From Lab to Life: Investigating the Role of Social Contact for Anxiety and Related Autonomic Responses

Vom Labor ins Leben: Die Erforschung der Rolle von sozialem Kontakt für Angst und damit verbundene autonome Reaktionen

DISSERTATION

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Submitted by
Marthe Erda Gründahl
from Buxtehude, Germany

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Submitted on: ………………………..………………

Office stamp

Members of the Thesis Committee

Chairperson:	Prof. Dr. Carmen Villmann
Primary Supervisor:	Prof. Dr. Grit Hein
Supervisor (Second):	Prof. Dr. Martin Herrmann
Supervisor (Third):	Prof. Dr. Andre Pittig

Date of Public Defence: ………………………..

Date of Receipt of Certificates: ………………………..

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Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 declaration of Helsinki.

Conflict of interest

The author declares no competing interests.

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Abbreviations

ADS-K	Allgemeine Depressionsskala - Kurzform (engl.: Center for Epidemiologic Studies Depression Scale)
AIC	Akaike information criterion
ANOVA	Analysis of variance
ASI-3	Anxiety Sensitivity Index-3
App	Application (smartphone)
BDI-V	Simplified Beck Depression Inventory
BIC	Bayesian information criterion
BMI	Body mass index
BP	Blood pressure
bpm	Heartbeats per minute
cb	Centred between
CFA	Confirmatory factor analysis
CFI	Comparative fit index
CI	Confidence interval
COVID-19	Coronavirus disease 2019
CS	Conditioned stimulus
cw	Centred within
ECG	Electrocardiogram
EFA	Exploratory factor analysis
EMA	Ecological Momentary Assessment
HR	Heart rate
HRV	Heart rate variability
Hz	Hertz
ICC	Intraclass correlation coefficient
IP	Interaction partner
ISI	Inter-stimulus interval
ITI	Inter-trial interval
LISD	Loneliness and Isolation during Social Distancing (scale)
ln	Natural logarithm
M	Mean

MAP	Minimum average partial
ML	Maximum likelihood
µS	Micro Siemens
MSA	Measure of sampling adequacy
MSPSS	Multidimensional Scale of Perceived Social Support
NEO-FFI	NEO Five Factor Inventory
PANAS	Positive and negative affect schedule
PHQ-2	2-item Patient Health Questionnaire
RGB	Red green blue (color model)
RMSEA	Root mean square error of approximation
RMSR	Root mean square of the residuals
RMSSD	Root mean square of successive differences
SCR	Skin conductance response
SD	Standard deviation
SE	Standard error
SGSE	Schüchternheits- und Geselligkeitsskalen für Erwachsene (engl.: timidness and sociability scale for adults)
SI	Social interaction
SIAS	Social interaction anxiety scale
SRMR	Standardized root mean square of the residuals
STAI	State-trait anxiety inventory
T1	Time before learning (study 1)
T2	Time after learning (study 1)
T3	Time after test (study 1)
UCLA	University of California Los Angeles (Loneliness Scale)
US	Unconditioned stimulus
V	Volt
VAS	Visual analogue scale
VIF	Variance inflation factor

Summary

Humans are social beings. As such, social contact is a crucial part of everyday life, and being with others can enhance our mental and physical health. Among others, this can be caused by reducing effects of social contact on the negative affective experiences of fear and anxiety, a phenomenon called social buffering. These buffering effects of social contact are potentially shaped by personal factors, e.g., the gender or relationship of interaction partners.

The three studies presented in this dissertation investigated different forms of social contact and related social buffering effects on anxiety-related responses using different methodological approaches. We examined the effects of social involvement during painful stimulation on fear-related responses in a laboratory learning task (study 1); the role of specific interaction partner characteristics (gender, familiarity) for anxiety-related responses in everyday-life social interactions assessed via Ecological Momentary Assessment (study 2); and anxiety in association with loneliness and related social factors during a time of limited social contact in everyday life, as reflected by self-report questionnaires assessed online (study 3).

Study 1, a laboratory experiment with female participants (N = 97), investigated the impact of social influence (social involvement without direct physical presence or interaction) compared to self-influence or no influence on pain in the context of pain relief learning. Results showed that the observed reductions in autonomic responses (skin conductance responses) and increases in fear ratings following pain relief learning were independent of social influence. The minimalistic and controlled social setting of the laboratory may have prevented expected social buffering effects.

Using modern Ecological Momentary Assessment methods (smartphone-based surveys and portable sensors), study 2 (N = 96; male and female participants) targeted social buffering effects in the more ecologically valid setting of everyday life. On five consecutive days, we repeatedly assessed the participants' state anxiety and anxiety-related cardiovascular responses (heart rate, heart rate variability), as well as characteristics of recent social interactions and the interaction partners involved. Analyses of over 1,500 social contacts revealed gender-specific effects, e.g., social buffering effects of familiarity on heart rate in women, but not men.

In contrast to studies 1 and 2, study 3 investigated anxiety in the absence of social contact caused by social distancing, i.e., restrictions in social and physical contact. More specifically, it examined how differences in anxiety related to loneliness and related social factors. Based on two mixed-gender samples assessed online (N_{Sample1} = 244, N_{Sample2} = 304), we validated a

self-constructed scale for the differential measurement of state and trait loneliness and social isolation and investigated how this scale was linked to mental health outcomes, including state anxiety. Study 3 implied “reverse” social buffering effects, i.e., increases in anxiety when social contact was limited and loneliness increased. At the same time, more trait sociability and sense of belonging showed buffering-like effects by relating to lower anxiety levels.

In sum, this dissertation’s three studies showed that minimal social contact may not be sufficient to reduce fear-related responses, and that the social buffering effects of more complex social situations are shaped by social and personal factors such as familiarity and gender. During limited social contact, lower anxiety levels are related to inter-individual differences in sociability, social belonging, loneliness, and social isolation. In contrast, anxiety-related responses during daily social interactions are reduced with more familiar or opposite-gender interaction partners. By taking research from lab to life, this dissertation underlines the diverse nature of social contact, its potential impact on anxiety-related responses, and thus its relevance to mental health.

Zusammenfassung

Der Mensch ist ein soziales Wesen. Soziale Kontakte sind ein wichtiger Bestandteil des alltäglichen Lebens, und das Zusammensein mit Anderen kann unsere psychische und körperliche Gesundheit verbessern. Dies kann unter anderem dadurch bewirkt werden, dass soziale Kontakte die negativen affektiven Erfahrungen von Angst und Furcht verringern. Dieses Phänomen wird als „Social Buffering" bezeichnet. Solche „puffernden" Effekte sozialer Kontakte werden möglicherweise durch persönliche Faktoren beeinflusst, z.B. das Geschlecht oder die Beziehungen zwischen den Interaktionspartner:innen.

Die drei in dieser Dissertation vorgestellten Studien untersuchten verschiedene Formen des sozialen Kontakts und damit einhergehende Social Buffering-Effekte auf angstbezogene Reaktionen mithilfe unterschiedlicher methodischer Ansätze. Wir erforschten die Auswirkungen von sozialer Beteiligung während schmerzhafter Stimulation auf Furchtreaktionen bei einer Lernaufgabe im Labor (Studie 1); die Rolle spezifischer Merkmale von Interaktionspartner:innen (Geschlecht, Vertrautheit) auf angstbezogene Reaktionen in alltäglichen sozialen Interaktionen, gemessen mittels Ecological Momentary Assessment (Studie 2); und Angst in Verbindung mit Einsamkeit und damit zusammenhängenden sozialen Faktoren während einer Zeit begrenzter sozialer Kontakte im Alltag, welche anhand von online ausgefüllten Selbstbericht-Fragebögen erfasst wurden (Studie 3).

Studie 1, ein Laborexperiment mit weiblichen Teilnehmerinnen (N = 97), untersuchte die Auswirkung von sozialem Einfluss (soziale Beteiligung ohne direkte körperliche Anwesenheit oder Interaktion) im Vergleich zu eigenem oder keinem Einfluss auf Schmerz im Zusammenhang mit Pain Relief Learning (Schmerzlinderungs-assoziiertem Lernen). Die Ergebnisse zeigten, dass die beobachtete Verringerung der autonomen Reaktionen (Hautleitfähigkeit) und die Steigerung der Furcht-Ratings nach dem Pain Relief Learning nicht durch sozialen Einfluss bedingt waren. Das minimalistische und kontrollierte soziale Setting des Labors könnte die erwarteten Social Buffering-Effekte verhindert haben.

In Studie 2 (N = 96; männliche und weibliche Teilnehmer:innen) wurden moderne Methoden des Ecological Momentary Assessment (Smartphone-basierte Befragungen und tragbare Sensoren) eingesetzt, um Social Buffering-Effekte in einem ökologisch valideren, alltäglichen Setting zu untersuchen. Dazu wurden an fünf aufeinanderfolgenden Tagen wiederholt die State-Angst und angstbezogenen kardiovaskulären Reaktionen (Herzfrequenz, Herzratenvariabilität) der Teilnehmenden sowie Merkmale der letzten sozialen Interaktionen

und der beteiligten Interaktionspartner:innen erfasst. Die Analyse von über 1500 sozialen Kontakten ergab geschlechtsspezifische Effekte, z.B. Social Buffering-Effekte von Vertrautheit auf die Herzfrequenz von Frauen, aber nicht von Männern.

Im Gegensatz zu den Studien 1 und 2 befasste sich Studie 3 mit Angst in der Abwesenheit von sozialem Kontakt, welche durch soziale Distanzierung (Einschränkungen im sozialen und physischen Kontakt) verursacht wurde. Dabei wurde genauer untersucht, wie Unterschiede in der Angst mit Einsamkeit und damit verbundenen sozialen Faktoren zusammenhängen. Anhand von zwei geschlechtsübergreifenden Stichproben, die online erfasst wurden ($N_{Stichprobe1} = 244$, $N_{Stichprobe2} = 304$), validierten wir eine selbstkonstruierte Skala zur differenzierten Messung von Einsamkeit und sozialer Isolation auf dem State und Trait-Level und prüften, wie diese Skala mit Merkmalen psychischer Gesundheit (einschließlich State Angst) zusammenhängt. Studie 3 ergab "umgekehrte" Social Buffering-Effekte, also eine Zunahme von Angst bei fehlenden sozialen Kontakten und zunehmender Einsamkeit. Gleichzeitig zeigten mehr Geselligkeit und ein Gefühl der Zugehörigkeit (Faktor „sociability and sense of belonging“) eine puffernde Wirkung, indem sie mit einem niedrigeren Angstniveau einhergingen.

Insgesamt haben die drei Studien dieser Dissertation gezeigt, dass minimaler sozialer Kontakt möglicherweise nicht ausreicht, um furchtbezogene Reaktionen zu reduzieren, während die Social Buffering-Effekte komplexerer sozialer Situationen von sozialen und persönlichen Faktoren wie Vertrautheit und Geschlecht beeinflusst werden. Bei eingeschränktem sozialen Kontakt sind niedrigere Angstwerte mit interindividuellen Unterschieden in Geselligkeit, sozialer Zugehörigkeit, Einsamkeit und sozialer Isolation verbunden. Im Gegensatz dazu sind angstbezogene Reaktionen bei alltäglichen sozialen Interaktionen geringer, wenn die Interaktionspartner:innen vertrauter sind oder einem anderen Geschlecht angehören. Indem sie die Forschung aus dem Labor ins Leben holt, unterstreicht diese Dissertation die Vielfältigkeit sozialer Kontakte, ihre potenziellen Auswirkungen auf angstbezogene Reaktionen und somit ihre Bedeutung für die psychische Gesundheit des Menschen.

1 Introduction

We human beings are social beings. We come into the world as the result of others' actions. We survive here in dependence on others. Whether we like it or not, there is hardly a moment of our lives when we do not benefit from others' activities. For this reason, it is hardly surprising that most of our happiness arises in the context of our relationships with others.

Dalai Lama XIV

(as cited in Rumjaun & Narod, 2020, p. 85)

Yes – we humans are social beings. We tend to seek the presence of and contact with others. Consequently, social contacts are a crucial part of our everyday life (Cacioppo & Cacioppo, 2014; Cohen, 2004; Frith & Frith, 2007) and bring intrinsic benefits with them. From an evolutionary perspective, social contact and collaboration ensure our survival (e.g., through social learning; Frith & Frith, 2007). From an economic perspective, social contacts can direct and foster economic and technological innovation, profit, and progress (Salas et al., 2018; Teece, 1992). From a clinical perspective, social contacts can improve our mental and physical health (Cacioppo & Cacioppo, 2014), e.g., by reducing stress and related anxiety responses (Hennessy et al., 2009; Taylor, 2011). However, contact with others can also have negative effects, such as when social interactions result in conflicts causing physical injuries or mental health deprivations (Cohen, 2004; Trevillion et al., 2012). This shows how social contacts have a significant impact on our well-being, physiological functioning, and affective experience (Cohen, 2004; Thoits, 2011; Uchino, 2006).

Social contact can take many forms. There can be physical presence or contact, but no interaction (Goldstein et al., 2016; Hennessy et al., 2009; Qi et al., 2021). Conversely, there may also be social involvement without physical presence, such as when another person is remotely responsible for a current act or experience of an individual like monetary gain or loss (Marco-Pallarés et al., 2010). Then there is the broad field of social interaction − social situations that involve verbal or non-verbal communication between two or more individuals (Argyle, 2017; Hall, 2018). Finally, an individual can even be affected by the absence of others, particularly when social contact is wanted, but not fulfilled (Fetchenhauer & Huang, 2004; Lee & Cagle, 2017). Whichever form it takes, social contact involves two or more individuals, and these social partners bring personal characteristics that shape the social contact and alter its effects (Mascret et al., 2019; Qi et al., 2021; Well & Kolk, 2008). For instance, the persons involved in a social contact may know each other or be strangers, match or differ in personal factors like age, gender, and ethnicity, and act passively or show a specific behaviour. Social contact is complex and diverse (Cohen, 2004; Frith & Frith, 2007; Thoits, 2011; Uchino, 2006), and this should be kept in mind when investigating social contact and its effects.

Processes that are potentially influenced by social contact include the basic human experiences of fear and anxiety. Fear and anxiety are important mechanisms that aim to protect an individual by warning about danger and evoking adaptive responses for coping with a threat, be that physical or other. They are associated with high physiological and cognitive stress responses (Hamm, 2020; LeDoux & Pine, 2016; Lonsdorf et al., 2017; Öhman, 2008). Thus, maladaptive fear and anxiety can cause unnecessary subjective and physiological arousal and stress responses (Amstadter, 2008; Pittig et al., 2018). When recurrent and persistent, they are associated with psychosocial and psychological dysfunctions (Kroenke et al., 2007; Öhman, 2008), impaired physical and mental health (Kroenke et al., 2007; Pittig et al., 2018), and reduced quality of life (Olatunji et al., 2007; Rapaport et al., 2005). Moreover, fear and anxiety are involved in the development of anxiety disorders and related psychiatric symptoms, which further underlines their relevance in the clinical and subclinical context (Daniel-Watanabe & Fletcher, 2021; Domschke, 2022; Stegmann et al., 2022). Consequently, factors that reduce anxiety can be protective to our mental and physical health. Previous studies imply that another person's behaviour (e.g., social support; Taylor, 2011) or even their mere presence (Hennessy et al., 2009; Kikusui et al., 2006) can reduce fear and anxiety-related responses, a phenomenon called social buffering.

