if any), all manipulations, and all measures administered in each of the studies.

Study 1

We hypothesized that people would feel less lonely when they made downward social or temporal contrasts, and more lonely when they made upward social or temporal contrasts. We had no reason to expect that one type of contrast (social versus temporal) would be more effective, but we left this as an empirical question. We randomly assigned participants to make

downward or upward social or temporal contrasts—or in a control condition, not to make any contrasts—before measuring their current feeling of loneliness.

Loneliness is most often measured using the 20-item revised UCLA Loneliness Scale (Russell, et al., 1980), which we administered. However, the UCLA scale addresses feelings in general over an extended period of time: respondents indicate "how often" (*never, rarely, sometimes,* or *always*) they feel left out, isolated, shy, etc. If participants average their responses over an extended period of time, combining how they feel immediately after the manipulation with how they remember feeling in the recent past, then this scale provides a less-than-ideal tool for identifying an effect of the contrasts manipulation. Moreover, some UCLA scale items refer to commonalities with others (e.g., "My interests and ideas are not shared by those around me") which might be affected by contrasts between one's present and an alternative without necessarily tapping the emotional experience of loneliness. Accordingly, we also measured loneliness by simply asking participants how true it was that "right now, I feel lonely."

Method

Participants and Design

Two hundred fifty-five individuals recruited via MTurk[1] (www.mturk.com) completed the survey materials in return for a $.48 payment. We concluded data collection when reaching the pre-determined sample size of 50 per condition, which a G*Power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) shows has 95% power to detect an effect size of $f = 0.275$ in a 5-group ANCOVA with two covariates. Four people were excluded from analysis for not writing as directed in response to the manipulation, as discussed in more detail in the Manipulation Check section below. The final sample of 251 included 127 men, 123 women, and one who identified as

"agender," ages 18 to 70 (M = 37 years, SD = 12.59). The experiment used a 2 (contrast direction: downward, upward) x 2 (contrast type: social, temporal) between-subjects design with an additional no-contrasts control condition.

Materials and Procedure

Participants were randomly assigned to one of the five experimental conditions. In the social contrast conditions, they read instructions that elicited contrasts between their own and others' living situations:

> First, we are interested in how your present living situation (who you live with, where you live, how you live) *compares to other people's living situations*. In the space below, please briefly describe two ways that your present living situation is [better / worse] than other people's living situations.

The text in brackets differed depending on whether participants were assigned to make downward or upward contrasts. Participants in the downward contrasts condition were asked to identify ways their own living situation was better, and those in the upward contrasts condition were asked to identify ways their own living situation was worse. We used parallel instructions in the temporal contrast conditions to elicit contrasts between present and past living situations, except that we removed the text that appears in italics above, and instead asked participants to describe how their present living situation: "…*compares to your living situations in the past*." The fifth group of participants, assigned to a control condition, were not asked to make any contrasts and proceeded immediately to the measures below.

Thereafter, participants were asked: "Right now, how true is this statement of you? 'I feel lonely.'" The 7-point response scale had the options *extremely untrue* (1), *moderately untrue* (2), *somewhat untrue* (3), *neither true nor untrue* (4), *somewhat true* (5), *moderately true* (6), and *extremely true* (7). They then completed the 20-item Revised UCLA Loneliness Scale (Russell et

al., 1996), which asks respondents to indicate "how often you feel the way described in each of the following statements," where options are *never* (1), *rarely* (2), *sometimes* (3), and *often* (4). We computed the sum of the 20 items for each participant after reverse-coding the appropriate items ($\alpha = .96$). Participants also reported their gender, age, relationship status, and living situation (live alone or live with other people), and provided any comments they wished to, before being presented a code with which to obtain payment via MTurk.

Results and Discussion

Manipulation Check

A member of the research team read all responses, and four respondents that did not follow instructions (i.e., did not describe elements of their present living situation) were excluded from analysis.

Initial examination of the responses showed that in many cases, it was not possible to distinguish between social and temporal contrasts. For example, a participant wrote: "I have personal space that no one else can enter." This is clearly a downward contrast but it's not clear whether the contrast is to other people who do not have personal space, or to a time in the past when the participant did not have personal space. Other examples where direction can be inferred but social versus temporal cannot are: "There is no fighting" and "I don't get to see my friends very often".. . While reading, the researcher also coded whether or not each respondent mentioned other people. This coding was used in follow-up exploratory analyses described below.

Preliminary Analyses: Demographic Characteristics and Loneliness

Although only a minority of participants (35; 14%) lived alone, they reported more loneliness than those who lived with others, both in terms of current feelings ($M_{Alone} = 4.23$, $SD =$

1.88 versus M_{Others} = 2.94, *SD* = 1.84) and on the UCLA scale (M_{Alone} = 49.09, *SD* = 12.73 versus M_{Others} = 40.69, *SD* = 13.47), *t*s(249) > 3.44, *p*s ≤ .001. Men and women did not differ in loneliness, *t*s(248) < .92, *p*s > .35, but age was related to loneliness, such that older participants reported less momentary loneliness, $r(249) = -.12$, $p = .008$, and marginally less loneliness on the UCLA scale, $r(249) = -.12$, $p = .055$. With participants ranging in age from 18 to 70, these negative correlations are in line with research finding that loneliness is higher in late adolescence and young adults than in middle-aged adults (review by Qualter, et al., 2015). Importantly, randomization was effective; the portion of participants living alone versus with others did not differ across the experimental conditions, $\chi^2(4) = 6.87$, $p = .14$, nor did participant age differ across condition, $F(4, 246) = 1.56$, $p = .19$. To increase the power to detect an effect of the contrast manipulations over and above the role of these other factors, we adjusted for living status and age in subsequent analyses.

Momentary Loneliness (Single-item measure)

Because the design was not fully factorial (2 x 2 plus a control condition), we began by simply assessing differences across the five conditions, using an ANCOVA with condition as a between-subjects factor and age and living status (alone or with others) as covariates. When the single-item measure of current loneliness was the dependent variable, the effect of condition was not significant at the $p < .05$ level, $F(4, 244) = 2.14$, $p = .07$. Nevertheless, given the preliminary and thus somewhat exploratory nature of this initial study, we conducted a series of contrasts to answer specific research questions. We calculated adjusted marginal means for both momentary loneliness (single-item) and UCLA loneliness by condition. These group means, adjusted for living status and age, are depicted in Figure 1.

First, we compared downward to upward contrasts, collapsing across the social versus temporal conditions. As predicted, downward versus upward contrasts produced relatively lower versus higher loneliness, $F(1, 194) = 4.85$, $p = .029$, $\eta^2_{partial} = .023$. Next, we tested whether downward contrasts reduced loneliness, and whether upward contrasts increased loneliness, compared to the control condition. Downward contrasts did reduce loneliness, $F(1, 151) = 7.49$, $p = .007$, $\eta^2_{partial} = .047$, but upward contrasts did not affect loneliness compared to the control condition, $F(1, 145) = .67$, $p > .25$. Finally, we tested whether social versus temporal contrasts had different effects on loneliness. They did not; participants who made downward contrasts were similarly lonely if these contrasts were social or temporal, $F(1, 92) = .795$, $p > .25$, and participants who made upward contrasts were also similarly lonely whether their contrasts were social or temporal $F(1, 98) = .01$, $p > .25$. This was not surprising given that our examination of participants' written responses to the contrast manipulations suggested that contents of social and temporal contrasts were largely indistinguishable.

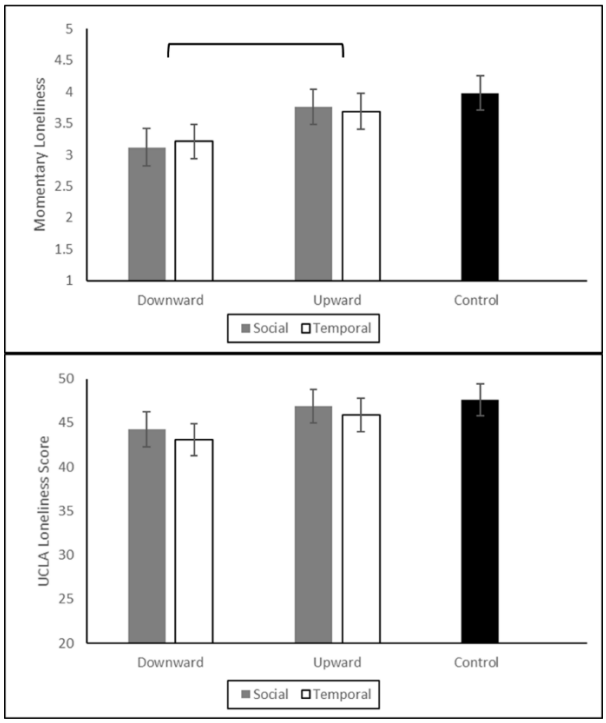

Figure 1.1. Adjusted marginal means for each condition for Study 1. Since the control condition included no contrasts, we present it separately in black. Momentary loneliness is a single item 7-point response scale and the UCLA scale has 20 items with a 4-point response scale. These values are adjusted for age and living status (alone, with others). Error bars are standard error and brackets indicate significant differences at the $p < .05$ level.

As noted in the Manipulation Check section above, some participants' contrasts referred to contact with others (e.g., I do/do not live with a loving partner) while some did not (e.g., I do/do not have spare money). It is conceivable that the latter types of issues still have downstream effects on contact—having no spare money might prevent one from spending time with friends or meeting new people, for instance. However, these types of contrasts do not unambiguously alter the comparison standard for determining a desired level of social contact, and so they might have weaker or no appreciable effects on loneliness (see Swann, Chang-Schneider, & Larsen McClarty, 2007). As this was the first study and somewhat exploratory in nature, we wondered whether (social or temporal, downward or upward) contrasts focusing on contact with other people have stronger effects on subsequent loneliness. To examine this

question, we divided participants in the contrast conditions into those who had generated one or two contrasts mentioning other people (n = 95) and those who had not generated any contrasts mentioning other people (n = 103), and repeated the analyses above separately for these two groups.

For participants whose contrasts mentioned other people (plus participants in the control condition), an ANCOVA with the 5 experimental conditions as a between-subjects factor and age and living status as covariates showed a significant effect of condition on feelings of loneliness, $F(4, 141) = 2.823$, $p = .027$, $\eta^2_{partial} = .069$. As in the full sample, downward versus upward contrasts reduced loneliness, $F(1, 91) = 6.808$, $p = .011$, $\eta^2_{partial} = .065$, and downward contrasts reduced loneliness compared to the control condition, $F(1, 108) = 9.17$, $p = .002$ $\eta^2_{partial} = .078$, but upward contrasts did not affect loneliness compared to the control condition, $p > .25$.

For participants whose contrasts did *not* mention other people, the ANCOVA showed no effect of condition, $F(4, 149) = .64$, $p > .25$, $\eta^2_{partial} = .017$, and so we did not conduct any follow up contrasts. Although these results must be interpreted with caution because participants were not randomly assigned to make comparisons about contact with others versus comparisons about other aspects of the living situation, they suggest—as one would expect—that it is contrasts pertaining to contact with other people that appreciably affect loneliness, at least in a sample of this size. In other words, the effect of our contrast manipulation was only found for the 52% of the 198 participants in the contrast conditions who mentioned other people in their contrasts.

This finding is useful in speaking against an availability bias or mood-based explanation for the results. Participants who thought about how their house was comparatively bigger or income comparatively better should have felt happier, and had a heightened availability of mood-congruent thoughts, than participants who thought about how their house was smaller or income

worse. However, these participants did not differ in the loneliness they reported, speaking against such mundane explanations for the manipulation's effects.

UCLA Loneliness Scale

We followed the same series of steps to analyze UCLA Loneliness Scale scores. As with the single-item measure, an ANCOVA with the 5 experimental conditions as a between-subjects factor and age and living status (alone versus with others) as covariates showed no significant effect of condition, $F(4, 244) = 1.20$, $p > .250$. The UCLA scores by condition mirror the pattern of self-reported current feelings of loneliness (see Figure 1), the differences were just smaller. However, when we tested effects on UCLA scores for participants whose contrasts mentioned other people (plus participants in the control condition), there was a significant effect of condition on feelings of loneliness, $F(4, 141) = 3.48$, $p = .01$, $\eta^2_{partial} = .084$. Just as with momentary feelings of loneliness, in this portion of the sample, downward versus upward contrasts produced relatively lower versus higher loneliness, $F(1, 143) = 3.17$, $p = .002$, $\eta^2_{partial} = .051$, and downward contrasts reduced loneliness compared to the control condition, $F(1, 108) = 4.93$, $p = .028$, $\eta^2_{partial} = .044$, but upward contrasts did not affect loneliness compared to the control condition, $F(1, 85) = .44$, $p > .25$.

These results represent initial support for the idea that loneliness is influenced by differences in the standard to which people compare their present achieved social contact. Identifying how achieved contact with others was better than a comparison target reduced loneliness compared to identifying how achieved contact was worse than a comparison target. These results are consistent with the idea that momentary social cognition—for instance, the relationships and standards presently on one's mind—can exert powerful effects on judgment. Here these results extended to answers on the UCLA loneliness scale, a trait measure—

suggesting that even relatively fleeting social cognition can influence the way that people retrospect on and report their experiences over the recent past.

Secondary to the difference between participants who made downward versus upward contrasts, we saw that downward contrasts reduced loneliness compared to a no-contrasts control condition, suggesting that such contrasts might be an effective intervention against loneliness. Although this recommendation is consistent with the finding that the most successful RCT-tested interventions against loneliness target social cognition (Masi, et al., 2011), one must consider that reducing loneliness compared to a control condition depends on the average level of loneliness for control participants and perhaps on their existing social cognition; we do not know what kinds of contrasts, if any, control condition participants mentally make when they evaluate and report on their loneliness. Since an intervention to reduce loneliness is likely to be most effective when developed using samples of individuals with high levels of loneliness, in our non-clinical samples we instead focused on replicating and understanding the relative effects of making downward versus upward contrasts.

Study 2

The aim of Study 2 was to replicate the effect on loneliness of downward versus upward contrasts. In order to strengthen this effect, and in hopes of identifying it in the whole sample rather than a subsample (based on the content of the contrasts), we explicitly instructed all participants to make contrasts about contact with others. As in Study 1, however, they were free to consider the quantity or quality of contact, or both dimensions.

We further utilized a portion of the sample in Study 2 to test another question of interest: would the effects of the manipulation be sustained over time? We did not necessarily anticipate that they would be, since the effects of social cognition on judgment should dissipate when the

cognition changes. However, it was conceivable that effects would linger temporarily; we conducted seven daily follow-ups with a sub-sample of participants to see if this was the case, and if so, how long the effects persisted.

Method

Participants and Design

Six hundred and thirty-one individuals in the USA recruited via MTurk, who had not participated in Study 1, completed the baseline survey materials in return for a $1.00 payment; a subset received an additional payment of up to $2.00 for completing follow-up surveys. We used a target sample size of 150 per cell and omitted the no-contrast control condition. This change meant that data would be analyzed with a 2 (contrast direction: downward, upward) x 2 (contrast type: social, temporal) between-subjects ANOVA. With two covariates (as in Study 1) this sample size had 98% power to detect an effect of the size observed in Study 1 (Faul, et al., 2007). Upon content analysis, 30 (4.7%) were excluded since they did not complete the contrasts as assigned. The final sample included 341 men, 259 women, and 1 person who identified gender as "FTM." Respondents were ages 18 to 82 (M = 32 years, SD = 9.80). Participants were randomly assigned to one cell of the 2 (contrast direction: downward, upward) x 2 (contrast type: social, temporal) between-subjects design (*ns* per cell = 147-154).