This dissertation aims to shed light on the conditions under which anxiety-related social buffering takes place, specifically when and how social contact reduces fear and anxiety as well as the related autonomic responses. Thus, the studies measured anxiety-related responses on both a subjective and an autonomic level, and in different social situations inside and outside the laboratory. In previous research, social contact and related social buffering effects were mostly investigated in the laboratory. Today, the modern methodology of Ecological Momentary Assessment (EMA) enables research to move from the laboratory to real life, namely into naturalistic settings with higher ecological validity. This dissertation's first study investigates the effects of minimal social contact on fear-related responses in the highly controlled setting of the laboratory. The second study uses EMA to examine anxiety-related responses during everyday-life social interactions, and thus, in more diverse and complex social settings without experimental manipulation. The third and final study also investigates anxiety in everyday life, this time via online surveys and in relation to the absence rather than the presence of social contact.

The main constructs and methods of this dissertation are introduced in more detail below. The first section provides insight into the concept of social buffering by summarizing the findings of previous studies that investigated how the presence or absence of social contact affected anxiety-related responses. In the second section, fear and anxiety are more clearly defined and their relevance to psychological research and mental health is presented. The third section presents the experimental approaches and measures for investigating social contact and anxiety-related responses used in previous research and this dissertation. The final section outlines the objectives pursued by this dissertation's three studies by presenting open questions and hypotheses regarding social buffering effects in lab and life.

1.1 Social buffering

Social buffering has been a topic of interest to biological, psychosocial, and clinical research for some time. Previous studies have repeatedly revealed social buffering effects, such as the reducing effects of social presence (Hennessy et al., 2009; Kikusui et al., 2006) and social interaction (Kikusui et al., 2006; Krahé et al., 2013) on stress and anxiety-related subjective and physiological responses. Among others, social contact has been shown to reduce pain (Che et al., 2018; Krahé et al., 2013) and fear responses (Hennessy et al., 2009; Kikusui et al., 2006). This dissertation focuses on fear and anxiety-related social buffering effects.

In humans, social buffering effects are typically inferred from a reduction of reported stress-related affective experiences (e.g., anxiety) and/or an adaptive change in autonomic responses caused by the presence or behaviour of another person (Abad et al., 2010; Ditzen et al., 2008; Ryska & Yin, 1999). Participants experiencing a stress or anxiety-inducing situation such as aversive stimulation or a public speech in the presence of another person showed lower responses in comparison to those experiencing them alone (Ditzen et al., 2008; Qi et al., 2021). Other studies have extended the social manipulation, e.g., by modulating the familiarity (e.g., stranger vs. friend) or affiliative behaviour (e.g., social support vs. no support) of the social partner (Kikusui et al., 2006; Taylor, 2011). Importantly, even in the mere presence of another person, the overall social buffering effect might be modulated by characteristics of the interaction partners, such as their gender or their perceived similarity (Qi et al., 2021; Qi et al., 2020). Autonomic responses influenced by the presence or extent of social contact during stress inductions include reductions in state anxiety (Ditzen et al., 2008), heart rate (HR;

Thorsteinsson & James, 1999), and skin conductance response (SCR; Qi et al., 2021). In turn, these measures represent established indicators of lower acute (social) stress and anxiety (Behnke & Sawyer, 2001; Boucsein, 2012; Grillon et al., 2007; Schiweck et al., 2019).

1.1.1 Buffering components of social contact

In general, social buffering encompasses the overall effect of social presence (Hennessy et al., 2009; Kikusui et al., 2006). However, several factors can modulate the buffering effects of the presence or contact with others on fear and anxiety-related responses. Based on previous findings, the extent of social buffering may be altered by a person's characteristics including gender or trait anxiety (Hyde et al., 2011; Qi et al., 2021; Well & Kolk, 2008). In addition, characteristics of the interaction partner(s) such as their gender or familiarity may play a role (Glynn et al., 1999; Holt-Lunstad et al., 2003; Mascret et al., 2019; Phillips et al., 2009).

Gender differences in overall anxiety levels have been indicated by enhanced anxiety-related responses in female compared to male participants, both on a subjective level with higher anxiety ratings (Kelly et al., 2008; Villada et al., 2016), and on a physiological level with higher HR (Glynn et al., 1999; Kudielka et al., 2004) and lower heart rate variability (HRV; Hamidovic et al., 2020). However, findings regarding gender differences in social buffering effects are mixed. Some laboratory studies found more pronounced social buffering-related response reductions in either women (Qi et al., 2021; Reddan et al., 2020) or men (Kirschbaum et al., 1995; Well & Kolk, 2008), whilst others did not find gender differences in social buffering effects (Lepore, 1992; Shahrestani et al., 2015). Results concerning effects of the interaction partner's gender are also inconsistent. Some findings imply social buffering effects of female interaction partners on autonomic responses, such as a reduction in fear-related SCR by mere social presence in female but not male dyads (Qi et al., 2021), or reductions in systolic blood pressure (BP, another autonomic stress indicator; Chida & Hamer, 2008) in both men and women when receiving social support from female but not male social partners (Glynn et al., 1999). Other studies also showed social buffering effects from male interaction partners with reduced cardiovascular reactivity (systolic BP, HR) in women in the presence of their male romantic partner (Phillips et al., 2006) or when receiving social support from a male friend (Phillips et al., 2009).

In contrast to findings regarding the interaction partners' gender, the results with familiar interaction partners were more consistent in showing an overall protective effect. Laboratory studies imply that there is a more pronounced reduction in anxiety-related responses with familiar compared to non-familiar social partners (Eisenberger, 2013; Krahé et al., 2013). Participants showed decreased state anxiety during psychosocial stress when provided with social support from familiar vs. unfamiliar persons (Mascret et al., 2019). In everyday life, healthy participants showed lower BP when interacting with family members or romantic partners compared to unfamiliar persons (Holt-Lunstad et al., 2003). However, the interplay of gender and familiarity effects remains unclear, particularly in everyday-life social contact.

1.1.2 The absence of social contact

While social presence and social contact can have buffering effects, the insufficiency or absence of social contact can lead to maladaptive subjective and autonomic effects, including increases in stress and anxiety-related responses (Abad et al., 2010; Beutel et al., 2017; Hawkley & Cacioppo, 2010).

An absence of social contact can have many causes. Among others, it can result from social isolation due to objectively or subjectively insufficient social networks (Lee & Cagle, 2017; Santini et al., 2020), or from reductions in physical proximity and social contacts for the prevention of virus or disease transmission (i.e., social distancing; Ahmed et al., 2018; Elmer et al., 2020; Fiorillo & Gorwood, 2020; Shim, 2013). Such a lack of social contact, whether objective or perceived, has previously caused social isolation and feelings of loneliness. These are in turn important risk factors for developing somatic and mental illness, including anxiety disorders (Elovainio et al., 2017; Hawkley & Cacioppo, 2010; Masi et al., 2011). In accordance with this, higher levels of social isolation and feelings of loneliness have been related to higher subjective anxiety levels (Abad et al., 2010; Beutel et al., 2017) and increased autonomic responses, such as raised systolic BP (Hawkley & Cacioppo, 2010). It is clear however that not everyone is similarly affected by the absence of social contact (Jong Gierveld et al., 2006). For instance, individuals who are more extroverted may suffer more from the acute lack of social contact due to their dispositional need for social engagement (Gubler et al., 2020). Others may particularly suffer if their access to social relationships providing emotional closeness and support had already been limited (Cornwell & Waite, 2009b; Lee & Cagle, 2017). Consequently, while feelings of loneliness and social isolation could enhance anxiety, factors like access to social support, social belongingness, and introversion could have buffering-like effects on anxiety in times of limited social contact. The individual's gender could also play a role. Previous research has suggested higher loneliness levels in women compared to men

(Beutel et al., 2017; Victor & Yang, 2012), while others have found higher loneliness in men (Barreto et al., 2021).

In conclusion, based on previous findings, anxiety-related responses in the presence or absence of social contact can vary in relation to different social and personal factors.

1.2 Fear and anxiety

Fear and anxiety are established constructs of interest across different scientific fields, including psychological and psychiatric research, medicine, and biology (LeDoux & Pine, 2016; McLean & Anderson, 2009; Michopoulos et al., 2017; Öhman, 2008; Taschereau-Dumouchel et al., 2022). The terms “fear” and “anxiety” are often used interchangeably (Fox & Shackman, 2019). Their distinction is a frequently discussed topic in scientific research, and close conceptual relations and overlaps of fear and anxiety are undeniable (Öhman, 2008). For both fear and anxiety, the subjective responses and their related defensive behaviours are accompanied by physiological changes such as increased autonomic arousal (Hamm, 2020; Lonsdorf et al., 2017; Öhman, 2008). A key differentiating factor between the concepts is the time, specificity, and predictability of the threat. Fear relates to short-lasting conscious affective states and experiences when facing imminent and immediate threat or danger. In contrast, anxiety refers to more diffuse and longer-lasting cognitive and affective states and experiences towards uncertain or distal sources of harm (Davis et al., 2010; LeDoux & Pine, 2016; Öhman, 2008). In laboratory settings, fear typically relates to a stimulus-specific response, such as a temporary physiological change (e.g., a startle eye blink) towards a short, discrete stimulus (e.g., a geometric shape) that predictably co-occurs with an aversive event (e.g., brief bursts of white noise). Anxiety on the other hand could be reflected in elevated physiological arousal, indicated for example by increased HR while awaiting recurring yet unpredictable aversive experiences (e.g., pain induced by electric stimulation; Davis et al., 2010; Lonsdorf et al., 2017). For the purposes of this dissertation, fear and anxiety are defined as distinct yet interrelated constructs that both produce subjective and autonomic threat responses.

Fear and anxiety can either describe emotional states that occur in a specific situation and within a limited time frame, or they can refer to personality traits that are characteristic to a person and endure despite context and time (Öhman, 2008). In particular, many researchers and clinicians distinguish between anxiety on the state and trait level (Kennedy et al., 2001; Spielberger & Gorsuch, 1983). State anxiety refers to a temporary reaction to adverse events like pain or social stress. Its intense emotional state is characterized by factors including apprehension, worry, and tension. In contrast, trait anxiety refers to more stable personality features characterized by factors like a predisposition to appraise situations as threatening or an avoidance of anxiety-inducing situations (Kennedy et al., 2001; Knowles & Olatunji, 2020). Both state and trait anxiety are associated with increases in physiological arousal and decreases in mental health and well-being, including anxiety and depressive disorders (Chambers et al., 2004; Öhman, 2008; Zsido et al., 2020). Since this dissertation targets differences in temporary anxiety-related responses during specific social situations, it focuses on state anxiety.

As indicated above, fear and anxiety are of great importance to psychiatric research and practice. Anxiety disorders are among the most prevalent and costly mental disorders (Bandelow & Michaelis, 2015; Polanczyk et al., 2015; Steel et al., 2014). Fear and anxiety play important roles in their development, extent, and persistence, as anxiety disorders are characterized by excessive experiences of fear and anxiety and related behavioural impairments (Hamm, 2020). Fear is more closely associated with phobic disorders and anxiety with generalized anxiety disorders, while their combination relates to panic disorders and social anxiety (Daniel-Watanabe & Fletcher, 2021; Öhman, 2008). Importantly, anxiety disorders are comorbid with other psychiatric disorders, particularly depressive disorders, and can be a risk factor for both their severity and persistence (Kessler et al., 2015; Newby et al., 2015). Factors with the potential to reduce fear and anxiety, such as social contact, are therefore of great relevance for the prevention and treatment of anxiety and other mental disorders (Daniel-Watanabe & Fletcher, 2021; Hamm, 2020). To include anxiety-reducing effects of social contact adequately into interventions, we first need to examine under which conditions social buffering is effective, particularly in everyday life.

1.3 Measuring fear and anxiety during social contact

There are various indicators of fear and anxiety as well as diverse methodological approaches to the investigation of social contact and its buffering effects. Subjective ratings and questionnaires measure fear and anxiety on the cognitive level, while autonomic measures capture fear and anxiety-related physiological changes like increases in HR and SCR. In laboratory-based research, methods for fear and anxiety induction include painful stimulation (Lindner et al., 2015; Meulders, 2020; Meulders & Vlaeyen, 2013), aversive sounds (Green et al., 2020; Qi et al., 2020), mental tasks (e.g., arithmetic tasks; Bement et al., 2010; Phillips et al., 2009), and anxiety-inducing social situations (e.g., public speech tasks; Ditzen et al., 2008;

Heinrichs et al., 2003; Mascret et al., 2019). In everyday life, anxiety can change depending on a variety of situational factors such as work-related stress (Sonnentag & Fritz, 2015; Wilson et al., 2020), exam situations (Dimitriev et al., 2016; Macher et al., 2013), or public health crises like the COVID-19 pandemic (Asmundson & Taylor, 2020; Mertens et al., 2020). The laboratory enables the investigation of social contact and its relation to fear and anxiety in a controlled setting, while EMA and online surveys allow for the ecologically more valid assessment of diverse social contacts in everyday life. The measures and methodological approaches to social buffering central to this dissertation are outlined in more detail in the following section.

1.3.1 Subjective measures

Laboratory settings with fear or anxiety induction frequently use single items rated on visual analogue scales or Likert scales for the assessment of anxiety or fear (Lonsdorf et al., 2017). For instance, fear towards a conditioned vs. neutral stimulus may be compared with ratings of the question “how strong is your fear towards [this stimulus]?” (e.g., a picture; Lau et al., 2008; Prenoveau et al., 2013). Similar single-item questions have been used to assess state anxiety levels during everyday-life social situations (e.g., "Right now, I am feeling..." indicated with anchors ranging from "very calm" [0] to "very anxious" [10]; Daniel et al., 2020).

Subjective anxiety measures range from single-item ratings to multiple-item questionnaires. State as well as trait measures of anxiety can be assessed with established and validated questionnaires containing more than one item (see e.g., Ditzen et al., 2008; Qi et al., 2021). The most frequently used measure of state and trait anxiety is the state-trait anxiety inventory (STAI; Laux et al., 1981), a measure that can be applied in both healthy and clinical populations (Zsido et al., 2020). It consists of two subscales which assess state and trait anxiety with Likert rating scales and can be used simultaneously or separately, as well as in various short forms. While this dissertation’s first study implemented single-item fear ratings, studies 2 and 3 focused on questionnaire assessments of state anxiety using the STAI.

1.3.2 Autonomic measures

To gain a more thorough understanding of human behaviour and experience, many studies additionally measure the physiological processes underlying and interacting with psychological processes of interest (Wilhelm et al., 2012). Self-reports can assess conscious indicators of fear and anxiety, but they are prone to self-report bias such as social desirability (Van de Mortel, 2008). Autonomic measures represent more objective indicators of arousal and anxiety than self-reports as they can measure subconscious bodily processes. A combination of subjective and autonomic measures is therefore well-suited to capture differential aspects of fear and anxiety (Öhman, 2008; Wilhelm et al., 2012), also in relation to social contact (Ditzen & Heinrichs, 2014; Heinrichs et al., 2003). Indicators of increased physiological arousal are suitable autonomic measures of anxiety that have been well validated in the social buffering research outlined above, including increases in endocrine responses (e.g., cortisol; Kirschbaum et al., 1995), SCR (Boucsein, 2012; Qi et al., 2021) and HR (Thorsteinsson & James, 1999), as well as decreases in autonomic flexibility indicated by HRV (Schwerdtfeger et al., 2020). This dissertation includes three autonomic measures: SCR (study 1), HR, and HRV (study 2).

1.3.2.1 Skin conductance responses

Skin conductance, also referred to as electrodermal activity or galvanic skin response, describes the state of electrical conductance of the human skin resulting from sweat gland activation caused by arousal of the sympathetic nervous system. While the skin conductance level captures more general tonic components of skin conductance and thus refers to general changes in autonomic arousal, SCR captures the more rapid phasic changes in the electrical conductivity of the skin which may be stimulus-specific (Braithwaite et al., 2015; Critchley & Nagai, 2013; Raugh et al., 2019). Due to its sensitivity to sympathetic arousal (without alterations caused by parasympathetic activity), skin conductance is used as an indicator of physiological arousal in relation to emotional and cognitive states, including responses during anxiety-eliciting situations. In laboratory settings, event-related changes in SCR can indicate changes in sympathetic arousal associated with fear learning (Boucsein, 2012; Delgado et al., 2006) such as enhanced SCRs towards fear-conditioned stimuli signalling danger or pain (Andreatta et al., 2013; Knight et al., 2006). In contrast, reductions in SCR can indicate social buffering effects, e.g., in the presence of a female interaction partner (Qi et al., 2021).

1.3.2.2 Heart rate

HR is another common measure of autonomic nervous system activity. It is measured in number of heartbeats per minute (bpm). HR is influenced by both sympathetic and parasympathetic activity (Camm et al., 1996; Thayer et al., 2012). In the presence of a (social) stressor, augmented sympathetic activity induces physiological arousal causing an increased HR (Grillon et al., 2007; Kudielka et al., 2004; Petrowski et al., 2010), which enables an adaptive response to the threat. In such moments, HR is increased by sympathetic activation as well as vagal withdrawal from decreased parasympathetic inhibition of HR. In contrast, decreases in HR in safer and more stable situations are due to lower sympathetic and higher parasympathetic activity (Appelhans & Luecken, 2006; Schiweck et al., 2019; von Dawans et al., 2018). Increases in HR can indicate higher social stress (Schwerdtfeger & Friedrich-Mai, 2009; von Dawans et al., 2018) and higher anxiety levels (Behnke & Sawyer, 2001; Pittig et al., 2013), while decreases in HR during social contact can indicate social buffering effects (e.g., in relation to social support; Phillips et al., 2009; Thorsteinsson & James, 1999).

1.3.2.3 Heart rate variability

HRV is another biomarker of psychological stress and related adaptive responses (Kim et al., 2018; Thayer et al., 2012). It is a quantitative marker of autonomic nervous system activity influenced by both sympathetic and parasympathetic activity. HRV describes the fluctuation in the time intervals between adjacent heartbeats (Malik et al., 1996) and can be measured with different metrics (i.e., time-domain, frequency-domain, and non-linear HRV indices; Shaffer & Ginsberg, 2017). In general, these beat-to-beat fluctuations show less linearity and more spatial and temporal complexity in healthy individuals (McCraty & Shaffer, 2015; Shaffer & Ginsberg, 2017). Higher HRV can indicate a higher capability to respond and adapt to the presence of a stressor by spontaneously (down-)regulating sympathetic and parasympathetic activation. Accordingly, augmented autonomic flexibility (higher HRV) relates to higher social skills and more successful stress regulation in social situations (Appelhans & Luecken, 2006; Petrocchi & Cheli, 2019), including the adaptive regulation of HR (Kok & Fredrickson, 2010). Lower levels of HRV on the other hand are associated with mental illnesses, including anxiety disorders (Koval et al., 2013; Laborde et al., 2011; Thayer et al., 2012). Beyond the clinical context, negative relations between anxiety and HRV have also been found in healthy and young individuals (Hamidovic et al., 2020; Paniccia et al., 2017; Petrowski et al., 2010). Social buffering effects can be implied by enhanced HRV levels, e.g., caused by social contact with friends or family members (Schwerdtfeger et al., 2020). In contrast, the lack of social contact has been associated with decreases in HRV (Horsten et al., 1999).

1.3.3 Methodological approaches

1.3.3.1 Laboratory studies

Traditionally, social contact, fear, and anxiety have been investigated in the laboratory, a predominantly artificial but controlled context. As indicated above, increases in fear and anxiety can be induced with methods like painful stimulation (e.g., via air pressure; Lindner et al., 2015) or psychosocial stress tasks (e.g., social comparison and evaluation; Birkett, 2011; Geva et al., 2014). Paradigms can target responses to the fear or anxiety induction itself (e.g., pain), and/or related processes like fear or relief learning. For instance, participants may learn to associate a stimulus preceding an aversive event with the fear-related experiences (i.e., increases in subjective and autonomic fear responses; Andreatta et al., 2013; Knight et al., 2006; Lonsdorf et al., 2017). Similarly, relief-like experiences (reductions in subjective and autonomic fear responses) may become associated with stimuli that follow an aversive experience (Andreatta et al., 2012; Gerber et al., 2014). Importantly, such fear or anxiety inductions can be combined with experimental manipulations of social presence, thus exposing social buffering effects like lower anxiety-related responses in participants experiencing aversive stimuli in the presence of another person vs. alone (Qi et al., 2020). Moreover, the social partner as well as the social behaviour can be altered. For instance, one study compared the participants' performance during a mental arithmetic stress task whilst varying the social partner's characteristics (female vs. male; stranger vs. friend) as well as their supportive behaviour (providing encouraging phrases vs. remaining silent), thus revealing social buffering effects which were represented by lower anxiety-related responses with more familiar and more supportive (male) social partners (Phillips et al., 2009).

Laboratory designs have contributed considerably to our understanding of the interrelation between physiological and psychological processes and functioning, including social phenomena (Raugh et al., 2019; Wilhelm et al., 2012). Their constrained conditions and protocols allow for systematic experimental manipulation and equal test procedures between participants, which in turn ensures a reliable investigation of the relationship between different independent and dependent variables. Causes and mechanisms of specific phenomena or constructs of interest (e.g., social contact and anxiety) can be concisely examined by observing the effects of specific changes to the experimental procedure, e.g., regarding differences between experimental groups (Wilhelm et al., 2012). The high level of experimental control characteristic to laboratory research is particularly relevant for physiological measurements like SCR, HR, and HRV. Their controlled assessment in laboratory settings almost eliminates confounding factors and enhances internal validity (Boucsein, 2012; Quintana & Heathers, 2014; Raugh et al., 2019). However, this control also limits the transferability, and crucially thus the ecological validity of laboratory-based findings to psychophysiological processes and situations in everyday life (Raugh et al., 2019; Wilhelm et al., 2012). Aspects of the laboratory setting, like its artificial stimuli or the awareness of being continuously observed, could alter the participants' behaviour, experience, and related emotional and physiological responses, hence biasing the findings and their validity (Wilhelm et al., 2012). In conclusion, laboratory designs are indispensable in the investigation of specific causal relationships, but can be limited in recreating and capturing complex real-world contexts and experiences (Goodman et al., 2018; Junghaenel & Stone, 2020; Shiffman et al., 2008; Walz et al., 2014), including social contact and anxiety (Daniel-Watanabe & Fletcher, 2021; Myin-Germeys et al., 2016). In contrast, other methodological approaches that are based in participants' everyday life, like online or EMA studies, allow for the investigation of social effects in a naturalistic setting.

1.3.3.2 Ecological Momentary Assessment

EMA, also known as experience sampling or ambulatory assessment, encompasses a collection of modern research methods and techniques that have rapidly expanded psychological and psychiatric research and practice over the past decades (Junghaenel & Stone, 2020; Trull & Ebner-Priemer, 2014; Verhagen et al., 2016). EMA measurements are usually active while participants pursue their daily lives. Repeated, real-time assessments of a person's current state, experiences, and/or behaviour (e.g., collected with smartphone apps or electronic diaries) can be combined with repeated or continuous physiological and physical measurements (e.g., HR and body posture collected via smartwatch or ECG). EMA sampling schemes can include time-based and/or event-based assessments (Conner & Mehl, 2015; Shiffman et al., 2008; Wilhelm et al., 2012). In the context of social contact and anxiety, a randomly timed EMA prompt could inquire about previous social interactions (Schwerdtfeger et al., 2020), while an event-based assessment could be initiated following predefined anxiety-inducing events (e.g., public speaking; Helbig-Lang et al., 2016). This enables EMA to collect data about multiple aspects of human experiences (e.g., social contacts) which can be recorded simultaneously, repeatedly, over time, and in different contexts, allowing for analyses on both a within- and between-person level (Lee, 2021; Moskowitz & Young, 2006; Shiffman et al., 2008; Trull & Ebner-Priemer, 2009). Advances in technological possibilities, including the size and portability of assessment methods, have rapidly expanded EMA's possibilities (Raugh et al., 2019). Today, smartphones are the prevalent EMA tool (Colombo et al., 2019; de Vries et al., 2021).

The repeated, in-the-moment EMA measurements minimize constraints and biases associated with artificial laboratory settings and retrospective self-reports (e.g., recall bias) which limit the ecological validity of laboratory-based findings (Conner & Mehl, 2015; Junghaenel & Stone, 2020; Myin-Germeys et al., 2018; Shiffman et al., 2008; Trull & Ebner-Priemer, 2014). Still, EMA shows some limitations compared to laboratory research. EMA studies may demand more resources (technology, measurement time, and data complexity), and ambulatory physiological measurements are more susceptible to artefacts caused by movement or incorrect instrument application by the participant. Due to the limited control regarding confounding factors, and a higher risk for data loss, EMA studies may require bigger sample sizes and more complex statistical analyses. However, ambulatory sensors and electronic diary entries can capture many confounding factors, including physical activity, meals, and substance intake (Conner & Mehl, 2015; Junghaenel & Stone, 2020; Wilhelm et al., 2012). Overall, the numerous benefits of EMA have established its methodology as a promising and versatile research tool in scientific and clinical research.

1.3.3.3 Online surveys

Compared to laboratory research and EMA, online surveys provide a comparatively economic and flexible approach to collecting subjective data. Researchers can select a sample that is representative of a pre-defined target population and use online tools to present it with questions (e.g., clinical questionnaires; Krosnick et al., 2014; Maniaci & Rogge, 2014). In the context of social contact and anxiety, online surveys can collect information on social contacts like their quantity and quality, as well as subjective indicators of state and trait anxiety (Groarke et al., 2020; Hein et al., 2021). Today, the prevalence of Internet access makes online-based surveys a convenient, easily accessible, and user-friendly tool for collecting data from diverse and large samples from various locations (e.g., not restricted to student samples; Maniaci & Rogge, 2014). Online surveys can capture data outside the laboratory and in participants' everyday life, while providing indicators of measurement quality comparable to those of other methodologies (Brock et al., 2012; Maniaci & Rogge, 2014; Smyth, 2018). With cross-sectional surveys, researchers can capture the prevalence and/or frequency of a construct of interest as well as correlational natures between them at a single time point. While cross-sectional surveys do not provide information regarding causal relations, they are informative of the presence of an expected relationship as well as its potential mediators. Compared to EMA, panel surveys with two or more assessments follow a longitudinal design with greater time intervals between assessments. While the possibility to test for causal as well as correlational relations is a great advantage of longitudinal surveys, the repeated yet time-delayed assessments may reduce the findings' representativeness due to factors like sample selection bias, dropouts, or reactivity to the earlier survey's content (Krosnick et al., 2014; Maniaci & Rogge, 2014).

Notably, the inclusion of reliable physiological assessments into online surveys is impractical, as it would require conjoint approaches like additional laboratory or EMA assessments. Other limitations of online surveys compared to other methodological approaches include a lack of control over participants' attentiveness, focus, comprehension of study materials, and overall compliance. In comparison to EMA, online surveys may provide lower ecological validity due to less frequent assessments and less consideration of situational and contextual factors. At the same time, however, they allow for less burdensome and less costly collection of subjective data at a higher demographic range (Maniaci & Rogge, 2014; Smyth, 2018). Overall, online surveys are a valuable addition to a researcher's toolbox, at least when resources and possibilities for direct contact are limited.

1.4 Objectives and hypotheses

The three scientific works presented in this dissertation examine factors of social contact that can lead to anxiety-related social buffering in lab and life. Previous research has implied that social contact can reduce fear, anxiety, and related autonomic responses (Hennessy et al., 2009; Kikusui et al., 2006). Additional studies have determined factors that may influence these social buffering effects, including gender (Phillips et al., 2009; Qi et al., 2021) and familiarity of the interaction partners (Eisenberger, 2013; Holt-Lunstad et al., 2003). Moreover, the absence of social contact has been shown to have anxiety-enhancing effects (Abad et al., 2010; Santini et al., 2020), which may be buffered by personal factors like social connectedness and social support (Sacco & Ismail, 2014; Thoits, 2011). In the context of this dissertation, the three experimental methods outlined in the previous section were applied in subclinical samples to test the following main research questions:

1) Does mere social involvement without direct physical presence and social interaction suffice in producing fear-reducing social buffering effects in a laboratory-based fear induction paradigm?
2) Do social buffering effects previously found in the laboratory translate to everyday-life social interactions? In particular, (how) do everyday-life social buffering effects depend on characteristics of the interacting individuals, such as their gender and familiarity?
3) How does anxiety depend on personal social factors like feelings of loneliness and access to social support when social contact is limited?

To answer these questions, I investigated the fear-related effects of indirect social involvement in a laboratory-based pain relief paradigm (study 1). Then, I applied EMA to examine the effect of specific interaction partner characteristics (familiarity, gender) on anxiety-related responses in everyday-life in-person and virtual social interactions (study 2). Finally, I studied state anxiety in relation to loneliness and related social factors measured via self-report questionnaires in online surveys during a time of limited social contact in everyday life (study 3). See Table A for an overview of the three studies.

Table A

Main features of the three studies included in this dissertation.

	Study 1	Study 2	Study 3 (sample 1 / sample 2)
Methodology	laboratory study	EMA	online surveys
Sample size	97	96	244 / 307
Proportion of female participants	100.0%	53.1%	79.1% / 37.2%
Type of social contact investigated	minimalistic: social involvement	extensive: social interaction	reduced or absent: social distancing
Daily-life setting	no	yes	yes
Anxiety-related outcome			
subjective	fear rating (VAS)	state anxiety (STAI-S)	state anxiety (STAI-S)
autonomic	SCR	HR, HRV	none

Note. EMA = ecological momentary assessment; HR = heart rate; HRV = heart rate variability; SCR = skin conductance response; STAI-S = State-Trait Anxiety Inventory – state subscale; VAS = visual analogue scale.