Materials and Procedure

The initial survey was similar to the materials and procedure of Study 1. The contrast manipulations were modified such that participants were asked to make comparisons about contact with other people. We provided an example of the relevant comparison in order to make sure that the instructions were clear. All participants first read:

> First, we are interested in how your present living situation (who you live with, where you live, how you live) compares to other people's living situations, specifically in terms of contact with other people (who you interact with, how those interactions go).

Thereafter, they read text that differed by condition (the text in italics is the portion that differed). In the downward social contrast condition, instructions read:

> For example, you might think that your living situation is *better* than other people's *because you live with someone whose interests are compatible with your own, and many people don't*. This is just an example; you should come up with your own answers. In the space below, please briefly describe two ways that your present living situation, in terms of contact with other people, is *better* than other people's living situations.

In the upward social contrast condition, instructions read:

> For example, you might think that your living situation is *worse* than other people's *because many people live with someone whose interests are compatible with their own, and you don't*. This is just an example; you should come up with your own answers. In the space below, please briefly describe two ways that your present living situation, in terms of contact with other people, is *worse* than other people's living situations.

In the downward temporal contrast condition, instructions read:

> For example, you might think that your living situation now is *better* than in the past *because now you live with people whose interests are more compatible with your own.* This is just an example; you should come up with your own answers. In the space below, please briefly describe two ways that your present living situation, in terms of contact with other people, is *better* than past living situations.

And finally, in the upward temporal contrast conditions instructions read:

> For example, you might think that your living situation now is *worse* than in the past *because you used to live with people whose interests were more compatible*

> *with your own*. This is just an example; you should come up with your own answers. In the space below, please briefly describe two ways that your present living situation, in terms of contact with other people, is *worse* than past living situations.

After making the specified contrasts, participants completed the single-item measure of loneliness and the UCLA Loneliness scale. To camouflage the purpose of the study, we presented these items intermixed with five measures unrelated to loneliness. These measures asked participants about their liking for music, liking for reading, how much they had slept the previous night, how often in the past week they had eaten breakfast, and how often they had skipped meals; the latter two were taken from Hays, Stacy, and DiMatteo (1984), and shown to be unrelated to loneliness (Hays & DiMatteo, 1987). We then measured demographic information and gave the opportunity to comment as in Study 1.

For seven days thereafter, we emailed a subsample of participants (n = 256) a link to complete a short survey that allowed us to test whether initial effects of the manipulation would be sustained. To camouflage the purpose of the study, for the first six days, participants were asked to name what they had eaten for lunch the previous day[2] and to indicate how much they currently liked music and liked reading, as well as to answer the single-item question about loneliness. On the seventh day, participants were administered these items plus the UCLA Loneliness Scale and the two meal regularity items. They were asked how much they had enjoyed participating in the series of surveys and what they thought the study was testing. They were then provided with another opportunity to comment on the survey and thanked for participation.

Results

Immediate Effects

As in Study 1, a sizable minority of participants (95; 15.8%) lived alone, and they reported more loneliness than those who lived with others, both in terms of current feelings (M_{Alone} = 3.65, SD = 1.86 versus M_{Others} = 2.82, SD = 1.85) and on the UCLA scale (M_{Alone} = 44.34, SD = 14.25 versus M_{Others} = 39.72, SD = 13.23), ts(581) > 3.07, ps < .01. As in Study 1, gender did not relate to either measure of loneliness, Fs < 1, and older participants again reported less loneliness on the UCLA scale, r(599) = -.09, p = .02. They also reported less momentary loneliness, though the relation was only marginally significant this time, r(599) = -.07, p = .07. Just as in Study 1, therefore, we adjusted for living status and age when testing the effects of the contrast manipulations.[3]

We modified our analysis strategy from Study 1. Since there was no control condition we used a 2 (contrast direction: downward, upward) x 2 (contrast type: social, temporal) factorial ANOVA to test the effects of the contrast manipulations. In addition, we analysed the two dependent variables (current feelings of loneliness and UCLA scale scores) simultaneously. The two measures of loneliness were strongly correlated, r(599) = .66, p < .001, although not so highly as to be collinear, satisfying the requirement for MANOVA (e.g., below .8; "MANOVA Assumptions", 2020). A MANOVA with age and living status (alone, with others) as covariates showed a multivariate effect of contrast direction, F(2, 595) = 38.02, p < .001, $\eta^2_{partial}$ = .11, no multivariate effect of contrast type, p > .25, and no multivariate interaction effect of contrast direction by type, p > .25. Adjusted marginal means are presented in Figure 2. Whether social or

temporal in nature, downward contrasts reduced loneliness compared to upward contrasts on the single-item measure of current feelings, $F(1, 595) = 76.25$, $p < .001$, $\eta^2_{partial} = .11$, and on the UCLA scale, $F(1, 595) = 31.60$, $p < .001$, $\eta^2_{partial} = .06$. These effects remained strong when omitting age and living status as covariates (ps < .001).

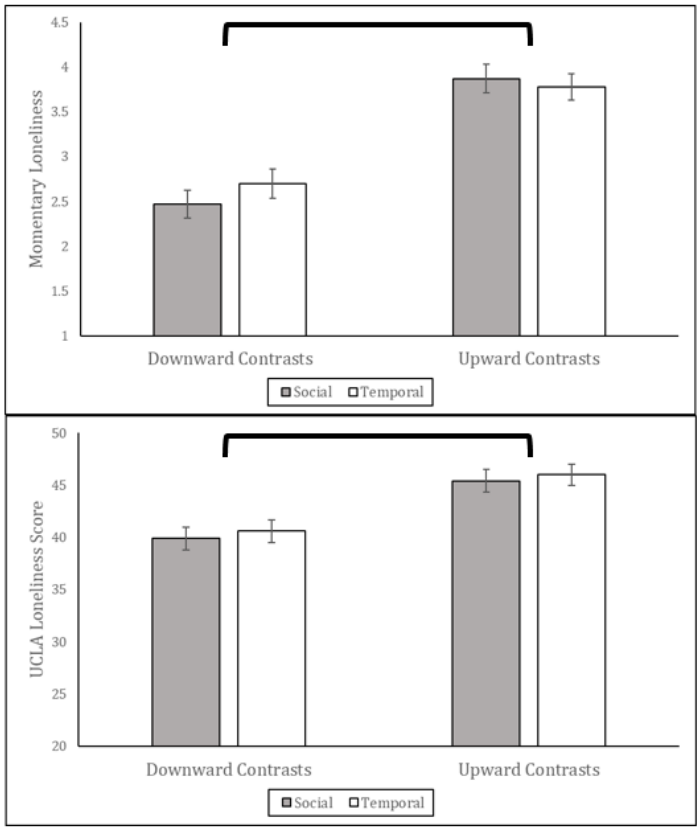

Figure 1.2. Adjusted marginal means for each condition for Study 2. Momentary loneliness is a single item 7-point response scale and the UCLA scale has 20 items with a 4-point response scale. These values are adjusted for age and living status (alone, with others). Error bars are standard error and brackets indicate significant differences at the p < .05 level.

Sustained Effects

Next, we tested whether differences in loneliness following the manipulation were sustained, for the set of participants who were contacted with innocuous daily follow-up surveys (n = 256). To do so we analyzed their daily reports of loneliness using Generalized Estimating

Equations. This analysis has the advantage of including all participants who completed at least one follow-up survey, unlike a traditional repeated-measures analysis where only all the participants who completed all follow-ups would be analysed. The predictors were baseline contrast direction (downward, upward), baseline contrast type (social, temporal), and day, plus all interaction effects. Again, living status and age were included as covariates. There was a significant effect of day, Wald $\chi^2(1) = 21.99$, $p = .003$, and a contrast direction by day interaction effect, Wald $\chi^2(1) = 46.21$ $p < .001$. Pairwise comparisons showed that although participants who made downward contrasts reported less loneliness than those who made upward contrasts immediately after the manipulation, $p < .001$, this difference was erased by the first follow-up survey, $p > .25$, and not detectable at subsequent follow-ups (see Figure 3). The lack of difference between condition on Days 1-7 indicates that the effects of the manipulation do not persist over time, at least not to an extent observable in a sample of this size.

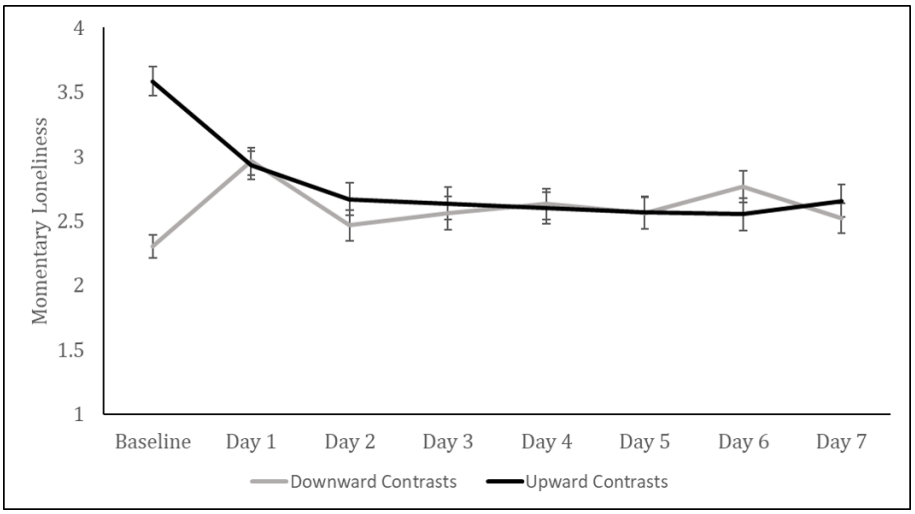

Figure 1.3. Average reported momentary loneliness at baseline, and over 7 further days, following the first contrast made. Error bars are standard error and the only significant group difference based on direction of contrast was found at baseline.

In Study 1, compared to the control condition, downward contrasts reduced loneliness, but upward contrasts did not significantly increase loneliness. One might therefore expect that

the difference between downward and upward contrasts immediately after the manipulation ("Baseline") is driven more by downward than upward contrasts; that loneliness in the upward contrasts condition is close to a theoretical control condition level. If this were the case, then we might also expect that loneliness on the follow-up Days 1-7 would be close to this level. Instead, Figure 3 highlights a relatively large reduction in loneliness in the days after making upward contrasts, and a relatively small increase in loneliness in the days after making downward contrasts. The picture painted by Figure 3 implies that each manipulation influenced loneliness (in opposite direction) relative to a hypothetical control condition, although we can only infer this given that there was no true control condition in this study.

As in Study 1, we hesitate to draw conclusions about one or the other condition driving the effect that we observed immediately after the manipulation, since it is likely to depend on participants' initial levels of loneliness. We addressed this question in Study 3.

Study 3

In Study 3, we used scores on the UCLA scale to divide participants into groups of low versus high loneliness, before asking them to make downward or upward social contrasts about their contact with others. This served two goals. First, with content analysis we could test whether people who were high in loneliness were *able* to make downward contrasts about their contact with others, and whether people who were low in loneliness were able to make upward contrasts, when asked to do so. Our supplementary analyses in Study 1 found a strong effect of the manipulation, on both momentary (single-item) loneliness and the UCLA scale, among participants whose contrasts mentioned other people. One mundane explanation for this finding is an attrition bias: participants in the downward contrasts condition who were extremely lonely refrained from making contrasts about their contact with other people (and mentioned their

income or the size of their house instead) because they were unable to make such downward contrasts. Finding that participants who are high in loneliness can in fact make downward contrasts about contact with others, and that participants low in loneliness can make upward contrasts about such contact, would speak against this explanation.

Second, we tested whether the manipulation was differentially impactful for people who were high or low in loneliness to start with. To identify a sufficient sample of participants relatively high in loneliness, we used a university student sample where loneliness was known to be rather widespread. Because doing so limited the possible sample size, we omitted the temporal contrasts conditions, reasoning that social contrasts might be more relevant to these relatively young participants. Peer comparisons are known to be ubiquitous for young adults like these (Gibbons & Buunk, 1999).

Finally, we administered a measure of interpersonal closeness in order to test the specificity of the manipulation and the extent to which it might be due to demand characteristics. Manipulating the way that participants see their own social contact as exceeding versus falling short of a standard for such contact should affect loneliness (e.g., Schoenmakers et al., 2012), but not the closeness participants feel to a specific other person. Finding that the manipulation affects feelings of loneliness but not interpersonal closeness would argue against demand characteristics as the explanation for the effect of the contrasts manipulation.

Method

Participants and Design

Two hundred forty-one undergraduate students at University of California, San Diego participated in the experiment for partial class credit. The sample included 44 men and 197 women, ages 18 to 35 (M = 20.62, SD = 2.13). The experiment used a 2 (social contrast

direction: downward, upward) x 2 (initial loneliness: low, high) between-subjects design. As in Study 1, we aimed for 50 participants per condition after excluding incorrect responses. Content analysis, which we used as a manipulation check and exclusion criteria in the first two experiments, played an additional role here: It allowed us to test whether participants high in loneliness were able to make downward contrasts. Exclusions are therefore described in more detail below.

Materials and Procedure

Participants first completed a survey including basic demographic information and the UCLA scale (Russell, 1996) as well as the Ten-Item Personality Inventory (Gosling, Rentfrow, & Swann, 2003) and Beck Depression Inventory (Beck, Steer, Ball, & Ranieri, 1996); the latter are not analyzed here. Cacioppo and Patrick (2008, p. 271) report that high loneliness is defined as summed UCLA scale scores of 44 or higher, so we created two groups, low (n = 111) versus high (n = 130), based on the cut-off score of 44.

Participants were then randomly assigned to make either two downward or two upward social contrasts using the instructions from Study 2. Thereafter they used a 7-point scale (1=*extremely untrue*, 7=*extremely true*) to indicate how a series of randomly-ordered statements applied to them. The measures included the single-item question about momentary loneliness ("I feel lonely") as in Studies 1 and 2, and filler items about liking for music and reading as in Study 2. We also added a single-item pictorial measure of interpersonal closeness, the Inclusion of Other in the Self scale (Aron, Aron, & Smollan, 1992). The scale depicts two circles representing "self" and "other" in seven degrees of overlap (depicted in online materials), which participants were asked to use to indicate the level of perceived closeness with their "closest friend."

Following these measures, we administered the Reading-the-Mind-in-the-Eyes test (Baron-Cohen et al., 2001) and the Empathy Quotient scale (Baron-Cohen & Wheelwright, 2004). These assessments addressed secondary hypotheses, and are not analyzed here. All test materials are posted at osf.io/6csyh.

Results and Discussion

Of 241 respondents, 70 (29%) did not make both of the contrasts they were asked to; in other words, they did not provide two contrasts that involved mention of other people, as instructed, and similar to our past cited studies, they were excluded. They were roughly evenly distributed across the downward (n = 31, 25.2%) and upward (n = 39, 33.1%) contrast conditions, $\chi^2(1) = 1.80$, $p = .18$. A binary logistic regression analysis indicated that participants low rather than high in initial loneliness were marginally less likely to complete the manipulation as instructed, b = .53, Wald $\chi^2(1) = 3.45$, $p = .063$; the odds of failing to complete the two instructed contrasts were 1.71 times higher for participants low in loneliness. However, there was no interaction effect between initial loneliness group and contrast condition, b = .28, Wald $\chi^2(1) = .95$, $p > .25$, indicating that the heightened tendency of participants low in loneliness to not make the instructed social contrasts was equally true whether they were instructed to make downward or upward contrasts. This finding strengthens the conclusions drawn from the supplementary results of Study 1 by speaking against an attrition bias driving those results.