Previous findings showed that social buffering effects emerge in the mere physical presence of another person (Kleck et al., 1976; McClelland & McCubbin, 2008; Qi et al., 2021). This raised the question of how extensive social contact needs to be to produce subjective and/or autonomic social buffering effects. In study 1, we used a laboratory-based pain relief learning paradigm to determine whether social contact without direct physical presence and interaction (mere social involvement) produces social buffering effects on fear-related responses. The female participants repeatedly received painful (i.e., fear-inducing) stimulation and could learn to associate the subjective and autonomic relief-like experiences that followed the aversive event with a stimulus presented during pain cessation (see e.g., Andreatta et al., 2012; Gerber et al., 2014). Another female person (seated in another room), the participant herself, or no one had influence on the occurrence of the painful stimulation. Based on previously found social buffering effects of social presence (including pain-related responses; Edwards et al., 2017; Sambo et al., 2010), we hypothesized that social involvement would lead to lower fear-related responses (SCR, fear ratings) compared to non-social conditions.

Social contacts in "real" life take place with a diversity of interaction partners, and social buffering effects may depend on the individual characteristics of the persons involved (Glynn et al., 1999; Reader & Holmes, 2016; Schwerdtfeger et al., 2020; Zaki & Ochsner, 2009). This posed the question whether social buffering effects evident in controlled laboratory settings are found in a similar manner in daily life. In study 2, we examined whether gender and familiarity, two factors previously found to moderate social buffering effects, affect anxiety-related responses in non-laboratory-based social interactions. We repeatedly captured interaction partner characteristics and state anxiety on five consecutive days using smartphone-based surveys while continuously measuring HR and HRV using portable electrocardiogram (ECG) sensors. Instead of SCR (study 1), HR and HRV served as anxiety-related autonomic responses due to their higher robustness to movement artefacts and other confounding factors (e.g., temperature) in less controlled settings (Critchley & Nagai, 2013; Wilhelm et al., 2012). Based on similar findings in the laboratory (Eisenberger, 2013; Krahé et al., 2013) and real-life contexts (Eisenberger, 2013; Holt-Lunstad et al., 2003; Lee, 2021), we expected lower subjective and autonomic anxiety-related responses for social interactions with more familiar interaction partners. Regarding gender-related effects, we expected higher overall responses in female participants (Glynn et al., 1999; Kudielka et al., 2004; Villada et al., 2016). Moreover, previous findings either implied stronger anxiety-reducing effects of female interaction partners in both men and women (Glynn et al., 1999; Kirschbaum et al., 1995; Qi et al., 2021), opposite-gender social buffering effects (Phillips et al., 2006; Phillips et al., 2009), or no gender-related buffering effects (Lepore, 1992; Shahrestani et al., 2015). We hence hypothesized that the gender of the interaction partner as well as the gender of the participant shape the social buffering effect such that either female interaction partners or interaction partners from the other gender entail the strongest social buffering effect. Alternatively, we expected no gender-related effects. While familiarizing myself with the EMA methodology in preparation of study 2, I wrote and published an opinion paper on methodological considerations regarding the integration of EMA into psychiatric practice (see Appendix A).

Finally, limited and absent social contact have previously been associated with increases in anxiety (Abad et al., 2010; Santini et al., 2020). Study 3 investigated whether anxiety-related responses during the restriction of social contact differ depending on personal factors in relation to social contact such as loneliness and social isolation and access to social support. As part of the global response to the COVID-19 pandemic at the time of data collection, so called "social distancing" measures directed individuals to restrict their social contacts and to keep a physical distance from others (Benke et al., 2020; Marroquín et al., 2020). This depicted an ecologically valid assessment context for limited social contact in daily life. In study 3, we developed and validated a novel questionnaire for a context-specific, state-trait measurement of loneliness and related social factors during times of social distancing, and then used it to investigate how these factors relate to differences in state anxiety. Based on previous findings, we expected higher anxiety in relation to higher loneliness and social isolation (Beutel et al., 2017; Hawkley & Cacioppo, 2010), lower anxiety levels with more access to social support (Cornwell & Waite, 2009b; Lee & Cagle, 2017), and higher anxiety and loneliness levels in women (Beutel et al., 2017; Leach et al., 2008; Victor & Yang, 2012).

Overall, this dissertation aims to contribute to a more profound understanding of anxiety-related social buffering, its moderating factors, and their validity in the laboratory as well as daily life. The results may offer important indications for the prevention and reduction of anxiety and related autonomic responses through social contact.

2 Publications

In accordance with the research objectives formulated above, three studies were conducted to investigate the conditions under which social contact affects anxiety-related subjective and autonomic responses. The studies are presented below and have been edited to fit the formatting of this dissertation. The content of the studies corresponds to the form published in the respective journal. The studies are presented in the following order:

Study 1: Gründahl, M., Retzlaff, L., Herrmann, M. J., Hein, G., & Andreatta, M. (2022). The skin conductance response indicating pain relief is independent of self or social influence on pain. *Psychophysiology*, 59(3), e13978. https://doi.org/10.1111/psyp.13978

Supplementary Material:
https://onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fpsyp.13978&file=psyp13978-sup-0001-Supinfo.pdf

Study 2: Gründahl, M., Weiß, M., Stenzel, K., Deckert, J., & Hein, G. The effects of everyday-life social interactions on anxiety-related autonomic responses differ between men and women. https://doi.org/10.31234/osf.io/rwu3t

Supplementary Material: https://osf.io/pt4a7/

Study 3: Gründahl, M., Weiß, M., Maier, L., Hewig, J., Deckert, J., & Hein, G. (2022). Construction and validation of a scale to measure loneliness and isolation during social distancing and its effect on mental health. *Frontiers in psychiatry*, 13:798596. https://doi.org/10.3389/fpsyt.2022.798596

Supplementary Material:
https://www.frontiersin.org/articles/10.3389/fpsyt.2022.798596/full#supplementary-material

After study 1 and 2, respectively, I shortly summarize the results and discuss their implications for the subsequent study.

The skin conductance response indicating pain relief is independent of self or social influence on pain

Marthe Gründahl[1], Leonie Retzlaff[1], Martin J. Herrmann[1], Grit Hein[1]*, Marta Andreatta[2, 3]*

[1] Center of Mental Health, Department of Psychiatry, Psychosomatic and Psychotherapy, Translational Social Neuroscience Unit, University of Würzburg, Würzburg, Germany

[2] Department of Psychology, Education & Child Studies/Clinical Psychology, Erasmus University of Rotterdam, the Netherlands

[3] Department of Biological Psychology, Clinical Psychology, and Psychotherapy, University of Würzburg, Germany

*shared senior authorship

Corresponding author: Dr. Marta Andreatta, Department of Psychology, Education & Child Studies/Clinical Psychology, Erasmus University of Rotterdam, Postbus 1738, 3000 DR Rotterdam, Netherlands. Email: andreatta@essb.eur.nl

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Abstract

Pain relief is defined as the ease of pain and is thus highly relevant for clinical applications and everyday life. Given that pain relief is based on the cessation of an aversive pain experience, it is reasonable to assume that pain relief learning would also be shaped by factors that alter subjective and physiological pain responses, such as social presence or a feeling of control. To date, it remains unclear whether and how factors that shape autonomic pain responses might affect pain relief learning. Here, we investigated how pain relief learning is shaped by two important factors known to modulate pain responses, i.e. social influence and controllability of pain. Skin conductance responses (SCRs) were recorded while participants learned to associate a formerly neutral stimulus with pain relief under three different pain conditions. In the social-influence condition (N = 34), the pain stimulation could be influenced by another person's decisions. In the self-influence condition (N = 31), the participants themselves could influence the pain stimulation. Finally, in the no-influence condition (N = 32), pain stimulation was simply delivered without any influence. According to our results, the SCRs elicited by the stimulus that was associated with pain relief were significantly smaller compared to the SCRs elicited by a neutral control stimulus, indicating pain relief learning. However, there was no significant difference in the pain relief learning effect across the groups. These results suggest that physiological pain relief learning in humans is not significantly influenced by social influence and pain controllability.

Keywords: backward conditioning, electrodermal activity, pain relief learning, social modulation

Introduction

Pain relief is defined as the ease of pain as an aversive state (Riebe et al., 2012; Solomon, 1980). The subjective and physiological pain relief responses can be studied using a relief-learning paradigm where a neutral stimulus is repeatedly presented after a painful stimulus (i.e., backward conditioning; Andreatta et al., 2010; Luck & Lipp, 2017). Here, implicit learning processes can be reflected in autonomic responses (Schultz & Helmstetter, 2010). If the neutral stimulus is presented within the pain cessation period, animals (rats, Acosta et al., 2017; honeybees, Kirkerud et al., 2017; drosophilia melanogaster, Yarali et al., 2008) or humans (Andreatta et al., 2016) learn to associate this formerly neutral stimulus with pain relief. As a result, the presence of the pain relief-associated stimulus ($_{relief}$CS) on its own leads to an attenuation of autonomic responses such as startle reflex responses (Andreatta et al., 2010; Luck & Lipp, 2017) and skin conductance responses (SCR; Andreatta et al., 2013) compared to a novel stimulus that is not associated with pain relief.

The SCR is predominantly mediated by the sympathetic cholinergic system (Critchley & Nagai, 2013). In the laboratory setting, at rest and constant temperature, changes in SCRs indicate changes in sympathetic arousal which have been associated with fear and pain learning (Boucsein, 2012; Delgado et al., 2006; Leknes et al., 2008). Experiencing pain is associated with increased SCRs, while relief is associated with reduced SCRs (Leknes et al., 2008). Previous conditioning research have found enhanced SCRs towards fear-conditioned stimuli signaling danger or pain compared to safety signals (Andreatta et al., 2013; Knight et al., 2006). Advancing these findings, signals of pain relief have been associated with reduced SCRs after conditioning, compared to both fear and safety signals (Andreatta et al., 2013).

Recent studies have started to investigate experimental factors that shape pain relief learning in humans. For example, it has been shown that pain relief learning unfolds on the subjective level if the pain is predictable. Neutral stimuli presented after unpredictable pain stimuli are associated with pain (resulting in negative valence) instead of pain relief (resulting in positive valence; Andreatta et al., 2013). A recent study implied that the subjective valence of a relief stimulus depends on the intensity of the aversive stimulation (Green et al., 2020). While pain relief is robustly indexed on the physiological level (indicated by attenuated startle and SCRs), subjective measures such as ratings seem to be additionally influenced by factors related to the presentation of the pain. This demonstrates a discrepancy between implicit and explicit measures (Andreatta et al., 2012; Andreatta et al., 2010; Green et al., 2020; Luck & Lipp, 2017; Strack & Deutsch, 2004).

Given that pain relief learning is based on the cessation of an aversive pain experience, it is reasonable to assume that factors that alter subjective and physiological pain responses also shape pain relief learning. Supporting this assumption, it has been demonstrated that increases in pain intensity are associated with increased relief ratings (Leknes et al., 2008). There is ample evidence that pain intensity is affected by a number of different factors, most importantly social factors (Che et al., 2018; Krahé et al., 2013) and the controllability of the pain stimulation (Salomons et al., 2004; Stephens et al., 2016; Wiech et al., 2006). With regard to social factors, social support such as helping (Hein et al., 2018) and offering sympathetic comments (Brown et al., 2003; Roberts et al., 2015) have been observed to reduce subjective and physiological pain responses. Overall, previous findings show that clearly expressed social support, like comforting words and touching, has stronger effects than less explicit social support like social presence (Che et al., 2018). Compared to more familiar social partners, for example, a friend, social effects of strangers are often less pronounced (Jackson et al., 2009; Krahé et al., 2013; Master et al., 2009). Nonetheless, recent studies demonstrated a reduction in pain perception (Edwards et al., 2017; Sambo et al., 2010) and autonomic fear responses (e.g., SCRs to an aversive sound, Qi et al., 2020) when another person was present, even if this person was a stranger. However, the results are inconsistent. For example, there is also evidence for an increase in pain responses in association with a social presence, for instance, if the present person shows a strong reaction to the pain stimulation (Hurter et al., 2014), or no social influences on pain processing at all (see e.g., Che et al., 2018; Modić Stanke & Ivanec, 2010). The effects of social influence on pain and subsequent relief learning remain unclear.

With regard to controllability of pain, there are studies showing that perceived control over pain reduced subjective (Wiech et al., 2006) and neural (Mohr et al., 2005; Salomons et al., 2004; Wiech et al., 2006) pain responses in healthy participants. In chronic pain samples, perceived control over pain (Stephens et al., 2016) and the belief in one’s functionality despite pain (i.e., "self-efficacy"; Mirjalili et al., 2011; Perry & Francis, 2013) were associated with a reduction in pain severity, pain-related cognitions, and emotionality (e.g., depression). Moreover, participants who actively learned to avoid aversive events showed lower SCRs than a non-avoidance group, both to a conditioned stimulus and during novel threat conditioning (Boeke et al., 2017). Notably, although reporting attenuated physiological pain responses, some studies on pain controllability show no differences in pain severity ratings (Mohr et al., 2012; Salomons et al., 2004). Others showed changes in perceived suffering, but not physiological responses (Löffler et al., 2018).

Overall, previous studies indicate that social influence and controllability of pain can influence subjective and physiological pain responses. However, it remains unclear whether these factors also affect pain relief learning. Hence, in the present study, we investigated if subjective and autonomic pain relief is modulated by social influence and controllability of pain, that is, two factors that play an essential role in modulating pain.

To do so, we used a relief-learning paradigm. In the learning phase, a pain stimulus was presented, serving as an unconditioned stimulus (US). A visual cue appeared after each pain stimulus and became the conditioned stimulus ($_{relief}$CS). In the test phase, the $_{relief}$CS was again presented, as was a novel control stimulus (control). The US was absent in this phase. Participants were randomly assigned to three different groups that received the pain (i.e., the US) under three different conditions. In one group, the frequency of pain stimulation could ostensibly be influenced by another person (a confederate) that was unknown to the participant and sat in another room (social-influence group). In the second group, the frequency of pain stimulation could be influenced by the participants themselves by actively avoiding the pain via key press (self-influence group). In the third group, the frequency of pain stimulation was determined by the computer program and could not be influenced (no-influence group). Notably, the frequency of pain stimulation and the test phase were similar in all three groups. Participants rated their fear, arousal, and the valence of the stimuli after each phase. Their SCRs were continuously measured. Note that unlike previous studies (e.g., Brown et al., 2003; McClelland & McCubbin, 2008), the social-influence condition did not include active social support. This was chosen to keep the three conditions as similar as possible. Social interactions introduce a high number of additional confounding factors which would have been difficult to reproduce in the non-social conditions.

Based on previous evidence from pain relief learning (Andreatta et al., 2016; Gerber et al., 2014; Luck & Lipp, 2017), we hypothesized that participants learn to associate the neutral stimulus with the prior experience of pain relief. If this is the case, the $_{relief}$CS should be rated as more positive and less arousing and fear-inducing than the control stimulus. Moreover, in the test phase, the SCRs elicited by the $_{relief}$CS should be reduced compared to the SCRs elicited by the control stimulus.

Based on findings that social presence and controllability of pain can decrease pain's aversiveness (Edwards et al., 2017; Mohr et al., 2005; Wiech et al., 2006), and given that pain relief learning is based on the cessation of an aversive pain experience (Gerber et al., 2014), we predicted reduced subjective and autonomic pain responses in the social-influence and self-influence group. If pain (i.e., the US) is perceived as less intense, participants should experience less pain relief (Leknes et al., 2008), resulting in reduced pain relief learning compared to the no-influence group. To reflect the diminished pain relief learning, the difference in SCRs and ratings between the $_{relief}$CS and control in the test phase should be significantly smaller in the social-influence and self-influence compared to the no-influence group.

Alternatively, inspired by studies that showed no effect of social influence and controllability on pain responses (Löffler et al., 2018; Modić Stanke & Ivanec, 2010), it is also possible that we observe comparable subjective and autonomic pain responses in the three experimental conditions (social-influence, self-influence, no-influence). In this case, we would expect no differences in pain relief learning between the experimental conditions, because there are no differences in the pain stimulus (US) that may drive differential pain relief learning. As a result, there should be no significant differences in SCRs and ratings between the $_{relief}$CS and control in the test phase between the social-influence, the self-influence and the no-influence conditions.

Method

Participants

One-hundred and twenty-five healthy female volunteers participated in the study. They received financial compensation for participating (12 €) and were recruited via university-based and public advertisements. The sample size was chosen based on comparable studies on pain relief learning (Andreatta et al., 2016; Andreatta et al., 2010). Moreover, we recruited one female student (confederate) trained to act as a partner in the social-influence group. We chose female participants and a female confederate to control for gender and avoid potential cross-gender effects in the social-influence group (which might occur if female participants are paired with a male confederate or vice versa; Hein et al., 2016). Besides age and gender, we controlled for body mass index (BMI; Aldosky, 2019). Ambient temperature (Wilcott, 1963) was kept similar across groups. Participants were asked not to consume nicotine or mind-altering substances prior to the assessment to prevent their cholinergic impact on SCRs (Boucsein et al., 2012). Further exclusion criteria were assessed by self-report or questionnaire (depression: ADS-K, see "Questionnaires") and included neurological, cardiac and psychiatric illness, epilepsy, chronic pain condition, hearing loss, pregnancy and lactation, and acute depressive symptoms.

We had to exclude 28 participants from the analysis. Twelve participants were excluded because of technical problems, interruption of the experiment, or missing ratings. Sixteen participants were defined as non-responders for the SCRs (mean <0.02 µS, see also "Data reduction") and consequently excluded from all analyses. In the end, we considered 97 participants for the analysis. 93.8% of participants had the highest German educational level, and 91.8% were students (see Table 1.1 for characteristics of the final sample). Participants were randomly divided into three groups according to the learning protocol.

Post-hoc power analysis using G*Power (Faul et al., 2009) showed that the final sample size (N = 97) had sufficient power to detect pain relief learning in SCRs (Power = 097; based on Phase x Group interaction for SCRs with partial η^2 = .079, see "Skin conductance response to the pain relief stimulus ($_{relief}$CS)").

The study was carried out in accordance with the Declaration of Helsinki (World Medical Association, 2001) and the American Psychological Association's ethical principles (American Psychological Association, 2017). The local ethics committee of the University Hospital Würzburg approved the study protocol.

Stimulus material

Pain stimuli

The *painful stimulus* (US) consisted of painful air-pressure-induced stimulation administered to the non-dominant hand's index finger by an Impact Stimulator (Franken Labortechnik) using a compressed air-accelerated projectile. The plastic projectile weighed 612 µg and was shot vertically through a Plexiglas tube attached to the left index finger, approximately 0.5 cm below the proximal nail fold. The stimulus intensity was individually determined using a threshold procedure (Hein et al., 2018; Huskisson, 1974). During pain threshold evaluation, we increased stimulation intensity step by step, starting at the lowest possible intensity (0.25 mg/s). The stimulus intensity was augmented by increasing the compressed air in steps of 0.25 mg/s (range = 2–6 mg/s). Participants rated each stimulation on a ten-level visual analog pain scale (Hein et al., 2018; Huskisson, 1974). The value 0 was defined as "not perceptible", 1 as "barely perceptible", 2–3 as "mild pain", 4–5 as "moderate pain", 6–7 as "severe pain", 8 as "considerably painful but still endurable" and 9–10 as "unbearable pain". The target value 8 on the pain scale marked the upper threshold, and the corresponding painful stimulation delivered by the Impact Stimulator served as the individual stimulation intensity for the experiment. The mean intensity of the US stimulation was 2.86 mA (SD = 0.65).

Visual stimuli

As visual stimuli (training, relief and control stimulus), we used three grey geometrical shapes (RGB: 145, 145, 145) presented at eye level over a black background for 6 s on a 19'' computer screen localized circa 140 cm in front of the participants. Shapes were a triangle (10 cm width × 8.6 cm height), a square (10.3 × 10.3 cm), and a circle (10.5 × 10.5 cm). The three different shapes and their roles as training, relief, and control stimulus were counter-balanced across the participants. In addition, a red (RGB: 255, 0, 0) or blue (RGB: 0, 128, 255) lightning bolt (4.1 cm width × 7.5 cm height) served as a signal stimulus. If the US followed, a rectangular frame (7.2 cm width × 7.9 cm height) in the same color briefly surrounded the lightning bolt (for more details, see "Procedure").

Ratings

After each experimental phase (Figure 1.1a), participants rated the valence ("how unpleasant vs. pleasant was the presented picture?"), arousal ("how strong was your arousal elicited by the presented picture?"), and fear ("how strong is your fear towards this picture?") of the visual stimuli using three different visual analog scales (VAS) ranging from 1 to 9. One indicates "very unpleasant" for the valence, "calm" for the arousal and "no fear" for the fear rating, while 9 indicates "very pleasant", "exciting" and "strong fear", respectively. After both the learning and test phase, we verified participants' contingency awareness by asking them to rate the intensity of the painful stimulation that they associated with each visual stimulus (i.e., US-expectancy ratings). The VAS ranged from 0 (no association) to 100 (perfect association). Both valence and US-expectancy ratings were additionally collected at three times throughout the learning phase for the visual relief stimulus (after 6, 12, and 18 trials, see Figure 1.1b; results reported in Supplementary Material). At the end of the experiment, all participants rated the painful stimulation's intensity again, as described above. Lastly, the overall tolerability of the experiment ("How tolerable did you find the experiment?") was rated on a 9-point Likert scale ranging from 1 ("easy to tolerate") to 9 ("very difficult to tolerate").

Questionnaires

Individual differences in dispositional (trait) anxiety were measured using the German versions of the Anxiety Sensitivity Index-3 (ASI-3; Kemper et al., 2011) and the trait anxiety subscale of the state-trait anxiety inventory (STAI; Laux et al., 1981). We collected the German state subscale of the STAI and the positive and negative affect schedule (PANAS; Krohne et al., 1996) at the beginning and at the end of the experimental session to assess the current emotional state of the participants. For the screening of depressive symptoms, we used the German 15-item short form of the Center for Epidemiologic Studies Depression Scale (Allgemeine Depressionsskala-Kurzform, ADS-K; Hautzinger & Bailer, 1993). In addition, participants of the social-influence group rated their impression of the other person (i.e., the confederate) regarding perceived similarity, likability, trustworthiness, supportiveness, and familiarity (Hein et al., 2016).

Procedure

After filling in the questionnaires, participants were informed that a series of geometrical shapes, a painful air-puff to the finger and loud white noises would be presented during the experiment and were instructed to fixate on the middle of the screen. We did not mention the contingency between $_{\text{relief}}$CS and US. Next, the electrodes were attached, and the pain threshold procedure was performed as described above.

Participants were randomly assigned to three different groups. Participants assigned to the social-influence group briefly met another person (confederate) seated in an adjacent experimental booth without any further contact with the participant. A staged lottery appointed the participant to the role of pain recipient and the confederate to the role of pain influencer. It was explained to both that the pain influencer (confederate) could support the receiver (participant) by learning to press the right one out of two keys on the German keyboard (K or L on a German keyboard) to avert pain stimulation. Thus, pain stimulation was seemingly influenced by another person, although it was in fact fixed. Participants assigned to the self-influence group learned to actively avoid the painful stimulation by pressing the right button out of two keys (K or L, counter-balanced). They were thus able to influence pain stimulation themselves. Participants assigned to the no-influence group had no influence on the delivery of painful stimulation. To keep motor responses comparable across the groups, participants of the social-influence group pressed a key to indicate whether they expected the other person to cancel their pain. Participants of the no-influence group pressed a key to indicate whether they expected a painful stimulus (K or L indicating yes or no, in counter-balanced order).

All participants underwent an identical experimental procedure (Figure 1.1a).

The experiment started with a habituation phase (7 trials) in which participants familiarized themselves with the trial structure, the response keys, and the geometrical shapes. The first three trials started with a fixation cross (2–4 s, duration varied randomly) followed by a red lightning bolt which lasted until participants pressed one of two keys (K or L). After the response, the lightning bolt remained on the screen for 1 s. A white fixation cross appeared for 6 s (inter-stimulus interval, ISI) followed by a geometrical shape (training). This was followed by a fixation cross (inter-trial interval, ITI, 9–16 s) after 6 s. Each of the remaining four trials started with the presentation of one of the two other geometrical shapes ($_{relief}$CS, control) for 6 s. An ITI of 15–20 s followed. Both shapes were presented twice in a randomized order.

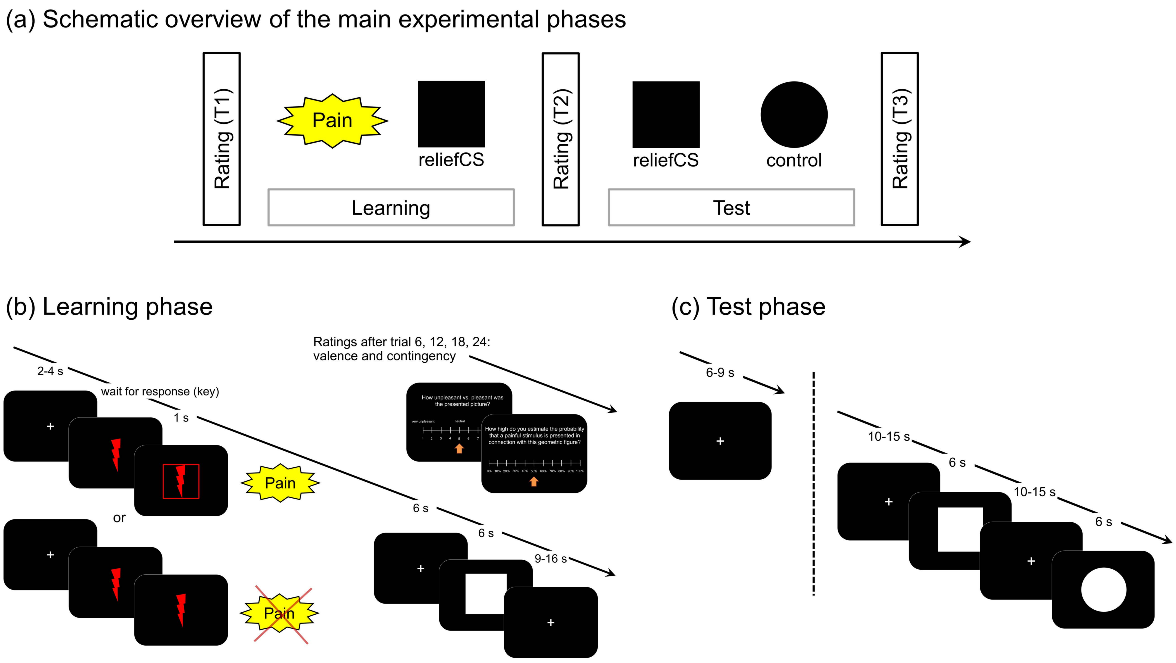

Figure 1.1 Main experimental phases. (a) Schematic overview of ratings, learning phase and test phase. (b) Detailed display of a learning phase trial with call for keypress (lightning bolt), US delivery (Pain) and $_{relief}$CS (here: square), and ratings of valence and contingency. (c) Detailed display of a test phase trial with presentation of $_{relief}$CS and control (here: circle), preceded by seven startle habituation trials.

Each trial of the learning phase (Figure 1.1b) also started with a fixation cross (2–4 s) followed by a red lightning bolt. The lightning bolt lasted until participants pressed one of two keys (K or L). After response, it remained visible for 1 s. In 25% of the cases, a rectangular frame surrounded the lightning bolt during this second, announcing subsequent painful stimulation (no frame = no stimulation). After a 6 s ISI, a geometrical shape ($_{relief}$CS) was presented for 6 s, followed by an ITI (9–16 s; Figure 1.1n). The learning phase consisted of 24 trials with seven US trials in the social-influence and no-influence group, and 31 or 32 trials with 7 or 8 US trials in the self-influence group. The increased trial number in the self-influence group resulted from additional trials. For fast learners, these trials included additional pain stimulations for the number of pain trials they had successfully avoided to keep the quantity of pain stimuli comparable across groups. Before starting the learning phase, participants of the self-influence group were informed that these trials would occur independently of their performance, indicated by a blue (instead of red) lightning bolt and rectangular frame. After every six trials containing a red lightning bolt, participants gave ratings on US-expectancy and valence of the geometrical shape ($_{relief}$CS). These ratings were included to allow for additional group comparisons in $_{relief}$CS evaluation throughout the learning phase and are reported in the supplementary material.

The test phase (Figure 1.1c) started with a short startle habituation sequence to decrease initial startle reactivity (Blumenthal et al., 2005). A fixation cross was presented, and seven startle probes were delivered at random intervals of 6–9 s. After startle habituation, each trial of the test phase started with a fixation cross (ITI, 15–20 s). The ITI was followed by the geometrical shape presented in the learning phase ($_{relief}$CS) or another geometrical shape (control) which was never presented during the learning phase, but only twice during habituation phase. Each shape was presented 12 times and in a pseudo-randomized order meaning that each condition was not presented more than twice in a row. The US was never delivered. During half of the trials (i.e., six trials per $_{relief}$CS, control), a startle probe (white noise) was randomly delivered 4 to 5.5 s after stimulus onset. Additionally, six startle probes were delivered during ITI to enhance the startle probes' unpredictability. Startle responses can serve as additional indicators of the learning (Andreatta et al., 2016; see Supplementary Material). In total, the test phase consisted of 24 trials.

Physiological data collection and preprocessing

Physiological responses were recorded with a V-Amp 16 amplifier and Vision Recorder V-Amp Edition Software (Version 1.21.0303, BrainProducts GmbH, Gilching, Germany). We applied a sampling rate of 400 Hz. The offline analyses of these responses were conducted with Brain Vision Analyzer Software (Version 2.2.0; BrainProducts GmbH).