Next, we tested the effect of the manipulation on the 172 participants who made the two contrasts as instructed, constituting in this case a check that the experimental manipulation was completed. As in Studies 1-2, men and women did not differ in the dependent variable indicator of momentary loneliness, $t(170) = .83$, $p > .25$. In this sample, a very small number of participants (n = 6, 3%) lived alone; they did not differ in present loneliness from those who

lived with others, $t(170) = .16$, $p > .25$. Age was also unrelated to present loneliness in this sample, $r(170) = -.08$, $p > .25$, unlike in Studies 1-2, probably because of the small age range of participants in Study 3. Therefore, we did not include age or living status as covariates in the analyses below.

Momentary loneliness and interpersonal closeness were correlated, $r(170) = -.30$, $p < .001$, so we next tested whether the effects of the manipulation would be specific to loneliness (rather than closeness), and whether these effects would depend on initial loneliness. To do so we conducted a repeated-measures ANOVA with on the scores, by adding measure (momentary loneliness or closeness) as a within-subjects predictor, along with the between-subjects predictors of loneliness group (low or high) and contrast condition (downward or upward). This analysis showed a marginally significant 3-way interaction effect of measure by contrast condition by initial loneliness, $F(1, 168) = 3.57$, $p = .06$, $\eta^2_{partial} = .021$ (see Figure 4).

To clarify this interaction we conducted between-group t-tests based on condition, separately on groups of "low" or "high" initial loneliness from the UCLA scale. For participants initially low in loneliness, downward contrasts resulted in marginally lower momentary loneliness than upward contrasts, $t(81) = -1.97$, $p = .053$. For participants initially high in loneliness on the UCLA scale, the contrasts manipulation had no effect on momentary loneliness, $p = .7610$. The contrasts manipulation did not appreciably affect perceived closeness to one's closest friend, for participants initially low in loneliness, or initially high in loneliness, ps $> .250$. The specificity of the manipulation's effect—influencing loneliness but not interpersonal closeness—speaks against demand characteristics as an explanation.

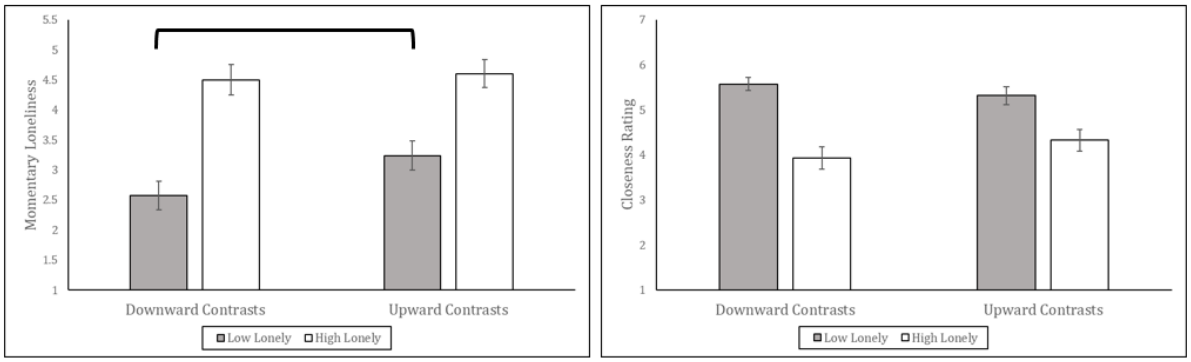

Figure 1.4. Momentary loneliness (single-item measure) and closeness to one's closest friend as a function of downward versus upward contrasts and initial loneliness (UCLA Loneliness scale score). These are group means and the error bars are standard error. The bracket indicates a finding within the Low Lonely group of contrast direction affecting loneliness at $p = .05$.

In light of the effects of downward versus upward contrasts seen in Studies 1 and 2, in samples where loneliness was rather low on average, it is probably unsurprising that the manipulation produced differences in loneliness for those students who were not highly lonely to start with. Nevertheless, this finding has important implications for the design of interventions against loneliness; it suggests that modifications would have to be made in order to utilize contrasts to decrease such feelings among the highly lonely.

In sum, the contrasts manipulation affected participants who were already low, but not high, in loneliness. This could, importantly, reflect an aspect of highly lonely individuals being somewhat resistant to such a brief contrast manipulation. It is possible that those already high in loneliness may not be affected by such a transitory consideration—whether they take it seriously or not—just because they may have already resigned to the "lonely mind" (Caccioppo & Hawkley, 2009).

High (trait) lonely participants didn't change in their (state) loneliness, so one interpretation would be that the effects are driven by the upward contrasts condition (i.e., upward contrasts increase loneliness). This interpretation would be in line with the relatively large

decrease in loneliness in the days following an upward contrasts manipulation that we observed in Study 2 (Figure 1). We therefore wondered what happens over time if people continue to make upward contrasts—do they experience sustained increases in loneliness? This question was not amenable to an experimental design since it would imply making people lonely (and perhaps inducing the negative health consequences of these feelings) over time. Instead, we used a panel survey.

Study 4

In Study 4 we analysed data from a population-representative sample of older adults in the United Kingdom. The measures of contrasts available in this panel study refer to courtesy and respect in service-based interactions (i.e., at restaurants, stores, or hospitals). These contrasts in Study 4 are more specific—and, one would expect, less important—than contrasts generated by participants in Studies 2-3, so we expected their effects to be weaker. However, the large representative sample that was contacted repeatedly in this study not only allowed us to track (small) predictive effects of upward contrasts on loneliness over time, it also complemented the American MTurk workers and university students who participated in Studies 1 to 3 to facilitate conclusions about generalizability.

Method

Participants and Design

The English Longitudinal Study of Aging (ELSA) includes approximately 12,000 respondents recruited to provide a representative sample of the English population aged 50 and over. Further information about the sample and methodology is available at http://www.elsa-project.ac.uk/. We analysed data from Waves 4 (2008-2009; n =11,050), 5 (2010-2011; n =10,275), and 6 (2013-2014, n =10,601).

Materials

The complete list of measures administered per wave is available at http://www.ifs.org.uk/ELSA/documentation. In order to test how upward contrasts relate to loneliness over time, we identified measures of both variables, as well as appropriate control variables, from the items administered.

Contrasts. At Wave 5 only, three items pertaining to upward social contrasts were presented in a section with the instructions: "In your day-to-day life, how often have any of the following things happened to you?" The first item asked whether "You are treated with less courtesy or respect than other people," the second asked whether "You receive poorer service than other people at restaurants or stores," and the third was "You receive poorer service or treatment than other people from doctors or hospitals." For all items, the response options were *almost every day* (6), *at least once a week* (5), *a few times a month* (4), *a few times a year* (3), *less than once a year* (2), and *never* (1). There were 7901 valid responses to the three items and their internal reliability was acceptable ($\alpha = .68$), so we summed responses to these items as an indicator of the frequency of upward social contrasts (ranged from 3 to 18, $M = 4.91$, $SD = 2.16$).

Loneliness. At Waves 4, 5, and 6, two items in the ELSA survey measured loneliness. On the first, respondents indicated whether or not they had felt lonely much of the time during the past week (*no* = 0, *yes* =1). The second item was: "How often do you feel lonely?" with response options *hardly ever or never* (1), *some of the time* (2), and *often* (3). At all three waves, responses to the two items were strongly correlated (Wave 4 $r(7346) = .57$, $p < .001$; Wave 5 $r(7988) = .57$, $p < .001$; Wave 6 $r(7712) = .56$, $p < .001$) and were summed to create a single indicator of loneliness (ranged from 1 to 4 at each Wave, $M_{T4} = 1.48$, $SD = .83$; $M_{T5} = 1.49$, $SD = .83$; $M_{T6} = 1.49$, $SD = .83$).

Control variables. Particularly in light of the way that upward social contrasts were measured in ELSA, it was important to establish that any link between contrasts and loneliness was not spuriously related to a third variable such as a negative worldview, or generalized negative affect. As the best available items to control for such a third variable, we used items intended to measure personality dimensions of neuroticism and agreeableness (Saucier, 1994). Cacioppo and Hawkley (2009) reported that the personality dimensions predictive of loneliness included high neuroticism and low agreeableness (see Cacioppo, et al., 2006; Marangoni & Ickes, 1989). To measure neuroticism, ELSA participants were asked to indicate how well "Moody" and "Nervous" described them, and to measure agreeableness, participants were asked to indicate how well "Sympathetic," "Warm," and "Helpful" described them, using response options *a lot* (1), *some* (2), *a little* (3), and *not at all* (4). These items were administered at Wave 5 only. We calculated the mean of the respective items to obtain indicators of neuroticism (α = .47, ranged from 1 to 4, M = 2.96, SD = .69) and agreeableness (α = .70, ranged from 1 to 4, M = 1.47, SD = .49). The two variables were only weakly correlated, $r(8847) = -.04$, $p < .001$.

Results and Discussion

First, we tested the cross-sectional relation of contrasts to expressions of loneliness, using the Wave 5 data. Thus, we modelled loneliness using multiple regression with amount of upward contrasts as a continuous predictor (Model 1). As expected, more frequent upward contrasts predicted higher concurrent loneliness, standardized $\beta = .14$, $t(7797) = 12.36$, $p < .001$, adjusted $R^2 = 1.9\%$. This relationship remained significant when controlling for neuroticism and agreeableness in Model 2, $\beta = .08$, $t(7722) = 7.28$, $p < .001$, adjusted $R^2 = 7.1\%$. As in previous work (Cacioppo et al., 2006; Marangoni & Ickes, 1989), in this multivariate analysis lower neuroticism predicted higher loneliness, $\beta = -.23$, $t(7722) = 20.31$, $p < .001$, and lower

agreeableness predicted higher loneliness, β = .05, $t(7722) = 4.59$, $p < .001$. Controlling for neuroticism and agreeableness helps to establish that the reason this measure of contrasts, which pertained to how one perceives treatment from others, relates to loneliness is not spuriously due to a negative way of seeing things. Results for both regression analyses are presented in Table 1.

Next, we tested the relationship between contrasts and loneliness over time. Loneliness was relatively stable over time (Wave 4 loneliness with Wave 5 loneliness $r(6902) = .65$, $p < .001$; Wave 5 loneliness with Wave 6 loneliness $r(7269) = .68$, $p < .001$), and sample sizes were slightly reduced by excluding participants who were missing responses at some waves. Nevertheless, contrasts at Wave 5 predicted loneliness at Wave 5 even when controlling for loneliness at Wave 4 along with controlling for neuroticism and agreeableness in Model 3, β = .03, $t(6687) = .03$, $p = .001$. Thus, in this population-representative sample of older adults in the United Kingdom, a small but reliable amount of the variance in loneliness was associated with upward social contrasts.

	adjusted R^2	Predictors	$\beta_{standardized}$	B	SE	*t* value	*p* value	VIF	AIC
Model 1	0.019	*(Intercept)*		1.218	0.023	53.12	< .001		18935.8
		Contrasts	0.139	0.053	0.004	12.36	< .001		
Model 2	0.071	*(Intercept)*		2.006	0.056	35.63	< .001		18316.9
		Neuroticism	-0.229	-0.274	0.013	-20.31	< .001	1.06	
		Agreeableness	0.051	0.086	0.019	4.59	< .001	1.01	
		Contrasts	0.082	0.031	0.004	7.28	< .001	1.06	
Model 3	0.433	*(Intercept)*		0.782	0.051	15.53	< .001		12290.1
		Loneliness at Wave 4	0.619	0.611	0.009	65.13	< .001	1.07	
		Neuroticism	-0.102	-0.12	0.011	-10.48	< .001	1.11	
		Agreeableness	0.032	0.054	0.015	3.5	< .001	1.01	
		Contrasts	0.031	0.012	0.004	3.24	0.001	1.07	

Figure 1.5. Regression Analysis Predicting Loneliness at Wave 5 from Other Wave 5 Predictors

However, controlling for loneliness at Wave 5, contrasts did not predict loneliness at Wave 6, $\beta = .014$, $t(7107) = 1.56$, $p = .12$.[4] In line with the theorizing above and results of the daily follow-up in Study 2, this result may speak to the importance of examining concurrent social cognition to understand loneliness. That is, contrasts are associated with loneliness at the same point in time, not in the future. If people make different contrasts (i.e., they change the way they think about their social contact), then loneliness should change.

Study 4 is valuable in showing a relationship between contrasts and changes in loneliness, which is not accounted for by personality indicators of a negative outlook on life, and which extends the earlier samples in age, culture, and representativeness. This relationship is particularly striking in light of the measure of contrasts, which by tapping courtesy and respect in service interactions, refers to contrasts that are more specific and probably less important than those identified in the experimental manipulations. In spite of their specificity and likely low importance, these contrasts explained variance in loneliness concurrently as well as from the past to the present. One limitation of the experiments (Study 1-3) that is not addressed in the survey design of Study 4, however, is whether people *spontaneously* make social and temporal contrasts when thinking about their contact with other people. We used content analysis in Study 5 to gain insight into this issue—how prevalent are such contrasts in conversations about daily life, what do they look like, and are they linked to expressions of loneliness.

Study 5

In the course of research about the experience of solo living, Klinenberg (2012) interviewed middle-aged middle-class adults and older adults who lived alone. These were long-

form, semi-structured interviews utilizing open-ended questions around the topic of living alone. Since contrasts were not the research topic of interest, participants were not asked whether or how they compared their social contact to others or to the past; therefore, we content-analyzed the interview transcripts to look for the presence of spontaneous contrast statements. We also noted whether or not participants, who lived alone and therefore were likely to have objectively low social contact, described themselves as lonely. To avoid coder bias producing a link between the presence of contrasts and perceived loneliness in a transcript, we used a multi-step coding method.

Participants and Design

There were 122 transcribed one-on-one interviews collected by Klinenberg (2012; see data collection details on p. 235-237) available for analysis. Interview subjects were adults who lived alone in major metropolitan areas of the United States, primarily four boroughs of New York City (Brooklyn, the Bronx, Manhattan, and Queens). Age and gender information, where available, is noted below.

Procedure

First, a research assistant read the 122 interviews and noted the interviewee's gender and age (if specified) as well as whether or not the interviewee was asked about loneliness. Twenty-five interviews that did not include this question were excluded from analysis. The remaining sample of 97 included 69 women and 28 men ages 33 to 97 (19 interviewees did not provide their ages). In this sample, 48 interviewees (49%) reported being lonely (i.e., said "yes" when asked if they were lonely), 39 (40%) reported not being lonely (i.e., said "no"), and 10 (10%) gave an unclear answer.

In the second step of coding, one of three research assistants read each of the 97 interviews and extracted each statement that they saw as pertaining to comparisons about one's life or living situation. They extracted 689 statements formed of one or more contiguous sentences, of which 314 (46%) were classified as social contrasts, 270 (39%) as temporal contrasts, and 105 (15%) as unclear or neither of these.

In the third step, the 584 social and temporal contrast statements from the 97 interviews were sorted in a random order and the identity of the interviewee was concealed. These statements were then coded by two research assistants as downward contrasts in which the present was better than the comparison standard, upward contrasts in which the present was worse than the comparison standard, or unclear/can't tell. After the first pass coding, the research assistants discussed approximately one-third of the cases on which they had disagreed, before re-coding the remaining disagreements. This method yielded high inter-coder agreement, Cohen's Kappa = .72. Of the 106 remaining disagreements, 75 (71%) were resolved by a third coder, and 31 (29%) that could not be resolved were discarded from analysis. This coding procedure resulted in 553 contrast statements from interviews with 96 participants; frequencies by direction and type, along with examples, are summarized in Table 2.

	Contrast Direction		
Contrast Type	Downward	Upward	Unclear
Social	130 (23.5%) *A lot of single women feel like failures or something and they get a man and they're just like oh good I've made it you know? And they'll marry a guy that almost, well not that they can't stand, but that bugs them and even that they've lost respect for or whatever but they've already put a year or two of dating into it and he's basically harmless and it's like going back into the dating world, it would be like having your teeth pulled out. They can't deal with that… And I just see a lot of that as being sort of false and not really my priority because of fear of not having someone or because my ego needs it or I need the validation.*	73 (13.2%) *Despite the way I live I am a very relational person and, to me, meaning comes from relationships so when there are not people there sometimes I think too much about…you get existential problems about living alone. What is this for? Who am I giving it to? Where is the love in my life? All these questions come to bear on you when you live alone in a different way. I say that to other people and they say that's not true, when you live with other people you get the same questions. They're just not as insisting because there's more distraction.*	93 (16.8%)
Temporal	103 (18.6%) *And being alone, really alone is a lot easier than being that alone that's because of the coldness in a relationship. I would much rather live alone then deal with something like that again.*	121 (21.9%) *I liked sharing the minutia of daily life, I liked things that—now that I live alone, so much of my daily experience never gets reported. But living with someone else you tell silly crazy things that don't matter in the big scope, but they make you feel more like a person when those little things register, so I liked that. I liked being able to plan in person whatever we were going to do.*	33 (6.0%)

Figure 1.6 Contrast frequencies and examples by type and direction in Study 5

Results and Discussion

The first thing to note is that contrast statements were common in the interviews. Considering only those contrasts where the direction was clear, interviewees made an average of 1.35 downward social contrasts (*SD* = 1.69), .76 upward social contrasts (*SD* = 1.06), 1.07 downward temporal contrasts (*SD* = 1.39), and 1.26 upward temporal contrasts (*SD* = 1.15). Eighty percent of interviewees made at least one clear downward contrast, and eighty-seven percent made at least one clear upward contrast. In the subset of participants (n = 80) where age could be identified, older participants were less likely to have made a downward temporal contrast, $r(78) = -.25$, $p = .026$.

How did contrasts in the interviews relate to expressions of loneliness? When we compared the three groups of participants, who were lonely, not lonely, and unclear in their response, there was no difference in the mean number of contrast statements of the various types, Fs(2, 93) < 1.09, ps > .25. However, in a binary logistic regression analysis, the presence (versus absence) of *downward* temporal and social contrasts together marginally predicted being lonely (versus not being lonely), $\chi^2(2) = 5.04$, $p = .08$. The coefficients on the dummy variables representing the presence of downward social contrasts, b = -.72, exp(b) = .49, and downward temporal contrasts, b = -.67, exp(b) = .51, indicated that the probability of being lonely was lower for participants who made these contrasts. The presence (versus absence) of upward temporal and social contrasts, on the other hand, was unrelated to loneliness (versus not being lonely), $\chi^2(2) = .05$, $p > .25$.

Why might the predictive links to expressed loneliness be driven by the presence versus absence of (downward) contrasts, rather than the number of contrasts of various types? Several factors are worth considering. Methodologically, extracting the comparative statements from

their context—which has the benefit of preventing coder bias (i.e., coders were blind to participants' loneliness when coding the direction of the contrasts)—has the side effect of leaving some statements unclear in direction. Presence versus absence is thus measured with more precision than number. More interesting theoretically, it is possible that contrast statements that are particularly strong or meaningful to the participant—information that is impossible to discern from an interview transcript—might compensate for more, but weaker, contrasts of opposite direction (Swann, et al., 2007). In sum, however, this content analysis suggests both the prevalence of spontaneous social and temporal contrasts about contact with others, and a link between those contrasts and loneliness.

General Discussion

Loneliness stems from the perception that the present living situation has inadequate social connection (Cacioppo & Patrick, 2008). As with many perceptions, *inadequacy* here is determined by comparing the present to a criterion, such as social connection *apparently* achieved by others or in one's own past. When the present living situation surpasses the criterion, people should feel less lonely than when the present living situation falls short of a criterion. In line with this speculation, the results from five studies suggest that downward contrasts, which depict the present quality and/or quantity of social contact as better than a given standard, produce lower loneliness than upward contrasts, which depict the present social contact as worse than a standard. These results contribute to an important gap in the literature on loneliness, which is generally defined in terms of a discrepancy between existing relationships and the standards desired for those relationships. Whereas previous research has largely focused on the existing relationships, the present studies show that the other component of the definition also plays an important, even causal, role.

The mixed methods of these studies contribute different strengths. The first three, with experimental designs, show a causal relation between contrasts and loneliness. Although this relation may well be bidirectional—lonely people probably have a tendency to see themselves as relatively worse off—very briefly induced downward versus upward contrasts produced consistent differences in loneliness, demonstrating that in this direction the relation can be understood as causal. The large survey dataset analysed in Study 4 indicated that upward social contrasts (even in specific and minor life domains) can explain variance in both concurrent loneliness and changes in loneliness over time, in a population-representative sample of older adults. And adding richness to the experimental and survey data, the content analyses in Study 5 suggest that temporal and social contrasts are a common ingredient in thoughts and conversations about daily life among individuals at risk of feeling lonely (i.e., solo dwellers).

The contributions of this research are both theoretical and practical. On the theoretical side, we show that loneliness is influenced by the standards against which people compare their social connections. This finding is fully in line with work that defines loneliness as a discrepancy between existing relationships and the standards desired for those relationships (e.g., Cacioppo & Patrick, 2008)— supporting it empirically complements the bulk of research that has focused on determinants in terms of relationships themselves rather than standards. It is also interesting theoretically to note that when social and temporal contrasts were both examined (Study 1, 2, 5), they appeared to exert similar effects. Note that there may be groups for whom one or the other type of contrast comes more naturally or is more powerful (see e.g., Lyubomirsky & Ross, 1997). However, in our studies both content and effects of the two types of comparisons were largely indistinguishable. The present research also suggests that downward contrasts may decrease loneliness (Study 1, 5) and upward contrasts may increase loneliness (Study 2, 3, 4)

compared to some reference value, but more research is needed on this point. We suspect the answer will depend at least in part on the level of loneliness and the style of thinking with which participants begin.

One practical implication concerns how to study downstream consequences of loneliness. Most investigations use correlational methodology. When experiments are utilized, they have relied on time- and labor-intensive methodologies like hypnosis to induce loneliness (Cacioppo, et al., 2006). Future research can use the quick and inexpensive identification of contrasts to induce relatively high versus low loneliness and study downstream consequences. Importantly, the effect of the contrast manipulation on momentary loneliness was mainly prevalent only when participants engaged in contrasts that mentioned other people.

A further practical implication concerns interventions against loneliness. Such interventions are often based on changing existing relationships—introducing participants to new people or helping them feel closer to those they know. Or, one might change the relationships that are salient; for instance, reminding people about their social connections, which enhances trust in others, reduces aggression in response to social exclusion (Twenge, et al., 2007). The present research suggests that targeting the standards against which these relationships are evaluated is a fruitful avenue to explore, but more exploration is needed. Indeed, interventions targeting social cognition appear to be the most beneficial (Masi, et al., 2011), but they often involve weeks- or months-long sessions of cognitive therapy. Future research might explore how to make the effects of contrasts identified here more powerful, perhaps by having participants make more than 2 contrasts, by inducing social and temporal contrasts at the same time (see Zell & Alicke, 2009), by building on temporal contrasts to help participants generate counterfactual statements about what they could have done differently and could do differently in the future

(Epstude & Roese, 2008; Smallman & Roese, 2009), or by harnessing assimilation processes as well as contrasts. Then, incorporating contrasts into social cognition interventions might make those interventions more expedient as well as more effective.

The present studies focused on downward and upward comparisons in which people identify dissimilarities between their present living situation and a standard. One should note that making comparisons by identifying similarities, which leads to assimilation rather than contrast in judgment (Bless & Schwarz, 2010; Mussweiler, 2003), might produce effects opposite to those hypothesized and identified here. For example, people instructed to identify ways that their living situations were *similar to* someone else's living situation might feel less lonely if that someone else had a high rather than low quality of social contact. Assimilation processes explain why merely seeing a well-off target (e.g., someone with extremely high-quality relationships) does not necessarily make observers feel lonely (Bless & Schwarz, 2010). Interventions against loneliness based on social comparisons might therefore induce both downward contrasts and upward assimilation.

In addition, future research might usefully extend the examination of comparison processes. For instance, one could examine lateral comparisons (i.e., no difference between self and other; no change between past and present), or comparisons to a possible future self. This latter type of comparison might occur spontaneously if people assimilate their circumstances to a downward social target and feel threatened that a possible future self could end up in the same situation as the worse-off other, or if people assimilate their circumstances to an upward social target and feel inspired that a possible future self could end up in the same situation as the better-off other (e.g., Strahan & Wilson, 2006). Future studies may also add mood measures taken (before and) after the manipulation, in order to rule out possible more generalized mechanisms of

the manipulation's impact on loneliness judgments. We also note that SES / income level was not incorporated in these studies, but as it shapes potential valuation of life conditions, it should be measured in future studies.

Finally, while the present paper focused on the role of social comparisons, it is important to remember that feelings of loneliness are determined by multiple sources. Classic work focused on aberrant processing of social stimuli that promote positive social interactions (Cacioppo & Hawkley, 2009). More recent theorizing highlights a possible role of interoceptive dysregulation, in which lonely individuals lose the ability to accurately "tune in" to one's own internal, especially emotional, states and properly used them in social judgments (Arnold, Winkielman, & Dobkins, 2019). Recent related research also highlights the deficits in spontaneous responding of lonely individuals to positive signals of social connection (Arnold & Winkielman, 2020). As such, future studies may explore the interaction of higher-order social comparison processes with these more basic mechanisms.

In sum, the primary contribution of this series of studies is the attention to the comparison standards that people use to evaluate their loneliness. Feelings of loneliness produce unmistakable emotional distress, often accompanied by a host of undesirable health consequences (Cacioppo & Patrick, 2008). As the present research highlights, these feelings depend not only on objective information about existing relationships, but also on the way that people think about those relationships and the standards against which people compare them.

Chapter 1, in full, is a reprint of the material as it appears in Frontiers in Psychology 2021. Arnold, Andrew J.; Kappes, Heather; Klinenberg, Eric; Winkielman, Piotr, 2021. The dissertation author was the primary investigator author of this paper.

Chapter 2:

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.

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, & Christaskis, 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; Dezecache 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 (Sonnby-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).

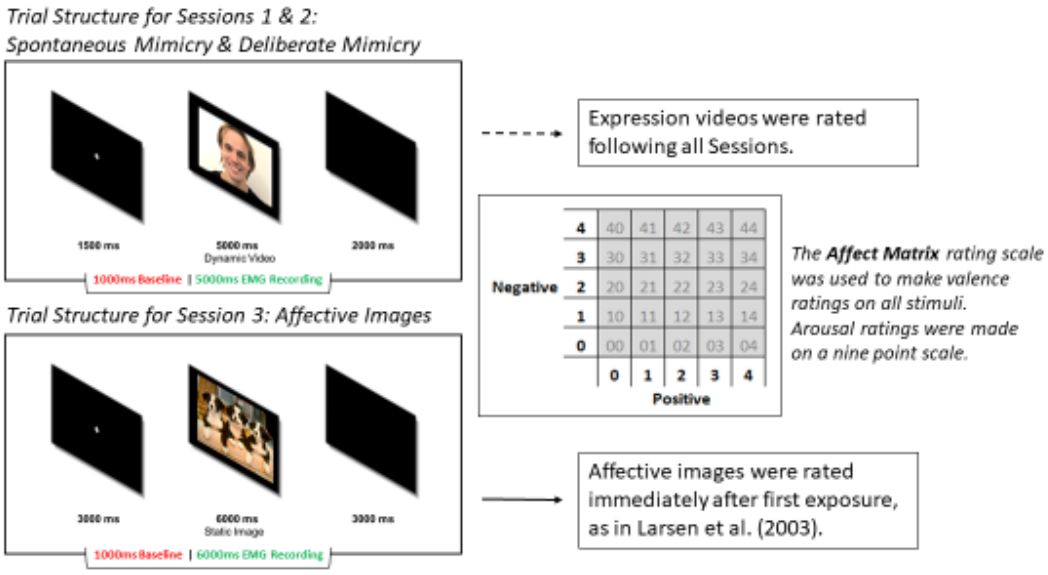

Figure 2.1. Task Design.

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 makings 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 supercilii (brow), according to fEMG processing standards (Tassinary 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 supercilli 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 *p*s > .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 (*p*s > .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: $F(3,99) = 233.01$, $p < .001$, $\eta^2_{partial} = .876$. 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: $F(3,99) = 143.87$, $p < .001$, $\eta^2_{partial} = .813$. 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: $F(3,99) = 3.87$, $p = .012$, $\eta^2_{partial} = .105$. 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.

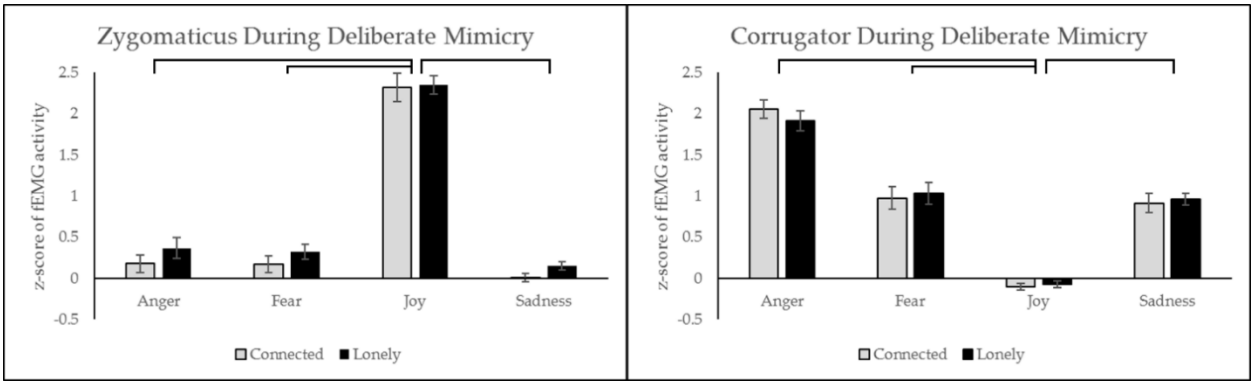

Figure 2.2. Average Deliberate Mimicry Activity to Facial Expressions. Significant emotion differences are noted by brackets and error bars represent SEM.

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: $F(3,99) = 3.46$, $p = .019$, $\eta^2_{partial} = .095$. 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: $F(3,99) = 3.51$, $p = .018$, $\eta^2_{partial} = .096$. 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 ($p > .250$).

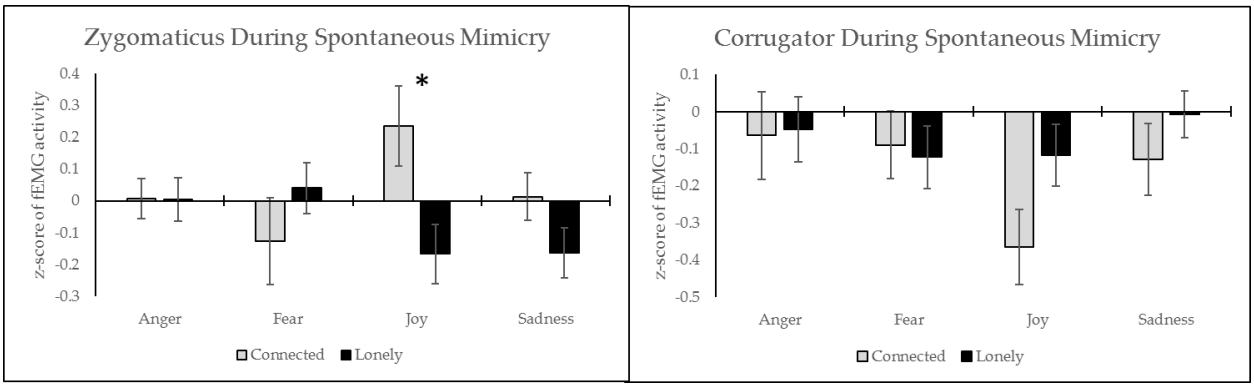

Figure 2.3. Average Spontaneous Mimicry Activity to Facial Expressions. Significant group differences are noted by * and error bars represent SEM.