SCR was continuously recorded by delivering a constant current of 0.5 V using two 5 mm Ag/AgCl electrodes. These were placed on the palm of the non-dominant hand, the first 2 cm above the hypothenar eminence and the other 2 cm distal. Considering that the startle-eliciting sounds modulate SCRs (de Haan et al., 2018; Sjouwerman et al., 2016), we excluded all trials containing a startle probe for the test phase analysis, which resulted in six trials per condition ($_{relief}$CS, control). In order to remove frequencies linked to other physiological responses (e.g., breathing), the electrodermal activity was offline-filtered, with a 1 Hz high cut-off filter. Data were segmented 1 s before to 8 s after stimulus onset. Following the guidelines (Boucsein et al., 2012), the SCR was defined as the difference (in µS) between the response onset (0.8–4 s after stimulus onset) and the first response peak. Responses below 0.02 µS were coded as zero and included in the analyses. We calculated a mean score for each participant through all the test phase trials for each condition. Those with a mean score lower than 0.02 µS were coded as non-responders and excluded from further analysis (see also Delgado et al., 2011). After having summed 1 to the raw scores, we then transformed the raw data into log to normalize the distribution (Boucsein, 2012). Taking extinction effects into consideration, the log-scores were then averaged for each condition, separately for the first half (early) and the second half (late) of the test phase.

Considering that pain relief strongly depends on the preceding stimulation's painfulness (Leknes et al., 2008), we further verified whether the three groups differed in their responses to the painful stimulation during learning phase. We considered both the responses to the painful stimulation and the responses to the preceding threat signal (i.e., the frame surrounding the lightning bolt for one second) because these two events were very close in time to each other. We calculated separate means for the painful stimulation and threat signal across all the responses. Because of the short ISI (i.e., 1 s), the responses to frame and pain may have overlapped. Therefore, we did three kinds of analysis to disentangle these responses. First, we considered the responses to the frame. Second, we considered the responses to the painful stimulation. Specifically, we averaged all the SCRs to the painful stimulation, meaning both the responses coded as such and the zero responses. However, we had to code numerous pain-responses as zero because the response onset was not visible due to the short delay between pain and frame. Third, we considered only those responses to the pain which were identifiable (i.e., we excluded the zero responses when averaging the SCRs to the US; N = 84).

Statistical analyses

All data were analyzed with IBM SPSS Statistics for Windows (Version 26). First, using analyses of variances (ANOVAs), we tested for differences in age, BMI, education level, anxiety sensitivity (ASI-3), state and trait anxiety (STAI), depression (ADS-K) and pain intensity ratings between the conditions.

Second, given that our hypotheses are based on a potential effect of social and self-influence on pain processing, we also tested for possible group differences in the response to painful stimulation (US) during the learning phase. To do so, we calculated two one-way ANOVAs with SCRs to the pain stimulus (US) or the symbol signaling pain (frame) as dependent variable and group (no-influence, self-influence, social-influence) as between-subjects factor.

Third, we investigated differences in pain relief learning on the subjective level. To do so, we conducted four separate three-way mixed measures ANOVAs with valence, arousal, fear, and US-expectancy ratings as dependent variables, group (no-influence, self-influence, social-influence) as between-subjects factor, and stimulus ($_{relief}$CS, control, training) and time (before learning [T1], after learning [T2], after test [T3]) as within-subjects factors. The factor time was included to detect change across experimental phases (T1, T2, T3 for valence, arousal and fear ratings; T2 and T3 only for US-expectancy ratings). Post-hoc simple contrasts (Bonferroni-corrected) were conducted to clarify the significant time x stimulus interaction.

Fourth, we investigated group differences in pain relief learning on the physiological level (SCRs), using a three-way mixed-measures ANOVA with SCR as dependent variable, group (no-influence, self-influence, social-influence) as between-subjects factor, and stimulus ($_{relief}$CS, control) and period (early, late) as within-subjects factors. The factor period was included because SCR amplitudes decrease with repeated stimulus presentation, for example, between early and late experimental trials (Boucsein et al., 2012; Qi et al., 2020). It represents averaged SCR log-scores calculated for the first and second half of the test phase. Post-hoc simple contrasts (Bonferroni-corrected) were conducted for the significant period × stimulus interaction. In response to the significant period × group interaction, we added an explorative analysis using separate two-way ANOVAs for SCRs in the early and late period of the test phase, with group (no-influence, self-influence, social-influence) as between-subjects factor and stimulus ($_{relief}$CS, control) as within-subject factor.

The alpha (α) level was set at 0.05 for all analyses. The effect size is reported as partial η^2. In case of violation of the sphericity assumption, the Greenhouse-Geisser test was applied, and the degree of freedom was consequently corrected. Simple contrasts (Bonferroni-corrected) were calculated as post-hoc tests for significant interactions. The data are available at https://github.com/Marthe-Gruendahl/pain_relief.

Results

Group characteristics and questionnaires

There were no significant differences between conditions in age, anxiety sensitivity, state and trait anxiety, depression scores, and pain intensity ratings (see Table 1.1).

Table 1.1

Characteristics of experimental groups.

	No-influence	Self-influence	Social-influence	Group comparisons
N	32	31	34	
Age (*SD*)	23.94 (3.62)	24.26 (3.36)	23.32 (3.37)	$F(2, 94) = 0.62$, $p = 0.540$
ASI-3 (*SD*)	19.50 (11.19)	17.68 (10.35)	21.26 (8.67)	$F(2, 94) = 1.03$, $p = 0.363$
BMI (*SD*)	23.34 (3.45)	21.67 (2.68)	23.51 (3.99)	$F(2, 94) = 0.05$, $p = 0.827$
High education level[1]	96.9%	100%	94.1%	$F(2, 94) = 0.90$, $p = 0.410$
STAI-Trait (*SD*)	36.97 (8.47)	35.26 (8.11)	35.56 (7.57)	$F(2, 94) = 0.41$, $p = 0.664$
STAI-State at start (*SD*)	36.16 (7.60)	34.32 (6.17)	35.41 (5.62)	$F(2, 94) = 0.13$, $p = 0.878$
STAI-State at end (*SD*)	37.60 (8.74)	38.10 (7.71)	38.32 (7.93)	
ADS-K (*SD*)	8.31 (4.65)	7.00 (3.92)	7.71 (4.41)	$F(2, 94) = 0.72$, $p = 0.489$
Pain intensity (*SD*)	2.98 (0.60)	2.80 (0.65)	2.80 (0.70)	$F(2, 94) = 0.79$, $p = 0.457$

Note: ASI-3 = Anxiety Sensitivity Index-3; BMI = body mass index; High education level = vocational technical diploma (“Fachhochschulreife”) or higher education entrance qualification (“Allgemeine Hochschulreife”); STAI = State-Trait Anxiety Inventory; ADS-K = Allgemeine Depressionsskala-Kurzform (depression scale).
[1] Low education level: no certificate, secondary school certificate (“Volks-/Hauptschule”), or intermediate secondary school certificate (“Mittlere Reife”).

SCRs to the painful stimulation (US) and its signal

We tested whether the experimental groups (no-influence, self-influence, social-influence) differed regarding the responses to the painful stimulation. The ANOVA investigating the SCRs to the frame (which signaled painful stimulation) revealed no significant differences between the experimental groups ($F(2, 94) = 0.593$, $p = 0.693$, $\eta_p^2 = 0.011$, Figure 1.2A). The ANOVA investigating the SCRs to the pain stimulation itself (US) also revealed no significant group differences ($F(2, 94) = 1.54$, $p = 0.220$, partial $\eta_p^2 = 0.032$, Figure 1.2B).

We conducted an explorative analysis, excluding 13 participants who did not show any evident response to the painful stimulation. Thus, we conducted the same analyses based on $N = 84$ ($n = 25$ for the no-influence group, $n = 30$ for the self-influence group, and $n = 29$ for the social-influence group, respectively). It confirmed the lack of group differences regarding SCRs to the pain stimulus ($F(2, 81) = 0.04$, $p = 0.959$, $\eta_p^2 = 0.001$; Figure 1.2C).

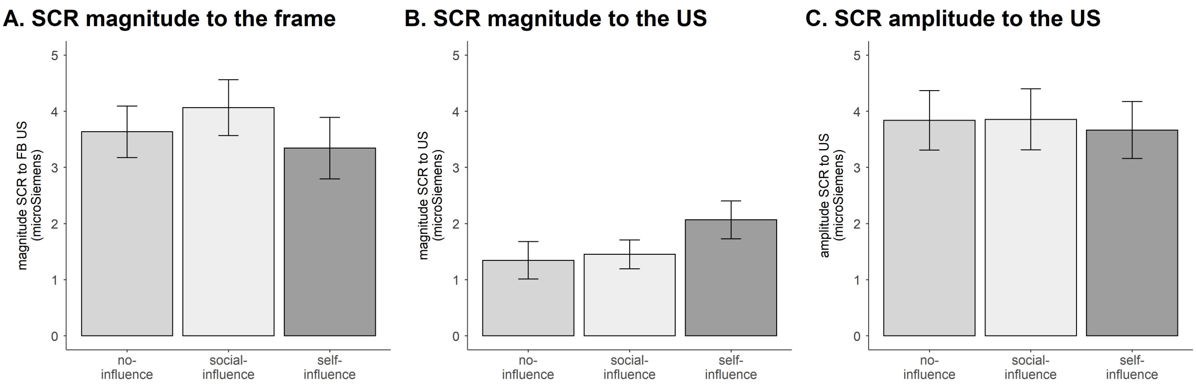

Figure 1.2 Means (with standard errors) of the SCRs to the frame (A.) and the US (B. and C.) separately for the three groups. For the magnitude of the SCR, we considered all responses meaning both those coded as such and the zero responses. For the SCR amplitude, only the responses as such were averaged.

Ratings of the pain relief stimulus ($_{\text{relief}}$CS)

We conducted three-way mixed measures ANOVAs to analyze participants' valence, arousal and fear ratings of the $_{\text{relief}}$CS, the control and the training stimulus collected before learning (i.e., after training phase; T1), between learning and test (T2), and after the test phase (T3; Figure 1.3). Another ANOVA investigated expectancy ratings at the last two time points (T2, T3). There were no significant main or interaction effects of group on any rating (all p values > 0.220), indicating that the three groups did not significantly differ in their ratings of the visual stimuli throughout the experiment (Figure 1.3).

However, the analyses revealed significant main effects of stimulus ($_{\text{relief}}$CS/control/training) on all ratings (valence: $F(2, 188) = 19.21$, $p < 0.001$, $\eta_p^2 = 0.170$, 95% CI [0.08, 0.26]; arousal: $F(2, 188) = 45.48$, GG-$\varepsilon = 0.912$, $p < 0.001$, $\eta_p^2 = 0.326$, 95% CI [0.22, 0.42]; fear: $F(2, 188) = 43.42$, GG-$\varepsilon = 0.894$, $p < 0.001$, $\eta_p^2 = 0.316$, 95% CI [0.21, 0.41]; US-expectancy: $F(2, 188) = 58.97$, GG-$\varepsilon = 0.822$, $p < 0.001$, $\eta_p^2 = 0.385$, 95% CI [0.28, 0.47]). The ANOVAs also yielded main effects of time on all ratings (T1/ T2/ T3: valence: $F(2, 188) = 32.00$, $p < 0.001$, $\eta_p^2 = 0.254$, 95% CI [0.00, 0.06]; arousal: $F(2, 188) = 26.91$, GG-ε = 0.905, $p < 0.001$, $\eta_p^2 = 0.223$, 95% CI [0.00, 0.07]; fear: $F(2, 188) = 49.62$, GG-ε = 0.910, $p < 0.001$, $\eta_p^2 = 0.346$, 95% CI [0.00, 0.10]; T2/ T3: US-expectancy: $F(1, 94) = 10.68$, $p = 0.002$, $\eta_p^2 = 0.102$, 95% CI [0.00, 0.03]). Moreover, there were significant stimulus x time interactions in all four ANOVAs (valence: $F(4, 376) = 32.26$, GG-ε = 0.851, $p < 0.001$, $\eta_p^2 = 0.256$, 95% CI [0.18, 0.32]; arousal: $F(4, 376) = 32.77$, GG-ε = 0.809, $p < 0.001$, $\eta_p^2 = 0.258$, 95% CI [0.18, 0.32]; fear: $F(4, 376) = 33.84$, GG-ε = 0.814, $p < 0.001$, $\eta_p^2 = 0.265$, 95% CI [0.19, 0.33]; US-expectancy: $F(2, 188) = 30.27$, $p < 0.001$, $\eta_p^2 = 0.244$, 95% CI [0.14, 0.34]; Figure 1.3), indicating that ratings for $_{relief}$CS and control changed over time.

Post-hoc simple contrasts (Bonferroni-corrected $\alpha < 0.017$) were conducted to investigate the stimulus x time interactions. See Figure 1.3 for ratings of valence (a), arousal (b), fear (c) and US-expectancy (d) of the three stimuli after each experimental phase.

Prior to learning (T1), results indicated comparable valence (all p values > 0.054), arousal (all p values > 0.628) and fear (all p values > 0.053) across the three visual stimuli.

After learning (T2), $_{relief}$CS was rated as more negative, arousing and threatening than both control (valence: $F(1, 94) = 23.67$, $p < 0.001$, $\eta_p^2 = 0.201$; arousal: $F(1, 94) = 35.52$, $p < 0.001$, $\eta_p^2 = 0.274$; fear: $F(1, 94) = 45.65$, $p < 0.001$, $\eta_p^2 = 0.327$) and training (valence: $F(1, 94) = 25.78$, $p < 0.001$, $\eta_p^2 = 0.215$; arousal: $F(1, 94) = 31.19$, $p < 0.001$, $\eta_p^2 = 0.249$; fear: $F(1, 94) = 43.84$, $p < 0.001$, $\eta_p^2 = 0.318$). Moreover, participants expected the painful US more with $_{relief}$CS than with control ($F(1, 94) = 44.60$, $p < 0.001$, $\eta_p^2 = 0.322$) and training ($F(1, 94) = 45.01$, $p < 0.001$, $\eta_p^2 = 0.324$). No significant differences were found between control and training (all p values > 0.679).

After test (T3), $_{relief}$CS was still rated as more negative, arousing and threatening than training (valence: $F(1, 94) = 63.30$, $p < 0.001$, $\eta_p^2 = 0.402$; arousal: $F(1, 94) = 97.54$, $p < 0.001$, $\eta_p^2 = 0.509$; fear: $F(1, 94) = 89.05$, $p < 0.001$, $\eta_p^2 = 0.486$). However, the control stimulus was rated as equally negative, arousing, and threatening as $_{relief}$CS (valence: $F(1, 94) = 0.04$, $p = 0.842$, $\eta_p^2 < 0.001$; arousal: $F(1, 94) = 2.75$, $p = 0.101$, $\eta_p^2 = 0.028$; fear: $F(1, 94) = 1.00$, $p = 0.319$, $\eta_p^2 = 0.011$). Moreover, the control stimulus was rated as more negative, arousing, and threatening than the training stimulus (valence: $F(1, 94) = 68.73$, $p < 0.001$, $\eta_p^2 = 0.422$; arousal: $F(1, 94) = 82.55$, $p < 0.001$, $\eta_p^2 = 0.468$; fear: $F(1, 94) = 65.24$, $p < 0.001$, $\eta_p^2 = 0.410$). This implies that throughout the test phase, the control stimulus was perceived as more aversive than before (T2; see Figure 1.3a-c). Regarding US-expectancy, the $_{relief}$CS was still more associated with US than training (F(1, 94) = 101.54, p < 0.001, η_p^2 = 0.519) and control (F(1, 94) = 5.68, p = 0.019, η_p^2 = 0.057). Throughout the test phase, control became more associated with the US than training (F(1, 94) = 77.44, p < 0.001, η_p^2 = 0.452; Figure 1.3d).