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: $F(1,33) = 4.80$, $p < .036$, $\eta^2_{\text{partial}} = .127$.

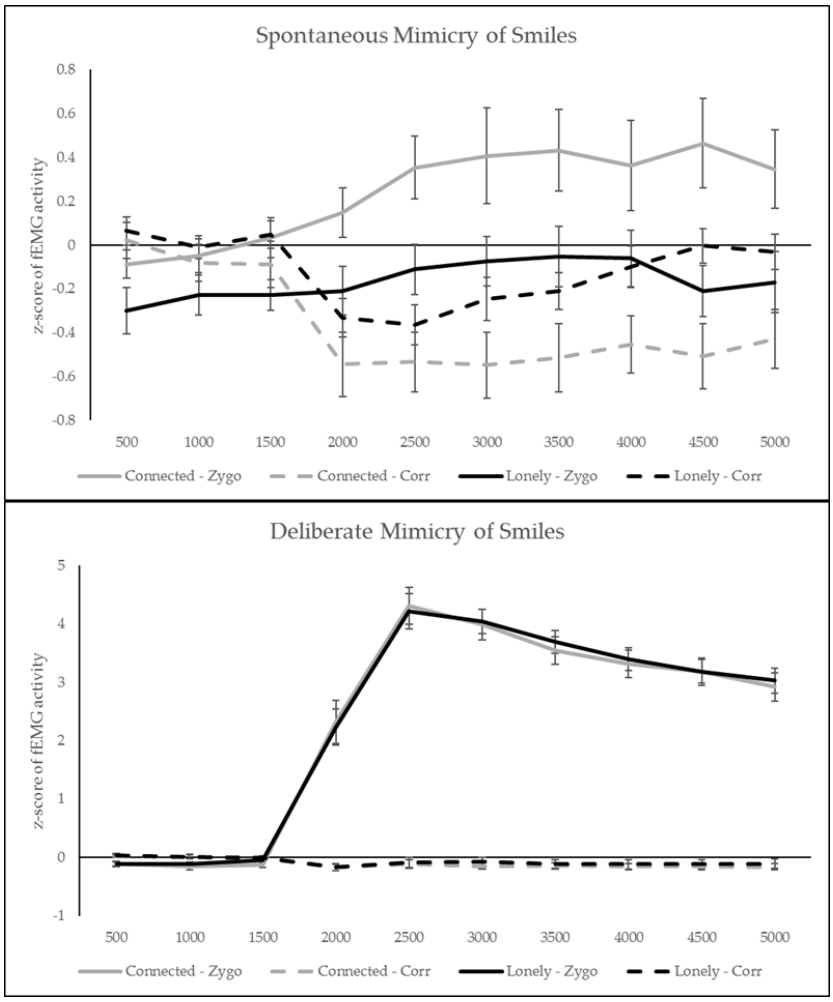

Figure 2.4. Loneliness is associated with impaired spontaneous, but intact deliberate, mimicry of smiles. In both plots, we plotted average muscle activity for both Zygomaticus and Corrugator during 500ms periods. Loneliness is associated with reduced activity of both muscles during spontaneous smile 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 (Tassinary & 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, $r(33) = -0.42$, $p = .012$, *CI*: [-0.66— -0.10].

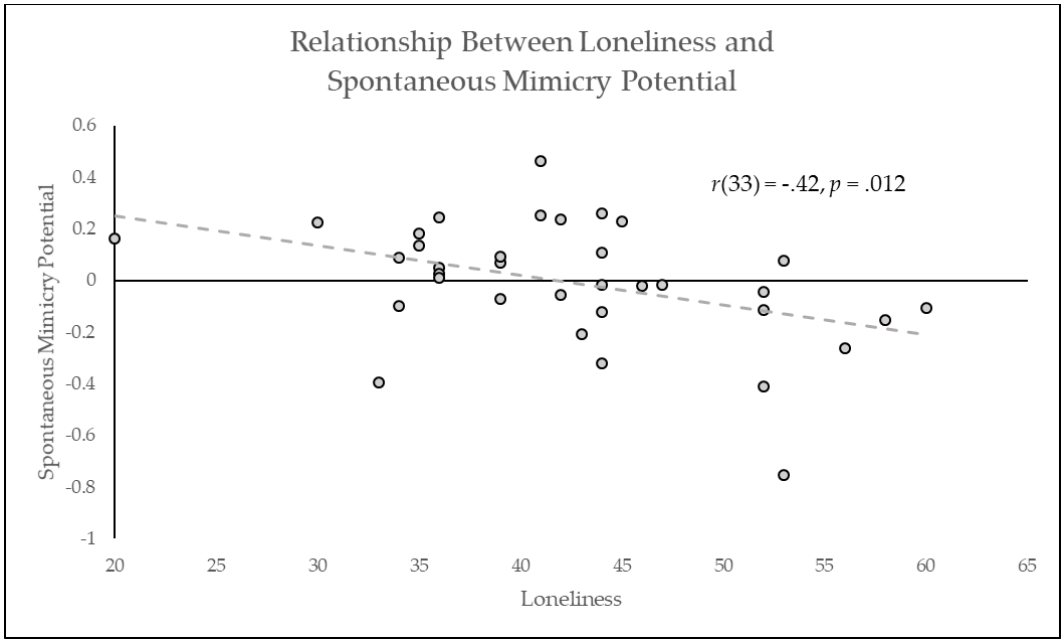

Figure 2.5. Loneliness is negatively correlated with Spontaneous Mimicry Potential (SMP).

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: $F(2,66) = 5.07$, $p = .009$, $\eta^2_{partial} = .133$. 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: $F(2,66) = 18.28$, $p < .001$, $\eta^2_{partial} = .356$. 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.

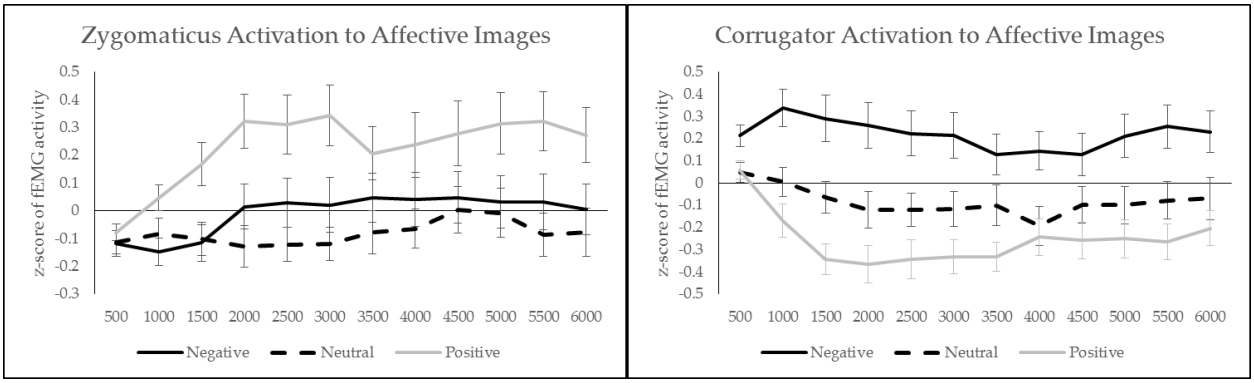

Figure 2.6. Affective Images Reliably Cause Smiling and Frowning Reactions. Loneliness was not associated with differences in reaction to Negative, Neutral, or Positive images.

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% CI: [0.12— 0.67]) and extraversion ($r(33) = -.60$, $p < .001$, 95% 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 *p*s > .250). Similarly, we found no differences in deliberate zygomaticus mimicry as a function of either construct (all *p*s > .250), or interactions between emotion and depression ($p = .122$) or extraversion ($p > .250$).

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 *dis*connection 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 (Sonnby-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 *hypo*vigilance 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.

Chapter 2, in full, is a reprint of the material as it appears in Social Neuroscience 2021. Arnold, Andrew J.; Winkielman, Piotr, 2020. The dissertation author was the primary investigator author of this paper.

Chapter 3:

Some Body to Trust: A meta-analysis revealing diminished interoceptive body trust in loneliness

ABSTRACT

Loneliness—perceived social isolation—is pervasive and detrimental to human health, reflecting thwarted social connection needs. Interoception—perception and appraisal of physiological states—reflects central regulation of motivation and behavior to fulfill homeostatic needs. Using meta-analysis of cross-sectional survey data, we demonstrate aberrant interoceptive sensibility in loneliness. Across 17 samples of over 4000 participants, diminished interoceptive body trust emerged as a consistent predictor of loneliness. We used multiple regression to demonstrate unique contribution of diminished body trust to loneliness compared to contributing factors depression and alexithymia, and protective factors gratitude and self-compassion.

This research highlights a core dysfunctional relationship to the bodily self in loneliness, with implications for disordered emotional and social processing, as well as interoceptive intervention for psychosocial health. We discuss the meaning of body trust in the context of its growing clinical interest and explore how interoception may represent intrapersonal connection which impacts feelings of interpersonal connection.

INTRODUCTION

"To form meaningful connections with others, we must first connect with ourselves."

~ Brene Brown

All humans harbor an evolved capacity for loneliness, as well as the capacity to understand and "connect" with themselves. Here we present the first known evidence linking loneliness to aberrant self-reported interoceptive sensibility, or how people consciously attend to, relate to, and appraise their bodily signals. We show that interoceptive body trust—a sense of felt

safety in the body and trusting of bodily signals—is particularly diminished in loneliness. Our results cast interoception in loneliness as a sense of fractured intrapersonal connection coexisting with poor interpersonal connection.

Social Connection and Affective & Cognitive Biases in Loneliness

For optimal health and functioning, quality social connection is a vital homeostatic need, and the goal of social connection and belonging underlies much of our cognition and behavior (Baumeister & Leary, 1995). Loneliness—*perceived* social isolation—results when this need is not fulfilled, and is distinct from objective social isolation, which does not always cause loneliness (Cacioppo & Hawkley, 2009). This subjective "social pain" evolved to motivate us to (re)connect, but carries dangerous consequences when loneliness persists. The importance of quality social connection for health is robustly demonstrated by studies on the associations of loneliness and specific physiological dysregulation (e.g., poor sleep; Hom et al., 2020) and heightened all-cause mortality risk (Rico-Uribe et al., 2018). Loneliness looms as a growing public health concern across many modern societies. Cross-temporal meta-analyses suggest overall loneliness across diverse populations has increased since the 1970s, particularly in young adults (Beucker et al., 2021).

Cacioppo & colleagues (2009) characterized loneliness with an underlying attentional bias—*hypervigilance for social threat* (HST), in which individuals automatically process negative—over positive—social phenomena. Because we require social connection, this paradoxically self-defeating bias serves to color the social world as aversive, with lonely people looking for potential signs of social rejection to confirm their maladaptive social predictions about themselves. Social behavior and accurate emotional processing may be subsequently dysregulated—e.g., automatic smile mimicry, an affiliative social signal, is impaired in

loneliness (Arnold & Winkielman, 2020). These cognitive and behavioral (mal)adaptations reflect a lonely mindset akin to "social learned helplessness", which can be hard to overcome. In general, loneliness reduction interventions are not very successful, with a recent review suggesting tailoring approaches to idiosyncratic social need perceptions (Fakoya et al., 2020). Idiosyncratic emotional and social perception in loneliness is further complicated by increased depression—though loneliness may be the more central malady since longitudinally, loneliness causes depression but not vice versa (Cacioppo et al., 2010). Additionally, loneliness is encumbered by reduced prosocial emotions of gratitude and self-compassion. Gratitude and self-compassion each carry benefits to psychosocial health, with gratitude strengthening perceived social bonds, and self-compassion predicting greater concern for others (Neff & Pommier, 2013). Loneliness is also associated with fear of compassion, perhaps reflecting the self-conscious lonely mindset encumbered in social cognition (Best et al., 2021). Gratitude and self-compassion, interestingly, represent "heartfulness"—affective components that mediate the salubrious effects of mindfulness on subjective well-being (Voci et al., 2019). Recently, interventions to increase gratitude (Bartlett & Arpin, 2019) and self-compassion (Andel et al., 2021) have proven successful in reducing loneliness. In the same vein, the most successful loneliness reduction interventions utilize training in mindfulness and meditation techniques (Lindsay et al., 2019), which can improve self-acceptance and accurate assessment of own's needs and emotions. Clearly, loneliness relies on perception of inadequate social connection—but what comprises perceptions of connection?

Interoception and Psychosocial Health

Interoception—the processing and appraisal of bodily states—is a central mechanism underlying psychosocial health, integrating selfhood and affect (Craig, 2009). Research interest

in interoception is increasing due to its formative role affect, motivation, and selfhood (Quigley et al., 2021). Interoceptive dysregulation underlies various mental health challenges (Khalsa et al., 2018). But curiously, few studies have examined how interoception may be dysregulated in loneliness. This is an important unanswered research question because interoception integrates a sense of self (Tsakiris, 2017) and appears to improve emotional clarity, since interoceptive failure results in alexithymia—difficulty identifying and describing one's emotions (Brewer et al., 2016). Combined, negative self-referential processing and distorted emotional perception may be rooted in interoceptive dysregulation.

Alexithymia was recently shown to predict greater loneliness and psychosocial stress, with reduced insula reactivity to emotional faces mediating this relationship (Morr et al., 2021). This study suggests that alexithymia reflects less "interoceptive resonance" of (social) emotion in the insula, which sustains loneliness and negative emotional consequences. To the extent that loneliness is associated with self-conscious maladaptive social cognition and negative affect, how might the bodily self manifest in loneliness?

Arnold & colleagues (2019), suggested that interoception may be dysregulated in loneliness, given its importance for sensing needs, perceiving emotion, and social cognition (von Mohr et al., 2021). They highlight that HST is exteroceptive—attuned to social stimuli outside of one's self, which may operate at attentional cost to interoceptive attention in social situations, impairing social affective learning. Recent theoretical accounts of social homeostasis (Lee et al., 2021) and dysfunctional brain-body interactions associated with loneliness (Quadt et al., 2020) particularly highlight the importance of interoception in adaptive social functioning. Interoception is a critical process by which an organism monitors its internal states to regulate levels of needed vital resources (e.g., food, water, and social connection) and motivate behavior

to acquire those resources (Petzchner et al., 2021). How might interoception monitor and motivate fulfillment of social needs?

Although beyond the scope of this article, the embodied predictive interoceptive coding (EPIC) model uses Bayesian active inference principles to detail how "interoceptive predictions" may arise and sustain maladaptive affective and physiological conditions, such as depression (Barrett & Simmons, 2015). Interoceptive predictions represent ongoing visceromotor adjustments to the body in anticipation of expected demands, based on appraisal of the current situation and prior experience in similar contexts. Integrating this account with those of Arnold (2019) and Qaudt (2020) and colleagues, the notion of a "locked-in" brain resistant to learning from (social) interoceptive input aligns with loneliness as "social learned helpless" driven by hypervigilance for social threat and predicts interoceptive dysfunction. The notion of self-defeating "interoceptive predictions" in social situations in loneliness invites further investigation, since it may reflect the self-conscious maladaptive social cognition inherent in loneliness (Cacioppo & Hawkley, 2009). For example, a lonely person at a party may expect social rejection, impairing certain affiliative social responses (e.g. smile mimicry; Arnold & Winkielman, 2020) that serve to make their dour social predictions a self-fulfilling prophecy. How interoceptive predictions may relate to self-beliefs and social expectations is a promising area for new research, but first we examine how interoceptive sensibility relates to loneliness.

Although there are different ways to operationalize interoception (Garfinkel et al., 2015), here we focus on interoceptive sensibility (IS)—subjective experience of bodily signals and their appraisal. The MAIA scales (Mehling et al., 2012) have been widely used to differentiate adaptive and maladaptive attentional orientations to the bodily self. Of the eight subscales of the MAIA, Body Trust has emerged as particularly relevant for mental health—diminished body

trust has been documented in depression (Dunne et al., 2021), suicidality (Rogers et al., 2018), and eating disorder symptomology, acting as a central "bridge" mechanism (Brown et al., 2020). Beyond specific clinical disorders, body trust also emerges as the strongest MAIA subscale associated with transdiagnostic symptom of alexithymia (Gaggero et al., 2021).

How interoceptive sensibility relates to brain function, and other emotional capacities, is just beginning to be examined. Smith and colleagues (2021) demonstrated resting state functional connectivity differences—with MAIA scores predicting lower visual cortical activity, which may reflect attentional predisposition to bodily sensation over visual imagery. Further, brief self-compassion training altered pain-related neural activity which correlated with increased self-compassion scores and MAIA scales, particularly for the body listening subscale (Berry et al., 2021). Contemplative practice—particularly body scan and breath meditation—for 3 months, similar to meditation interventions for loneliness, can increase MAIA scores, including body trust (Bornemann et al., 2015). Clearly, more research on MAIA scales and their neural representation is warranted, as they may reflect key capacities underlying psychosocial health.

Current Study

Loneliness is a core condition underlying psychosocial health, rising within modern populations, and given the utility for interoception in assessing an organism's needs, how interoception may serve social needs deserves more examination. Recognizing this, we asked how does loneliness relate to interoceptive sensibility?

With the attendant social stigma of loneliness (Kerr & Stanley, 2021) in young adult populations, and the potential utility for self-compassion to buffer against stigmatized identities (Wong et al., 2019), we wondered if subjective self-relevant interoceptive perception was associated with loneliness. We collected 17 samples of cross-sectional survey data from a

community-based college population across eight years, all of which included MAIA scales and the UCLA loneliness scale. Smaller subsets of these samples also included measures of depression, alexithymia, gratitude, and self-compassion, allowing us to test for the relative impact of IS to loneliness compared to known correlates. Using multiple regression and meta-analysis, we found that diminished body trust was a highly consistent predictor of loneliness, which may represent a core component of "intra-personal connection" that impacts perceptions of quality social connection.

METHOD

Participants and Design

Across 17 samples, we collected survey data from 4,292 undergraduates at the University of California, San Diego who received course credit for completing the survey (Age: M = 21.22; SD = 1.57; 73.9% female). The research protocol was reviewed and approved by the Institutional Review Board. Informed consent was obtained from all participants.

Survey Design & Scales of Interest

Surveys across the 17 samples varied in composition, here we report only scales of interest. All measures have been previously validated and standardized. Loneliness in all samples 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 that they feel this way. Total scores range from 20 to 80, with higher values reflecting greater loneliness.

Interoceptive sensibility (IS) in all samples was assessed with the Multidimensional Assessment of Interoceptive Awareness (MAIA) scales (Mehling et al., 2012). This 32-item

measure produces eight subscales: Noticing, Not Distracting, Not Worrying, Attention Regulation, Emotional Awareness, Self Regulation, Body Listening, & Body Trust. Participants respond on a 6-point Likert scale from 0 (Never) to 5 (Always), indicating the frequency that they agree with statements such as "I trust my body sensations." Subscales scores were averaged across the appropriate items.

Depression was assessed with the CESD-ML (Cacioppo et al., 2010) in four samples and the DASS21 (Lovibond & Lovibond, 1995) in thirteen samples. The DASS21 also assesses Anxiety and Stress, which were included in Wave 2 analyses. Participants respond on a 4-point Likert scale indicating the frequency they certain statements apply to them *over the past week*: "I felt down-hearted and blue."

Alexithymia was assessed with the Toronto Alexithymia Scale (TAS; Bagby et al., 1994), a 20-item measure which produces three subscales: Difficulty Identifying Feelings (DIF), Difficulty Describing Feelings (DDF), and External Oriented Thinking (EOT). Participants respond on a 5-point Likert, indicating the degree to which statements describe them: "I am often confused about what emotion I am feeling".

Gratitude was assessed with the Gratitude Questionnaire 6-item form (GQ-6; McCullough et al., 2002), which produces a total score of 6-42. Participants respond on a 7-point Likert scale, indicating the extent they agree with statements like: " I am grateful to a wide variety of people".

Self-Compassion was assessed with the Self-Compassion Scale-Short Form (SCS-SF; Raes et al., 2011), a 12-item measure which produces a total score from 12-60. Participants respond on a 5-point Likert scale, indicating the frequency they endorse statements such as: "I try to be understanding and patient towards those aspects of my personality I don't like."

The Inclusion of Other in the Self (IOS) scale (Aron et al., 1992) was adapted to assess "closest connection", a measure of felt closeness with one's closest friend. Participants respond 1-7 in this single-item pictorial measure, indicating which set of progressively overlapping circles (representing self and other), represents how much "closeness" or "overlap" they perceive with their "closest friend".

Data Cleaning and Management

Survey data were collected over a period of eight years (2013-2021), in 17 separate samples. Seven samples were collected in lab, completed prior to engaging in other behavioral tasks. Ten samples were collected remotely using Qualtrics (ref); in three of these samples we included "attention check" questions instructing a specific response to ensure they were reading the question. Participants who failed these responses were removed, listed under "AC_removed". Participants were instructed to complete the survey in one sitting with minimal distractions; however, for online samples this may not have always been followed. Thus, we implemented a duration-based screening procedure for all online surveys. Target duration for each survey was 30 minutes or less, so we first removed participants who took over 60 minutes for completion. Then for each sample, we calculated mean duration and standard deviation (SD) and removed participants who were three SDs away from the mean, as long duration suggests distraction and quick duration suggests inattentiveness. Participants removed in this way are listed under "D_removed". Exclusion criteria and counts for each survey are listed in Table 1.

Study Name	Date	AC_removed	D_removed	n	UCLA	MAIA	DEPRESSION	ALEXITHYMIA	GRATITUDE	SELF-COMPASSION	IOS/CC
L1	2013 FA	-	-	112	+	+					
L2	2015 FA	-	-	85	+	+	CESD-ML				
L3	2016 SP	-	-	115	+	+					
L4	2016 FA	-	-	226	+	+		+	+		
L5	2017 SP	-	-	199	+	+		+			+
L6	2017 SP	-	-	242	+	+	DASS21	+			+
L7	2019 SP	-	-	63	+	+	DASS21	+	+	+	+
O1	2015 SP	-	13	236	+	+	CESD-ML		+		+
O2	2016 WI	-	17	301	+	+	CESD-ML		+		+
O3	2016 SP	-	16	356	+	+	CESD-ML		+		+
O4	2017 SP	-	41	638	+	+	DASS21	+	+		+
O5	2018 WI	-	3	63	+	+	DASS21	+	+		+
O6	2018 SP	-	8	158	+	+	DASS21	+	+	+	+
O7	2018 FA	-	24	402	+	+	DASS21	+	+	+	+
O8	2019 SP	53	10	199	+	+	DASS21	+	+	+	+
O9	2021 WI	51	24	319	+	+	DASS21	+	+	+	+
O10	2021 FA	166	50	578	+	+	DASS21	+	+	+	+
			Wave 1	4292							
			Wave 2.1	3640							
			Wave 2.2	2662							
			Waves 3 & 4	1719							

Figure 3.1. Breakdown of scale inclusion across 17 independent samples. L indicates samples collected in lab, O indicates samples collected online through Qualtrics.

RESULTS

Loneliness Across 17 Samples

Average loneliness across all 4,292 participants score was M_{UCLA}=45.97, SD_{UCLA}=9.89 (Figure 2a), which is higher than other meta-analyses of young adult samples (Buecker et al., 2021). Self-reported gender and age did not impact loneliness scores (ps > 0.250).

Correlations between Loneliness and MAIA scales

As a first step, we computed a correlation matrix of all eight MAIA scales and Loneliness scores using data from all 17 samples. As seen in Figure 1, the correlations between Loneliness and several of the MAIA subscales were small (r = 0.2 – 0.4) to moderate (r = 0.4 - 0.6) in effect size, with the largest effect seen between Body Trust and Loneliness. In addition, similar to previous studies (e.g., Eggart, 2021), several of the MAIA subscales were moderately correlated with one another, with the largest effect seen between Body Listening and Self-Regulation (r = 0.61).

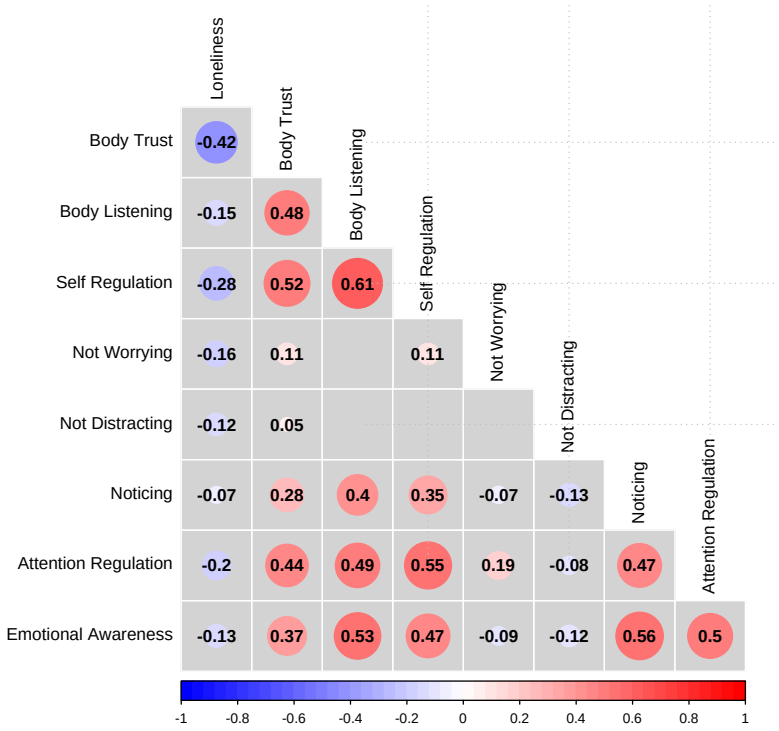

Figure 3.2. Significant zero-order between Loneliness and the 8 subscales of the MAIA. The size of the circle reflects the effect size, with blue representing a negative correlation and red representing a positive correlation.

Wave 1: The contribution of Interoceptive Sensibility to Loneliness

Given the moderate inter-relatedness between the eight MAIA scales in the zero-order correlations, our next step was to determine the *unique* contribution of each to Loneliness. To this end, we conducted a meta-analysis (using metaphor in R, see Methods) with all 17 samples, all of which collected UCLA Loneliness and the eight MAIA For each of the eight MAIA scales, this meta-analysis produces a standardized β for that subscale for each of the 17 samples, and then a "real" population effect as a summary statistic across the samples (which includes 95% confidence intervals). After confirming that there was no significant heterogeneity across the 17 samples ($Q(16) = 12.54$, $p > .250$), the meta-analysis revealed significant effects for five of the

eight MAIA subscales: Body Trust, Body Listening, Self-Regulation, Not Worrying, and Not Distracting. Because the effect of Body Trust was the strongest, in Figure 2, we show the resulting forest plot for this MAIA subscale. With the exception of one sample (05, with small n), all other samples revealed effect sizes whose confidence intervals did not overlap with 0. The summary statistic (at the bottom), revealed a β of -.385, $p < .001$, SE= .018, 95% CI = [.42,-.35]. (Forest plots for the other seven MAIA subscales are in Supplementary materials.)

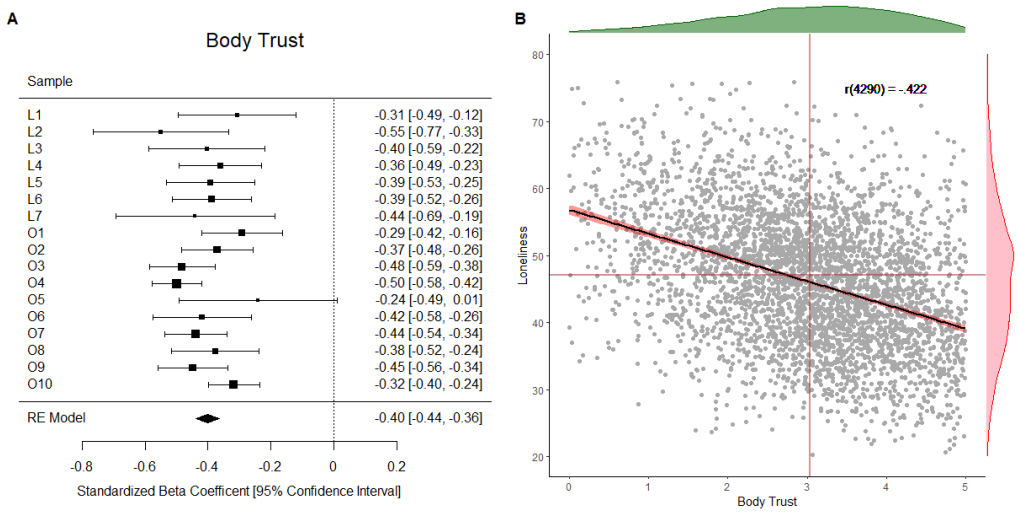

Figure 3.3. a. Forest plot depicting β effect sizes for each sample and overall meta-analytic effect: β = -.385 [-.42, -.35), p < .001. **b.** And regression line with distributions.

In Figure 3, we show violin plots for all five MAIA subscales that significantly (and uniquely) predicted Loneliness. As can be seen, Body Trust had the largest effect by far, being strongly negatively associated with Loneliness. Regarding the other four MAIA subscales, Loneliness was found to be positively associated with Body Listening, and negatively associated with Self-Regulation, Not Worrying, and Not Distracting. In the Discussion, we return to the meaning of these associations, and the fact that the association between Body Listening and Loneliness is negative in the zero-order correlation (above), yet positive once all the other scales are accounted for in the multiple regression. For the remainder of our analyses (Waves 2 – 4),

we present only the results pertaining to the Body Trust subscale of the MAIA. However, to take a conservative approach, we chose to still include the four other MAIA subscales that showed significant effects in Wave 1, so as to continually highlight the unique contribution of Body Trust (from interoceptive sensibility) to Loneliness.

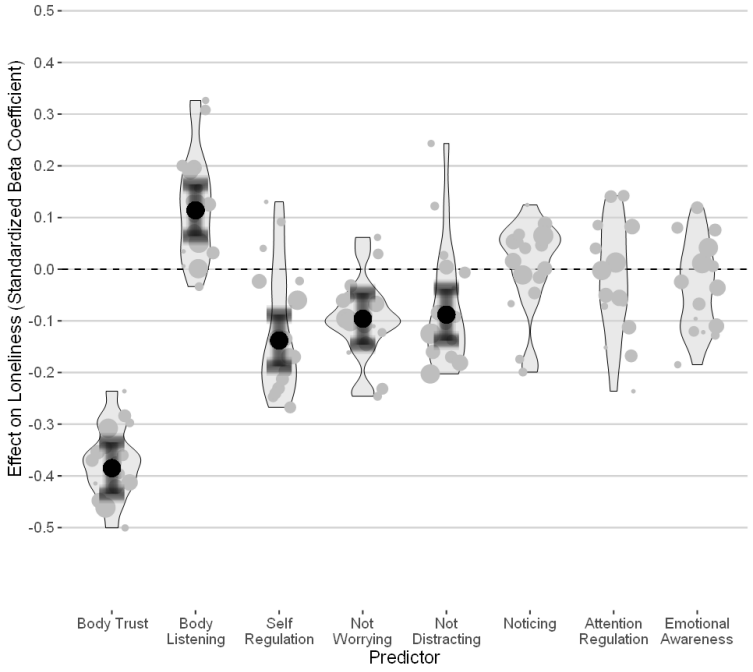

Figure 3.4. Violin plots represent relative frequency of effect size by width. Each sample is a circle sized by sample size. Black circles are means of all samples, with standard deviation error bars.