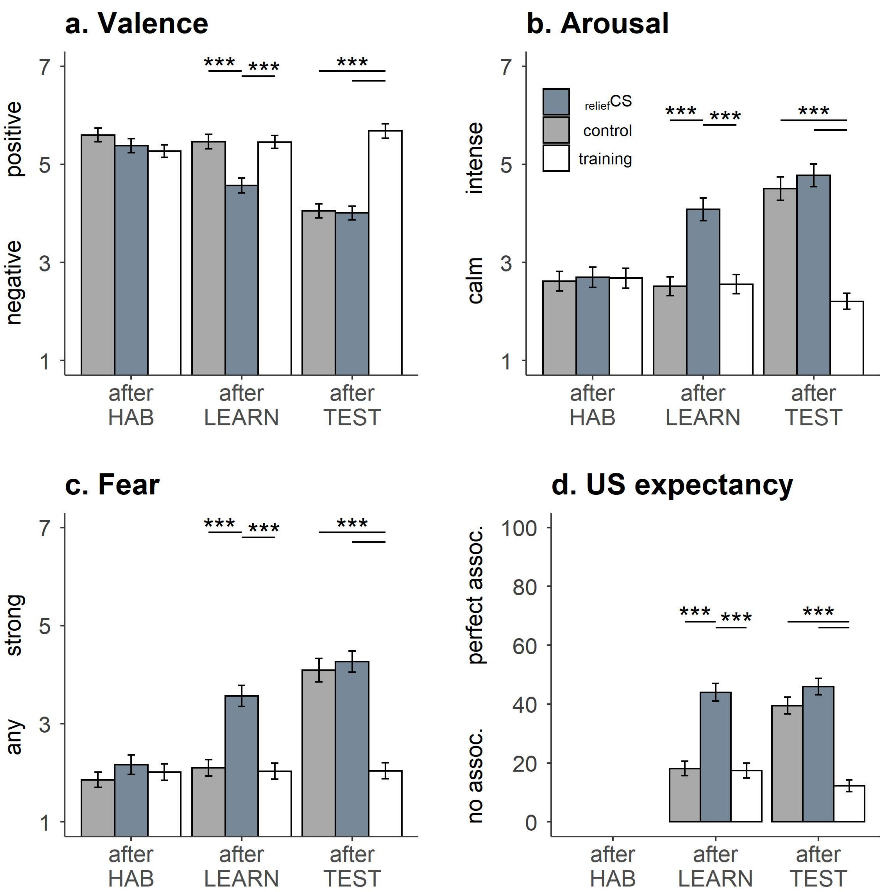

Figure 1.3 Means (with standard errors) of the ratings for (a.) valence, (b.) arousal, (c.) fear, and (d.) US-expectancy after the habituation phase (HAB), the learning phase (LEARN), and the test phase. Independently from the group, the $_{relief}$CS (blue-grey bars) was rated as more aversive than both control (grey bars) and training (white bars) after learning protocols. Through the test, the $_{relief}$CS maintained the aversive ratings, while control became more aversive. (***) p < 0.001, post-hoc simple contrasts for significant interactions.

Skin conductance response to the pain relief stimulus ($_{relief}$CS)

Given that previous studies have shown a general decline of SCRs over time (Qi et al., 2020), repeated-measures ANOVAs tested for differential effects in SCRs in the early and the late period of the test phase, with SCRs as dependent variable, group as between-subject factor, and stimulus ($_{relief}$CS, control) and period (early/late) as within-subject factors.

The stimulus x group x period interaction remained non-significant, $F(2, 94) = 1.22$, $p = 0.30$, $\eta_p^2 = 0.025$. However, the results revealed significant interactions between period x group ($F(2, 94) = 4.02$, $p = 0.021$, $\eta_p^2 = 0.079$, 95% CI [0.00, 0.19]) and period x stimulus ($F(1, 94) = 8.38$, $p = 0.005$, $\eta_p^2 = 0.082$, 95% CI [0.01, 0.20]; Figure 1.4). There were no other significant results (all $p > .303$).

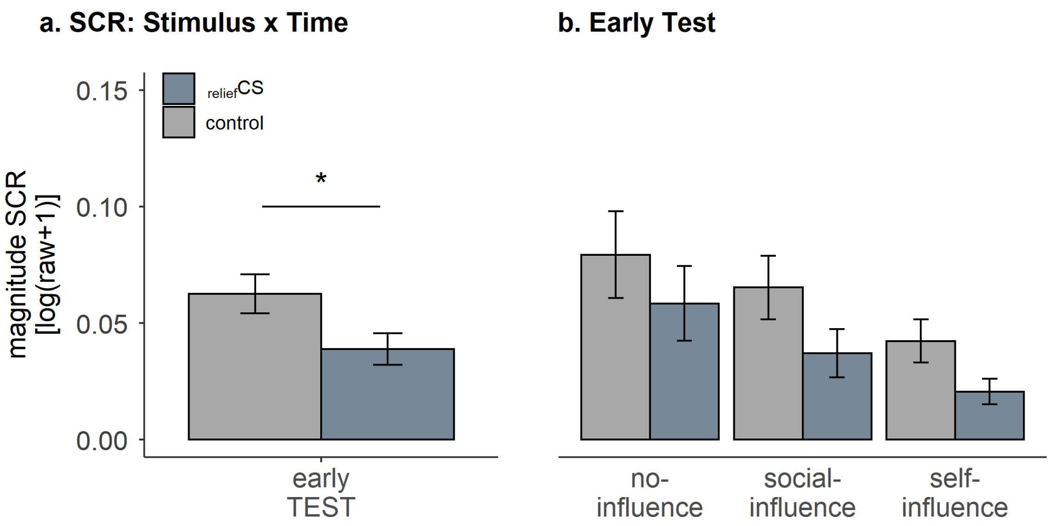

Figure 1.4 Means (with standard errors) of the SCR for (a.) the Stimulus x Time significant interaction, and (b.) the SCRs separated for the groups during early test. Independently from the group, the $_{relief}$CS (blue-grey bars) elicited lower physiological arousal than control (grey bars). Self-influence group showed the lowest physiological responses. (*) $p < 0.05$, post-hoc simple contrasts for significant interactions.

Post-hoc Bonferroni-corrected ($\alpha < 0.025$) simple contrasts for the period x stimulus interaction suggested successful relief learning as indicated by significantly lower physiological arousal to $_{relief}$CS as compared to control during the early test period ($F(1, 94) = 6.12$, $p = 0.015$, $\eta_p^2 = 0.061$, Figure 1.3a), but not during the late test period ($F(1, 94) = 3.30$, $p = 0.075$, $\eta_p^2 = 0.034$).

Considering that the three groups presented different physiological arousal during early vs. late test period, we added separate explorative ANOVAs for SCRs of the early vs. late period, with group (no-influence, self-influence, social-influence) as between-subjects factor and stimulus ($_{relief}$CS, control) as within-subjects factor. During the early period, we observed significant main effects for stimulus ($F(1, 94) = 6.12$, $p = 0.015$, $\eta_p^2 = 0.061$) and group ($F(1, 94) = 3.36$, $p = 0.039$, $\eta_p^2 = 0.067$), but not their interaction. No significant effects were found during the late period (all p values > 0.072). Again, conditioned pain relief was indicated by significantly reduced physiological arousal towards the $_{relief}$CS as compared to control. Moreover, post-hoc

Bonferroni-corrected ($\alpha < 0.017$) simple contrasts revealed lower physiological arousal for the self-influence group compared to the no-influence group ($F(1, 94) = 6.71$, $p = 0.011$, $\eta_p^2 = 0.067$), but not to the social-influence group ($F(1, 94) = 1.92$, $p = 0.170$, $\eta_p^2 = 0.020$). There was no significant difference in physiological arousal between the no-influence and social-influence group ($F(1, 94) = 1.57$, $p = 0.213$, $\eta_p^2 = 0.016$; Figure 1.4b).

Discussion

Our study tested whether social influence and controllability of pain affect pain relief learning. Based on studies showing that social influence and controllability of pain influence pain perception (Che et al., 2018; Stephens et al., 2016; Wiech et al., 2006), we hypothesized that these influences on pain perception might also affect pain relief learning, that is, the reduction of physiological responses to a stimulus associated with pain relief compared to a control stimulus. Alternatively, based on studies that showed no effects of social influence and controllability on pain (Modić Stanke & Ivanec, 2010; Mohr et al., 2012), we hypothesized that pain relief learning might be comparable under social-influence, self-influence and no-influence conditions.

Our results showed pain relief learning in the early test period, indicated by a reduction of SCRs to the visual stimulus associated with pain relief compared to a neutral control stimulus. These findings are in line with previous studies (Andreatta et al., 2013; Andreatta & Pauli, 2017; Luck & Lipp, 2017), demonstrating the robustness of pain relief learning in humans. Moreover, they replicate previous results showing similar effects in animals such as honeybees (Kirkerud et al., 2017) and drosophilia melanogaster (Yarali et al., 2008). Extending previous studies, we investigated whether the established effect of pain relief learning is altered by social influence and controllability of the pain stimulus. Our results showed a comparable magnitude of pain relief learning when the pain stimulus was influenced by another person (social-influence group), by the participants themselves (self-influence group), or passively administered by the computer (no-influence group).

Given that pain relief learning is based on the cessation of an aversive pain experience (Gerber et al., 2014), we assumed a lack of group differences in pain relief learning if there are no significant group differences in SCRs to the painful stimulation itself. In line with this assumption, the participants of the social-influence, the self-influence and the no-influence group showed comparable subjective and neural responses to the pain cue and the pain stimulus itself during the learning phase. At first glance, the lack of differential pain responses in the social-influence and the self-influence group compared to the no-influence group seem to be in contrast to previous studies showing that social contact and controllability can reduce pain responses (Boeke et al., 2017; Che et al., 2018; Edwards et al., 2017; Wiech et al., 2006). However, a closer look reveals that there are other studies that reported comparable pain responses in social and controllability conditions compared to passive pain administration (Löffler et al., 2018; Modić Stanke & Ivanec, 2010).

Regarding the effect of social influence on pain, previous findings are in fact heterogeneous. In line with our findings, Modić Stanke and Ivanec (2010) found no effects of a stranger's presence during experimentally induced pain on pain experience compared to being alone. In contrast, other studies found a reducing effect of social presence on pain expression (Karmann et al., 2014), pain perception (Kleck et al., 1976) and physiological arousal to an aversive stimulus (Kleck et al., 1976; Qi et al., 2020). In these studies, however, the other person was not involved in the control over pain. In other studies showing a social modulation of pain responses, the other person was physically present (Karmann et al., 2014; Kleck et al., 1976; McClelland & McCubbin, 2008) and actively offered help or support (Brown et al., 2003; Hein et al., 2018; Roberts et al., 2015). This suggests that social effects are stronger in more explicit expressions of social support (Che et al., 2018). In our study, participants of the social-influence group met the other person only briefly. They were told that this person might influence their pain stimulation, but the person did not actively offer comfort or help and was in a separate room. We deliberately chose the minimal social manipulation to keep the experimental conditions in the social-influence group as comparable as possible to the experimental conditions in the other two groups (i.e., the self-influence and the no-influence group), in which no other person or social cue was present. Although previous studies have shown that minimal social manipulations can reduce responses to aversive events (Edwards et al., 2017; Qi et al., 2020), it is conceivable that these effects are weaker than the effects of social comforting or helping (Che et al., 2018), or not evident as in the current study. Thus, they did not influence pain relief learning. Future studies should additionally incorporate a more active social condition to increase the comparability with previous findings of social pain modulation.

Regarding the effect of controllability, previous findings suggest moderating factors. For instance, Löffler and colleagues (2018) investigated the effects of pain controllability on physiological pain responses (SCR, heart rate) and found that controllability reduced perceived suffering, but not physiological responses to pain. The authors argue that internal control beliefs induced by different instructions might play an important role here. In line with this, other studies showed attenuated pain and changes in pain-related responses when pain was perceived as controllable rather than uncontrollable (Salomons et al., 2004; Wiech et al., 2006). In our study, participants of the self-influence group could avert the momentary pain stimulation, ostensibly based on their learning performance. Still, they received a number of painful stimulations to ensure comparability between groups. It is possible that this manipulation induced uncertainty, which may have counteracted control beliefs and therefore prevented effects of controllability on pain experience. In light of these results, stronger manipulations of controllability may be needed to trigger a modulation of the pain responses, and consequently, changes in pain relief learning.

That being said, we found a general decline in participants' SCRs to the pain relief stimulus compared to the control stimulus in the self-influence compared to the no-influence condition. This indicates that a certain degree of control over pain later results in a general reduction of physiological arousal, which is in line with previous findings (Boeke et al., 2017; Mohr et al., 2012; Salomons et al., 2004). However, this general effect did not affect pain relief learning. The finding that self-influence reduced the general arousal, but had no effect on pain relief learning suggests that the SCR measures collected with our paradigm can disentangle general arousal effects from effects of pain relief learning.

In the test phase, all three experimental groups showed a comparable and consistent reduction in SCRs to the pain relief stimulus compared to the control stimulus. However, this difference was not evident in participants' ratings. Instead, the pain relief and the control stimuli elicited more negative subjective arousal, valence and fear after the experiment than before the experiment. The discrepancy between a reduction in physiological responses to the pain relief stimulus on the one hand, and an increase in aversiveness ratings on the other hand, resembles previous findings. Other backward conditioning studies with painful stimulation (Andreatta et al., 2013; Andreatta et al., 2010; Luck & Lipp, 2017) or highly aversive sounds (Green et al., 2020) also showed increased implicit and decreased explicit valence following backward conditioning. This suggests that participants cognitively associated the pain relief stimulus with pain, but physiologically with the experienced pain relief. It is also conceivable that the SCRs and the ratings reflect distinct mechanisms. During the test phase, physiological arousal was continuously recorded and therefore might reflect ongoing learning processes. The ratings were asked at the end of the phase when the learning had terminated and might therefore reflect effects of previous learning (Lonsdorf et al., 2017). In line with this, we observed differences between $_{relief}$CS and control for the ratings just after the learning phase (T2) and for the SCRs at the beginning of the test phase (early period). These differences disappeared in both responses throughout the test phase, suggesting extinction learning (Milad & Quirk, 2012).