Wave 2: Accounting for Emotional Difficulties: Depression & Alexithymia

In nine samples, Depression was measured by DASS21 along with indices of Anxiety and Stress (n = 2662). Also included as predictors were three components of Alexithymia, as measured by the Toronto Alexithymia Scale: Difficulty Describing Feelings (DDF), Difficulty Identifying Feelings (DIF), and External Oriented Thinking (EOT). These extra six constructs, along with BT, were regressed onto loneliness. Across all samples, Depression (M= .428, SE=

.026), DDF (M=.253, SE= .037), and Body Trust (M= -.195, SE= .030) were all significant predictors of loneliness (ps < .001).

Even when accounting for negative emotionality, the contribution of Body Trust to Loneliness stayed significant (β = -.19, CI: [-.25 – -.13], see Table 1 for β values of the other constructs and model comparisons).

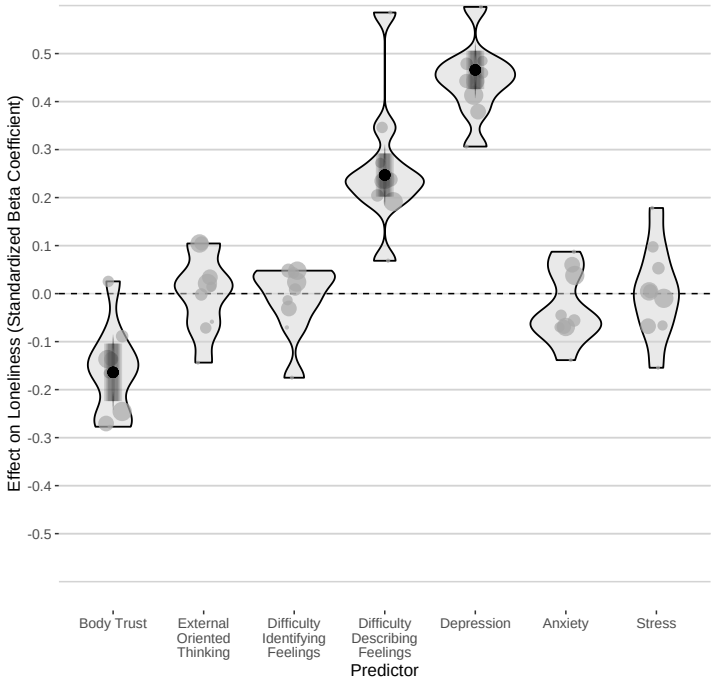

Figure 3.5. Violin plots for all eligible samples for significant loneliness predictors: Body Trust, Alexithymia_DDF, & Depression.

Wave 3: The Contribution of Body Trust to Loneliness Accounting for Positive Emotionality

In six samples (n = 1719), we collected indices of "positive emotionality": gratitude and self-compassion. A meta-analysis was conducted to investigate the unique contribution of Body Trust when these two "positive emotionality" constructs were included (plus the four subscales of the MAIA, and the two "negative emotionality" scales, that showed significant effects in Wave 1 and 2, respectively). Shown in Figure 5 are violin plots for Body Trust alongside the four other positive and negative emotionality constructs. As in Wave 2, the negative

emotionality constructs remained significant (although the effects of Depression were lower, owing to correlations between positive and negative constructs, see Figure 7, below). In line with previous literature, Gratitude and Self-Compassion were found to be negatively associated with Loneliness. Because zero-order correlational analyses (from Wave 4 data, see Figure 7 below) showed small to moderate associations between Body Trust and Self-Compassion (r = .47) and Gratitude (r = .32), it is not surprising that adding these constructs to the meta-analysis reduced the observed contribution of Body Trust to Loneliness. Nonetheless, even when accounting for positive and negative emotionality, the contribution of Body Trust to Loneliness stayed significant (β = -.11, *CI:* [-.15 – -.05], see Table 1 for β values of the other constructs and model comparisons).

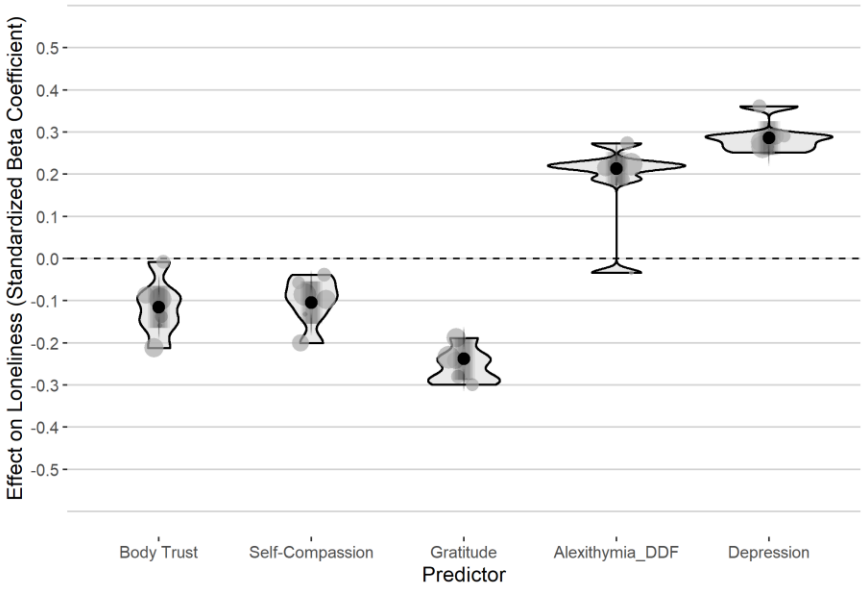

Figure 3.6. Violin plots for all eligible samples for significant loneliness predictors from Wave 3.

Wave 4: Accounting for Closest Connection (CC)

How might body trust impact social connection? To examine the potentially operative role of being "interoceptively on" and trusting one's own signals, we included the Inclusion of

Other in Self scale as a measure of "closest closeness" (CC). The IOS is a single-item pictorial measure, here used to rate perceived closeness to one's "closest friend". This person may be a partner, parent, or best friend, a role which, while critical for social well-being, is perhaps more instrumental in nature. That is, it's possible that engaging actively with one's interoceptive and emotional capabilities is not always (at least) crucial to maintain closeness with this person. We included CC in regressions and plotted significant meta-analytic effects as before in Figure 5. It is notable that while overall Loneliness remains the DV, by including CC as a predictor, the DV can now be considered perceived social connection beyond one's closest social connection.

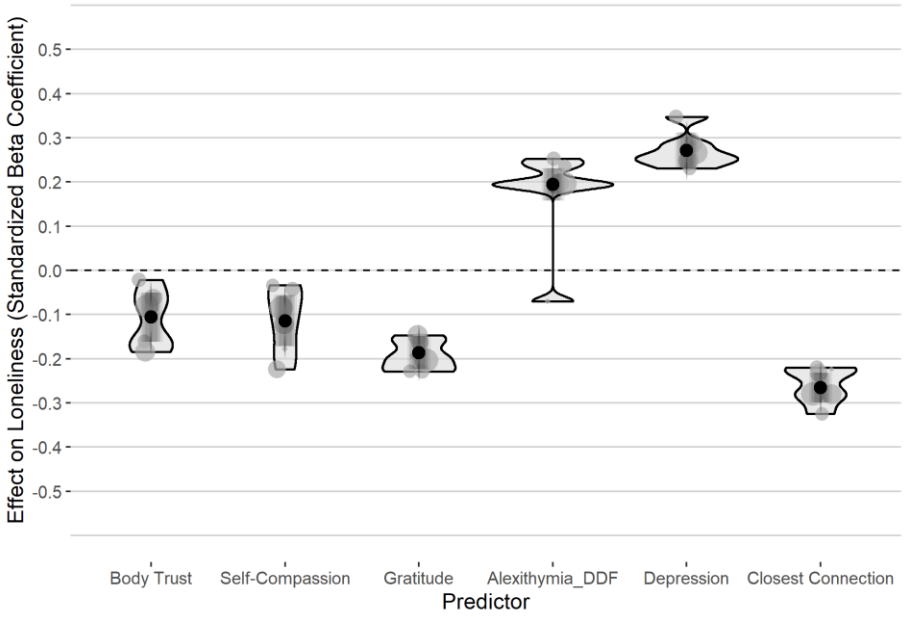

Figure 3.7. Violin plots including all significant previous predictors and CC.

Finally, we computed a total correlation matrix for all participants including all these six predictors along with loneliness. CC was correlated with loneliness at -0.41, suggesting the closeness of this relationship accounts for ~20% of variance in overall loneliness when other predictors are not included—the same at BT.

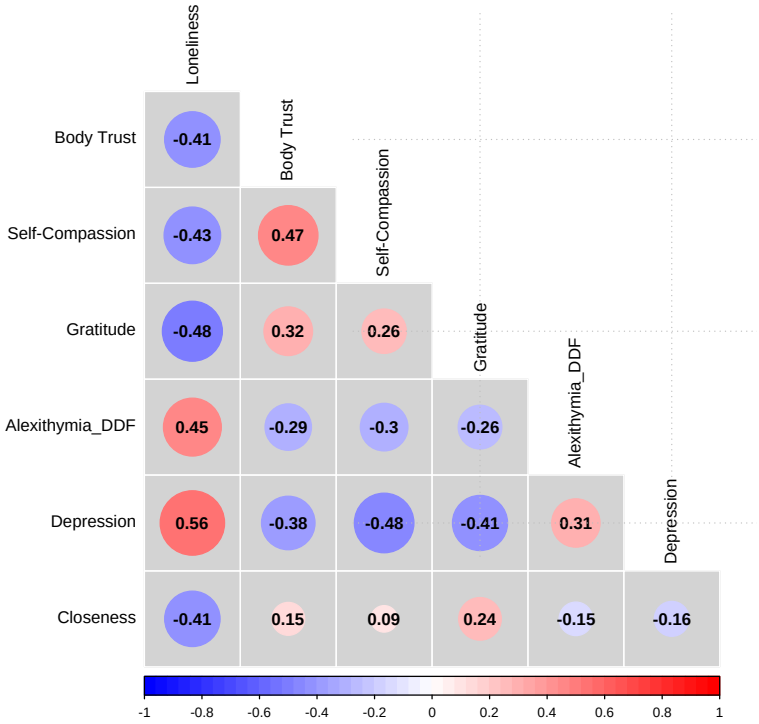

Figure 3.8. Correlation matrix including DV loneliness and 6 major predictors.

Model Comparison

	Beta Predicting Loneliness		
	(1)	(2)	(3)
Body Trust	-0.202***	-0.106***	-0.091***
	(0.016)	(0.021)	(0.019)
Alexithymia_DDF	0.258***	0.232***	0.212***
	(0.016)	(0.019)	(0.018)
Depression	0.416***	0.294***	0.280***
	(0.016)	(0.022)	(0.020)
Self Compassion		-0.105***	-0.113***
		(0.022)	(0.020)
Gratitude		-0.242***	-0.192***
		(0.020)	(0.019)
Closeness			-0.264***
			(0.017)
Observations	2,662	1,718	1,718
R^2	0.445	0.474	0.539
Adjusted R^2	0.445	0.473	0.537
Residual Std. Error	0.745 (df = 2658)	0.726 (df = 1712)	0.680 (df = 1711)
Significance levels		*p<0.05; **p<0.01; ***p<0.001	

Figure 3.9. Individual level regression model comparison
Model (1) from Wave 2, Model (2) from Wave 3, Model (3) from Wave 4.

Chapter 3, in part, is currently being prepared for submission for publication of the material. Arnold, Andrew J.; Dobkins, Karen. The dissertation author was the primary investigator author of this paper.

GENERAL DISCUSSION

Altogether, this dissertation aimed to assay, investigate, present, and inspire scientific research that can improve human health. Whether this goal will be reached is, as always, subject to uncertain forces, but the intent was pure, by focusing on quality social connection as a vital homeostatic need. As subjective perception produces so much of human flourishing or suffering, to examine intrapersonal—and especially *interoceptive*—mechanisms supporting the common need of quality social connection, may be useful to research in social-affective neuroscience. Indeed, the growing field of "social interoception" holds great potential for improving scientific understanding of emotion, well-being, and social connection, as well as inspiring interoceptive interventions for various clinical disorders. The research presented here addressed some gaps in the loneliness and interoception literature(s).

Our results from Chapter 1 constitute one of the first comprehensive studies on loneliness and comparisons. Naturally, social comparison is a ubiquitous process that occurs in myriad life domains (e.g., class, professional, family) but we showed relative domain specificity for comparisons involving perceived social contact to impact momentary feelings of loneliness (Study 1). Social comparisons were obviously interpersonal, comparing to an imagined other standard, while temporal comparisons (compare to your past self) were *intrapersonal*. Interestingly, both types of *downward* comparisons resulted in lower perceived loneliness (Studies 1-2) than control no-comparisons or upward comparisons conditions. We also showed more specificity of comparison effects to feelings of loneliness, with expected null effects on felt closeness to an established "closest friend" (Closeness results in Study 3). And finally, in Studies 4 and 5, we demonstrated that upward contrasts are associated with loneliness in a representative

community sample of older adults, and upward contrasts spontaneously occur in interview transcripts of single-dwellers.

In light of the earlier section on self-processing, self-other similarity and social connection, these results may provide clues for further research in self- and other-representations in social connection. Our comparisons/contrasts manipulation is an easy and brief tool for (momentarily) altering perceptions of loneliness through social representations, and could be made stronger by using specific social comparisons (as in Courtney & Meyer, 2020). Following the results from this study, which demonstrates robust self-representation (and social similarity) in mPFC, one intriguing research question is to further examine the differences and linkages between interoceptive (insular) and prefrontal self-representations.

In Chapter 2, we demonstrate the first evidence of altered spontaneous—but not deliberate—spontaneous facial mimicry in loneliness using fEMG. Our experimental design allowed us to show that spontaneous smile mimicry was associated with loneliness, but not spontaneous smiling to positive images, or explicit valence ratings, or reaction time to the stimuli. The latter results suggest that overt attention and engagement with the task was not the reason for selective impaired smile mimicry, but future studies should also test if the (implicit) cognitive bias in loneliness, hypervigilance for social threat, is related to mimicry and social responding. We also showed that these effects were relatively specific to loneliness, since depression and extraversion did not covary with any facial responding differences. And although we cannot conclude causality direction for the demonstrated association between loneliness and impaired smile mimicry, given other convergent results on loneliness and physiology, I expect future studies will show that loneliness impairs social responding, and not vice versa.

Since publication of our results, another study examined groups high and low in loneliness on ability to intentionally synchronize motor behavior with a target stimulus while participants were scanned in fMRI (Saporta et al., 2021). High-lonely individuals showed impaired behavioral synchronization performance along with altered functional connectivity in the "observation-execution" system which reflects motor monitoring, representation, and potentially mirror neuron activity. Another study demonstrated reduced behavioral synchrony and specifically smile mimicry in depressed vs. control participants during naturalistic social behavior, using blind behavioral coding of video-taped diagnostic interviews (Altmann et al., 2021). Although loneliness was not measured here, depression is often comorbid and these types of motor withdrawal during intentional and spontaneous social behavior may be common in both conditions. Other constructs related to loneliness are social anxiety and autistic symptomology, which were examined in a recent fEMG mimicry study. Folz and colleagues (2022) engaged participants under fEMG recording in a facial emotion recognition task, viewing videos of emotional expressions and making ratings of emotion type and confidence in each rating. This task design instituted different demand effects than our Session I of passive viewing to gauge spontaneous facial mimicry, and while expected SFM was observed (i.e., Zygomaticus to joy, Corrugator to Anger), social anxiety and autistic traits did not interact with fEMG activity. However, performance accuracy and confidence differed as a function of the measured traits. For social anxiety, higher trait levels predicted lower performance confidence, although performance accuracy was not affected. For autistic traits, higher levels were associated with worse recognition as well as a weakened link between performance and facial mimicry.

Other relevant research on facial mimicry, interoception, and their interaction has produced greater context for our findings. Here we review some recent studies and expand the scope, motivating further research. But first, consider these linking principles:

- mimicry is a ubiquitous social process that depends on a) an internal model of the bodily self as an effector and b) perception of the mimicked state on a social model
- facial mimicry activity contributes to muscle-specific emotion perception
- interoception is intimately involved with self-processing & self-other distinction
- loneliness is rooted in perception of self as lacking

Our original findings led us to wonder if lonely people are (or can be) aware of their (lack of) smiling, and if not, might this partly reflect interoceptive deficits? Studies explicitly linking interoception to mimicry are currently scarce, but considering the facilitation of interoception for adaptive behavior and the "smart" context-dependence and inherent social utility of spontaneous mimicry (Arnold & Winkielman, 2019), we might expect interoceptive ability to facilitate mimicry. Evidence for this was found by Imafuku and colleagues (2020), with greater heartbeat-counting accuracy (IAcc) predicting greater spontaneous smile mimicry, but only for models with direct gaze toward the participant. Less smile mimicry was found for averted gaze models, and the interoceptive-boost only was found in direct gaze trials. Similar results of interoceptive accuracy boosting strategic social processing were found using an emotional Go/NoGo paradigm, with images of fear or disgust expressions as trial stimuli (Chick et al., 2020). fEMG corrugator activity was recorded during task performance as a measure of facial mimicry, and a heartbeat-counting task measured IAcc. Higher IAcc was associated with higher perceptual sensitivity (accurate performance) for discriminating emotional faces, but not response bias tendency. Corrugator mimicry activity was more strongly correlated with task performance in

higher-IAcc individuals, and IAcc and corrugator mimicry was correlated only for Go—not NoGo—trials. These results suggest that accurate perception of interoceptive signals may also be functionally useful for social processing, since perception and emotion-specific corrugator mimicry was improved over those with less interoceptive accuracy. Taken together, the above studies may indicate interoceptive involvement in context/task-specific social processing involving the face and social emotion perception.

Given the importance of interoception for self-representation, it is also notable that another fEMG study demonstrated greater facial mimicry—particularly for smiles—for images manipulated to resemble one's own face (Olszanowski et al., 2022). This finding, however, brings up an interesting empirical question—perhaps self-salience can be expected in general, but might its emotional tone (and resultant behavioral consequences) could covary with self-beliefs, lay social expectations, depression, and loneliness? In other words, if participants held negative self-beliefs and a lonely, socially-defeatist mindset, would they not automatically mimic faces in which they see more of themselves?

This would be an interesting question to explore, since studies have shown that certain model identities that are conditioned as rewarding do elicit greater smile mimicry than unconditioned models (Sims et al., 2012). As reward here can be conditioned into certain social identities to produce greater mimicry, so can conditioned liking result from greater smile mimicry (Korb et al., 2015)—linking smiling and liking in time and context. However, what if loneliness reduces reward value of smiles themselves, tied to negative interoceptive predictions for social contexts? Whether loneliness, given its pervasive social cognitive affective shroud, would be sensitive to acute conditioning of social reward, or dampened by dour social (interoceptive) predictions, remains an open empirical question.

However, given the discovery of interoceptive dysregulation in loneliness, whether interoceptive mechanisms may play a role in social reward conditioning is an important question. One clue about this comes from a study by Korb and colleagues (2019), whereby certain facial identities were conditioned with punishment, resulting in inhibited smile mimicry. Functional imaging during such smile mimicry inhibition revealed greater mPFC activity, which was also functionally connected to activity in premotor and posterior insular cortices. These findings suggest that conditioned "bad" social identities elicit less smile mimicry due to top-down mPFC modulation of facial mimicry and facial feedback—and might the insula be involved in facial feedback? This type of "bad" social conditioning could be mediated by interoceptive predictions that redirect available resources away from processing the discredited stimulus, although more research on the formation of socially-based interoceptive predictions is needed. This is important because transcranial magnetic stimulation (rTMS) targeting the mPFC can experimentally increase spontaneous facial mimicry (Balconi & Canavesio, 2013).

Can differential neural social processing be trained? Take the case of adventure racers—elite athletes who operate in small teams enduring extreme environmental and physical challenges, who rely on efficient emotion processing to succeed. Compared to controls, a group of such racers showed differential neural activity across this network when processing emotional faces—markedly less mPFC and greater insular activity (Thom et al., 2014). This could reflect training-based self-resilience and efficient social processing, since reading team member's emotions during competition is a highly valuable skill. Although interoception was not measured in these elite athletes, it is possible that greater insular vs. mPFC activation reflects more facilitated "self-sufficient" spontaneous facial processing, more reliant on bottom-up interoceptive information than top-down control. This may effectively open the aperture for

deriving useful social information from micro-expression signals, though we must be careful about the problem of reverse inference from neural data alone.

As facial muscle activity has a reciprocal relationship social perception (and presumably learning), we can ask if awareness of facial activity might aid its strategic social functions. Though no studies yet have assessed "facial interoception" per se, there is precedence for promising investigation. One study addressed this topic by explicitly instructing some participants to attend to their facial reactions when performing a difficult facial emotion detection task. Participants were presented with briefly presented (10ms) happy or angry faces (or neutral) and made a 2-alternative forced-choice decision whether the face was emotional or neutral, while fEMG was recorded. Facial muscle activity aided performance in this difficult task, but instruction to attend to facial signals did not improve performance (Bornemann et al., 2012). Our lab has continued this line of research in a series of experiments, adding self-reported interoception (MAIA) measures as well as physical manipulation of smile mimicry by asking participants to hold a pen between their teeth, which "locks up" the zygomaticus muscle, preventing it from stimulus-evoked smiling or mimicry. We have found that disruption of smile mimicry does impair performance on difficult smile (but not frown) detection, but only in participants who report higher MAIA scores, reflecting their habitual tendency to use interoceptive signals in perception (Arnold, Bornemann, & Winkielman, in preparation). Interestingly, through perceptual performance is impaired in these individuals, they also report higher confidence in their performance—which could be due to misattribution of incidental zygomaticus activity. That is, zygomaticus activity from biting is not (interoceptively) registered merely as such, but due to reliance on interoceptive signals for perception and decision-making (higher MAIA scores), this activity is incorporated as evidence that a smile *was* seen on incorrect

trials (higher confidence in judgments). Accurate attribution of emotional information, and its covariation with interoceptive measures, may have important implications for social cognition and social connection. After all, interoception may be crucial for self/other distinction or deciding "where I end and you begin"— physically, psychologically, and emotionally—may be crucial for accurately assessing your emotional state and needs (compared to another), and engendering empathy (Palmer & Tsakiris, 2018).

Studies using the pen-biting facial feedback manipulation (FFM) have demonstrated that it does influence stimulus processing through introducing noise, increasing semantic retrieval demands for emotional expressions as measured by EEG processing signatures (Davis et al., 2017). In a task assessing working memory for happy and sad faces, FFM induced smiling activity that led to selectively greater memory for happy faces, which also shifted perceptual representations for the faces to more positive (Kuehne et al., 2021). Central (afferent) feedback from facial muscles can influence emotion perception even when incongruent with natural mimicry activity of the expression. Participants were asked to make gender-categorization decisions on expressions of anger and joy by activating their corrugator or zygomaticus muscles, and then asked to rate the valence of the image (Hyniewska & Sato, 2015). Zygomaticus activity increased valence scores compared to trials discriminated with corrugator activity, suggesting that facial feedback can color perception, but *mis*attribution of internal signals in social situations can occur.

Having clear intrapersonal accounting for emotional and interoceptive signals should aid encoding of affective experiences and over time, and improve social decision-making at least in terms of forming veridical social representations of others—e.g., should I trust her or not? The role of free-responding zygomaticus activity in social cognition is challenging to study in

ecologically valid conditions (i.e., without electrodes hanging from faces), but a new technique for minimally-intrusive zygomaticus recording has been developed to aid in more ecological approaches (Nascimben & Ramsoy, 2020). The emotion perception decrement linked to greater interoceptive sensibility (Arnold et al., in preparation) combined with enhanced positivity in facial recall (Kuehne et al., 2021) also relates to the perception of time—when faces are being flashed very fast, there is a smaller window to link facial activity to perception, but could facial activity itself bias time perception? One intriguing study recently examined this—whether zygomaticus or corrugator dynamic activity is systematically related to time perception. Results showed that dynamic corrugator activity tracked accurate duration judgments, while greater zygomaticus activity caused dilation (expansion) of time perception (Fernandes & Garcia-Marques, 2019). These authors suggest that one operative mechanism may be increased perceived familiarity, or fluency, also associated with zygomaticus activity (Winkielman & Cacioppo, 2002), and another speculative implication is that dynamic smiling activity may be part-and-parcel of deep emotional connection when time perception is often experienced subjectively differently.

Following on dynamic facial activity playing a constitutive role in concept activation (Davis et al., 2022) and emotional perception, might it also play a role in self-concept? A recent fEMG study can address this question—during a simulated online social interaction task, participants indicated likes/dislikes of other putative players, and saw other players putatively rating themselves. Following stress exposure, participants evinced greater corrugator activity (and less zygomaticus activity) during evaluation by others, reflecting context-induced negativity during self-evaluation (Kroll et al., 2021). These authors suggest that addressing internalized negative self-evaluation, perhaps indexed by corrugator activity during self-processing, could be

a novel indicator and target of veridical self-concept in social situations. Finally, facial affect may be confounded with the social past—Mason & colleagues (2012) examined well-being and self-concept recovery following the social disruption of a romantic separation. Results indicated that diminished self-concept recovery predicted worse well-being for eight weeks post-separation, and corrugator activity when thinking about the ex-partner was associated with worse self-concept recovery and exacerbated by love for the ex-partner.

To what extent interoception specifically plays a role in translating facial activity into affect, perception, and/or memory representations deserves more empirical attention. Might people more aware of their own facial activity—and signals sent to others—be more socially skilled? And would this ability depend more on interoceptive self-integration or simply accentuated monitoring of the social "border" between self and other during interaction? Here I propose new studies on "facial interoception" to address these questions, and potentially link disparate research on facial emotion, conceptual emotional representation, self/other processing, and social connection. Firstly, though no published work has addressed "facial interoception", facial muscle proprioception has been labelled in the literature. However, close anatomical examination of neural innervation and feedback circuity in the face reveal sensory receptors distinct from typical proprioceptors that sense limb position, and may carry extra functionality (Cobo et al., 2017). While facial muscle activity may traditionally be considered "proprioceptive" I argue it should be incorporated as interoceptive, since there are clues that subjective awareness of activity may impact its downstream effects and may itself construct (social) perceptual associations—this reflects the greater enactive role in for physiological interoceptive predictive processing frameworks, beyond mere efference copies. The neural representation of facial activity deserves more research to test how "interoceptive" it can be,

since it's involved in basic affect, self-representation, and social perception, all key functions of interoception. As for neural circuitry that might directly link facial interoceptive feedback to emotional processing and social perception, we might see an important role for the direct PFC—poINS (posterior insula) pathway recently identified as potentially important for socially-induced affect (Nachtergaele et al., 2019). One recent MEG study indicated that processing sad (compared to happy or neutral) faces increases neural activity representing the interoceptive heartbeat (similar to HEP, but measured with MEG), potentially suggesting direct interoceptive input as part of facial emotion processing (Kim et al., 2019).

Chapter 3 represents a long-term investigation of interoceptive sensibility in loneliness with Dr. Karen Dobkins. We are close to submitting the manuscript for publication, so especially appreciate your feedback here, compared to Chapters 1 & 2. Our results in Chapter 3 demonstrate the first known evidence of aberrant interoceptive sensibility in loneliness, most notably diminished body trust. Across 17 separate samples and a total sample size of 4,292 participants, we demonstrated a moderate-strong meta-analytic association between loneliness and diminished interoceptive body trust. We replicated associations between loneliness and depression, alexithymia, gratitude, and self-compassion, while comparing effect sizes between these constructs and body trust. Our results are extended by the inclusion of the IOS measure of "closest connection" to one's closest friend, which accounts for variance in loneliness as expected. Future studies may consider adding this single-item pictorial measure as a representation of perceived social connection with one's closest person.

The cross-sectional nature of our results engenders consideration of causal direction between loneliness and impaired interoception, and I expect further research to demonstrate this relationship is bi-directional and reciprocal. Nonetheless, these novel results aid the growing

corpus revealing diminished interoceptive body trust as a core frailty for psychosocial health. Just recently, entire research programs have blossomed around the role of body trust in eating disorders (Brown et al., 2020) and suicidality (Rogers et al., 2018).

Diminished body trust has also been associated with worse sleep (Arora et al., 2021), a physiological encumbrance of loneliness (Hom et al., 2020). In which ways interoceptive body trust relates to interoceptive accuracy and awareness looms as an important area for research, since body trust reliably impacts core psychosocial health, including loneliness. Given the intimate relationship between suicidality and fractured body trust, it is notable that suicide attempters exhibited worse interoceptive accuracy and less activation in mid/posterior insula during heartbeat perception, compared to controls (DeVille et al., 2020). This may suggest that indeed lack of interoceptive intrapersonal connection is associated with suicidality, the basis of which is rooted in the insula. In addition, adolescence appears to be a sensitive period of development ripe for interoceptive intervention, because body trust has been shown to decrease from childhood to adolescence (Jones et al., 2021). Finally, how body trust might reflect self-beliefs also deserves more empirical attention. Preliminary results of ours do suggest that (diminished) body trust partially mediates lower interpersonal trust that contributes to loneliness, and we are collecting more data on the relationships between body trust, self trust, and trust in others. An intrapersonal focus on BT, integrating selfhood and affect, can empower all (and underprivileged) individuals to mobilize their own conceptions of well-being, connection, and social change. We hope this research can inform health initiatives to help people achieve quality social connection, a requirement for optimal health and human functioning.

Coda: Integrating Self and Other Representations to Serve Humanity

> *"It's only a choice. No effort, no work, no job, no savings of money. Just a simple choice, right now, between fear and love. The eyes of fear want you to put bigger locks on your doors, buy guns, close yourself off. The eyes of love instead see all of us as one."*
> ~ Bill Hicks

Perception is defined merely by a single, subjective capture in a moment, and beliefs bleed into the resolution of any image, distorting the take-away for one (mal)adaptive reason or another. The basal need state of an organism naturally shapes its perceptual and behavioral repertoire, as one can barely function without food, when starvation cripples the body from any grand plans. This basal, unadorned state of loneliness lurks behind the collective eye, yet undermines each insidiously, un-watered, to bleak possibilities for mind or body. Outlook matters inasmuch as inward focus does. Interoception forms the basal perceptual window for conceptions of self, other, and relationship. Psychosocial health, while the responsibility of every individual, also relies on perception of connections and camaraderie with others. While some studies on loneliness have suggested a "locked-in brain", our investigations also suggest a "locked-out" body—that is, without body trusting, the mind is "locked-out" from the interoceptive wisdom of the body. Here is one dissertation aimed at greater connection.

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