Moreover, in our experimental protocol, startle-eliciting sounds were presented, and these sounds can be quite aversive. Previous studies demonstrated that associative learning mechanisms can be influenced by startle probes (de Haan et al., 2018; Sjouwerman et al., 2016). It is therefore possible that the startle probes had an effect on SCRs in our study. However, given that the startle probes were present in all three groups and our analyses are based on group comparisons, these effects are unlikely to affect our main findings.

There are some limitations which need to be addressed when discussing the present findings. As mentioned above, this study focusses on the evaluation of SCRs as an indicator of sympathetic activity. Future research should include the additional assessment of parasympathetic activity which is associated with self-regulation mechanisms (Laborde et al., 2017). For instance, this could be achieved with heart rate variability (HRV) as an index of vagal tone (Malik et al., 1996), a measure used in both pain (Koenig et al., 2014) and learning research (Pappens et al., 2014; Wendt et al., 2015). Additionally, a variety of factors are known to alter skin conductance levels, including age (Barontini et al., 1997; Gavazzeni et al., 2008), gender (Aldosky, 2019; Lonsdorf et al., 2015), weight (Aldosky, 2019), and mental disorders like depression (Dibbets et al., 2015; Schumann et al., 2017). While we controlled for these factors and found no differences across groups, other possible influences such as physical exercise on a regular basis (Salvador et al., 2001), caffeine consumption (Barry et al., 2005; Davidson & Smith, 1991), and hormonal changes due to the menstrual cycle or hormonal contraceptives (Goldstein et al., 2005; Lonsdorf et al., 2015) were not addressed and their potentially confounding effects cannot be excluded. However, because pain thresholds were individually calibrated, potential differences in pain perception caused by these uncontrolled factors are unlikely to influence our main results.

In sum, future studies should test the modulation of pain relief learning with designs that use stronger manipulations of social influence and controllability of pain, and more reinforced trials in the learning phase. Our current study's results suggest that physiological pain relief learning in humans is not significantly influenced by social influence and pain controllability.

Conflict of interest

The authors declare that they have no conflict of interest.

Author Contributions

Marthe Gründahl: Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing—original draft; Writing—review & editing. Leonie Retzlaff: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Validation; Visualization; Writing—review & editing. Martin J Herrmann: Methodology; Resources; Software. Grit Hein: Conceptualization; Funding acquisition; Project administration; Resources; Supervision; Validation; Writing—review & editing. Marta

Andreatta: Conceptualization; Data curation; Formal analysis; Methodology; Software; Supervision; Validation; Visualization; Writing—original draft; Writing—review & editing.

ORCID

Marthe Gründahl: https://orcid.org/0000-0003-1824-0523

Marta Andreatta: https://orcid.org/0000-0002-1217-8266

Implications for study 2

In study 1, we observed that minimal social involvement (social influence) did not alter fear-related autonomic responses (SCR) in a pain relief learning paradigm. The results showed that autonomic responses during pain cessation did not differ when another person, the participant, or no one (i.e., the computer) influenced pain induction. Furthermore, in a subsequent experimental phase following pain relief learning, the social condition did not differ from the others in their responses towards an aversive stimulus paired with a conditioned or neutral visual stimulus. While autonomic measures indicated pain relief learning (i.e., reduced SCR), subjective ratings implied fear learning towards the conditioned stimulus (i.e., higher fear ratings). This effect was also independent of social, self, or no influence. In short, study 1 revealed autonomic pain relief learning, but no social buffering effects.

Notably, the social aspect of study 1 was minimalistic, as the other person was a stranger, not physically present (i.e., seated in another room), and did not communicate with the participant throughout the experimental procedure. Moreover, despite important advantages regarding experimental manipulation and control, particularly concerning confounding factors for SCR, the laboratory setting of study 1 restricted the ecological validity of the social situation due to its standardized and minimalistic design. Finally, the inclusion of female participants and confederates only could have obscured gender effects on anxiety-related responses and social buffering effects. Consequently, study 2 was designed with EMA to take our research from the laboratory to a less minimalistic and more naturalistic social context: everyday-life social interactions. Due to their higher robustness towards movement artefacts compared to SCR, HR and HRV were chosen as autonomic anxiety-related measures. To account for the diversity and complexity of daily social interactions, study 2 assessed social factors like the familiarity of the interaction partner(s) or the in-person or virtual setting of the social contact. To account for possible gender effects, study 2 included both female and male participants and assessed the gender of their interaction partners.

The effects of everyday-life social interactions on anxiety-related autonomic responses differ between men and women

Marthe Gründahl*, Dr. Martin Weiß*, Kilian Stenzel, Prof. Dr. Jürgen Deckert, & Prof. Dr. Grit Hein

Center of Mental Health, Department of Psychiatry, Psychosomatic and Psychotherapy, Translational Social Neuroscience Unit, University of Würzburg, Würzburg, Germany

* These authors contributed equally to this work

Corresponding author: Marthe Gründahl, Translational Social Neuroscience Unit, Department of Psychiatry, Psychosomatics and Psychotherapy, Center of Mental Health, University of Würzburg, Margarete-Höppel-Platz 1, 97080 Würzburg, Germany.
Email: Gruendah_M@ukw.de

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Abstract

Social buffering, a phenomenon where social presence can reduce anxiety and fear-related autonomic responses, has been studied in numerous laboratory settings. The results suggest that the familiarity of the interaction partner influences social buffering, while also providing some evidence for gender effects. In the laboratory, however, it is difficult to mimic the complexity of real-life social interactions. Consequently, the social modulation of anxiety and related autonomic responses in everyday life remains poorly understood. We used smartphone-based Ecological Momentary Assessment (EMA) combined with wearable electrocardiogram sensors to investigate how everyday-life social interactions affect state anxiety and related cardiac changes in women and men. On five consecutive days, 96 healthy young participants (53% women) answered up to six EMA surveys per day, indicating characteristics of their most recent social interaction and the respective interaction partner(s). In women, our results showed lower heart rate in the presence of a male interaction partner. Men showed the same effect with female interaction partners. Moreover, only women showed decreased heart rate and increased heart rate variability with increasing interaction partner familiarity. These findings specify the conditions under which social interactions reduce anxiety-related responses in women and men, and thus, provide relevant indications for therapeutic interventions.

Introduction

Animal and human studies have shown that the mere presence of a conspecific can reduce physiological stress and fear responses (Christenfeld & Gerin, 2000; Kikusui et al., 2006), a phenomenon called social buffering (Hennessy et al., 2009; Qi et al., 2021). So far, social buffering has mostly been investigated in the laboratory. In human studies, participants typically experience a stress or anxiety-inducing situation (e.g., pain induction, public speech) alone or in the presence of another person. Some studies extend the social aspect, e.g., by modulating the familiarity (e.g., stranger vs friend) or affiliative behaviour (e.g., social support vs no support) of the interaction partner (Kikusui et al., 2006; Taylor, 2011). Social buffering effects are inferred from reductions of reported anxiety or adaptive changes in autonomic responses caused by the interaction partner's presence or behaviour (Ditzen et al., 2008; Ryska & Yin, 1999). For example, the presence of social support has been linked to reduced heart rate (HR; Thorsteinsson & James, 1999), indicating lower acute (social) stress (Grillon et al., 2007; Schiweck et al., 2019). In contrast, a lack of social contact (i.e., social isolation) has been associated with lower heart rate variability (HRV; Horsten et al., 1999), reflecting diminished behavioural and emotion-regulatory adaptability (Appelhans & Luecken, 2006; Schwerdtfeger & Friedrich-Mai, 2009).

The social buffering effects observed in the laboratory were modulated by various factors, including the gender of the participant, and the gender and familiarity of the interaction partner. Regarding familiarity, findings suggest stronger social buffering effects in the presence of more familiar interaction partners (Eisenberger, 2013; Krahé et al., 2013). Regarding the participant's gender, previous studies imply that men and women experience certain social situations differently. In general, self-reported anxiety tends to be higher in women (McLean & Anderson, 2009; Villada et al., 2016), paralleled by stronger physiological reactions such as higher HR (Glynn et al., 1999; Kudielka et al., 2004) and lower HRV (Hamidovic et al., 2020) in anxiety-inducing situations. Findings concerning gender effects in social buffering of anxiety are mixed, however. Some studies reported stronger effects in women compared to men (Qi et al., 2021; Reddan et al., 2020), while other studies showed the opposite (Kirschbaum et al., 1995; Well & Kolk, 2008). Yet other studies found no gender differences in general anxiety levels (Kelly et al., 2008; Trotman et al., 2019) or in social buffering effects (Lepore, 1992; Shahrestani et al., 2015).

Regarding the gender of the interaction partner, both men and women showed reduced autonomic responses (systolic blood pressure [BP]) when receiving social support from female, but not male social partners (Glynn et al., 1999). Similarly, other laboratory settings with anxiety-related autonomic measurements revealed social buffering effects in female, but not male dyads, e.g., on skin conductance responses (Qi et al., 2021). Challenging this result, other studies reported reduced cardiovascular reactivity (systolic BP, HR) in women in the presence of their romantic partner (Phillips et al., 2006) or when receiving social support from a male friend (Phillips et al., 2009). Yet, another study showed reduced cortisol levels in men in the presence of their (female) romantic partner, but not in women in the presence of their (male) romantic partner (Kirschbaum et al., 1995). Finally, a meta-analysis revealed no gender differences in the effect of social stress induction on HRV. In both genders, dyadic tasks designed to elicit negative affect decreased HRV, whereas dyadic tasks eliciting positive or no particular valence had no significant influence (Shahrestani et al., 2015).

Overall, findings from previous laboratory studies suggest that social presence and contact can reduce anxiety on the subjective and autonomic level, and that the gender of the participants and the interaction partner might play a role. However, the findings are inconsistent and were mainly observed in the laboratory where it is difficult to capture the complexity of everyday-life social interactions, for example, by including all possible combinations of same- and mixed-gender interaction partners at varying quantities. Thus, it remains unclear whether social buffering effects found in the laboratory transfer to social situations in everyday life. Here, we used smartphone-based Ecological Momentary Assessment (EMA) with wearable electrocardiogram (ECG) sensors to investigate how everyday-life social interactions affect subjective state anxiety and related cardiovascular changes depending on characteristics of both the participants and their interaction partners. EMA encompasses repeated, real-time subjective and/or physiological assessments of people's behaviour and experiences in a naturalistic setting. It can integrate multiple within- and between-subject variables simultaneously, further minimizing biases and measurement restrictions associated with laboratory settings. As such, EMA facilitates the economic testing of laboratory findings' ecological validity in everyday life (Conner & Mehl, 2015; Lee, 2021; Shiffman et al., 2008).

Previous studies successfully applied EMA to investigate changes of autonomic responses and started to uncover the effects of important social factors like familiarity in everyday life. For example, they revealed reduced cardiovascular responses (i.e., ambulatory BP) in healthy participants when interacting with family members or romantic partners compared to unfamiliar partners (Holt-Lunstad et al., 2003). Another EMA study showed increased HRV with familiar interaction partners (family, romantic partner) compared to strangers in shy individuals (Schwerdtfeger et al., 2020). In accordance with decreased state anxiety in response to social support from familiar vs unfamiliar persons during psychosocial stress in the laboratory (Mascret et al., 2019), EMA revealed lower self-reported anxiety levels when spending time with familiar vs less familiar social partners, particularly in socially anxious individuals (Hur et al., 2019). Similar relations were found between interaction partner familiarity and state social interaction anxiety (Lee, 2021), an anxiety measure closely related to higher state anxiety (Heimberg et al., 2010). These previous EMA studies provided first insights into the effect of social factors like familiarity, but did not consider the gender of the participants and interaction partners. Extending previous EMA work, we designed an EMA study to investigate how the gender of the participant and the interaction partner affect social buffering of state anxiety and related autonomic responses in everyday life, particularly regarding the effect of familiarity.

We hypothesized that women would show higher HR and lower HRV than men during everyday social interactions (Hamidovic et al., 2020; Kudielka et al., 2004). Based on previous findings (Glynn et al., 1999; Kirschbaum et al., 1995; Qi et al., 2021), we expected that men and women would show more adaptive subjective and cardiovascular responses (i.e., lower state anxiety, lower HR, higher HRV) in the presence of female interaction partners. Alternatively, we expected opposite-gender social buffering effects (Phillips et al., 2006; Phillips et al., 2009), or no effects of the interaction partners' gender (Shahrestani et al., 2015). Finally, we hypothesized that participants would benefit from more familiar interaction partners represented in decreased state anxiety (Lee, 2021) and HR, and increased HRV (Holt-Lunstad et al., 2003; Schwerdtfeger et al., 2020), and tested how these effects are influenced by the gender of the participants and their interaction partners.

Methods

Participants

122 healthy men and women aged 18 to 35 years participated in the study (two dropouts). After data curation, the final sample consisted of 96 participants (53.1% female; mean age = 25.17, *SD* = 4.12) with a total of 1,536 observations. Exclusion criteria included current pregnancy or lactation period, cardiovascular illnesses, chronic neurological disorders, acute psychiatric disorders, other severe medical illnesses, psychotropic medication, and visual and motoric impairments. We excluded nine participants after visual inspection of ECG data due to frequent

artefacts, and 15 participants with invalid baseline measurements. Invalid data were mainly caused by insufficient quality of ECG chest belts. A sensitivity analysis using G*Power software (version 3.1.9.7; Faul et al., 2009) revealed that the final sample size of N = 96 had a statistical power of > .80 with a 5% type I error rate to detect small to medium effect sizes (f^2 = .08) in a multiple regression model with 15 predictors (comparable to our models, see below). Given that the within-subject effects have larger level-1 sample sizes (equivalent to the number of observations nested within persons), we expected to have sufficient power to detect small effects. All participants provided written informed consent. The study protocol was approved by the ethics committee of the medical faculty of the University of Würzburg (vote #180/20) and complies with the Declaration of Helsinki.

Procedure

Participants were invited to a pre-session. A chest belt with ECG sensor was attached and the participant's schedule for the five EMA measurement days was enquired to adjust the 12-hour measurement time windows, starting one hour after the usual wake-up time. Participants filled in sociodemographic and clinical questionnaires. During the subsequent 5-min baseline measurement, the participants sat upright facing a 16:9 computer screen at approx. 140 cm distance. They were asked to relax while watching an audio-visual clip of an aquarium. Afterwards, the participants practiced the correct use of the ECG belt and the EMA questionnaire application (app) delivered on a study smartphone. Supervised by the experimenter, they answered the EMA survey in two imaginary situations (social, non-social) before receiving the study material. On five consecutive days, participants carried the smartphone with them while wearing the ambulatory ECG sensor within the 12-hour time windows. Within three days after the final assessment, they returned to the laboratory, filled in questionnaires, and received a financial compensation.

Measures

Trait questionnaires

Participants were screened for depression using the 15-item short form of the Center for Epidemiologic Studies Depression Scale (German: "Allgemeine Depressionsskala – Kurzform", ADS-K; Hautzinger & Bailer, 1993). In addition, we assessed participants' trait anxiety and social interaction anxiety using the trait anxiety subscale of the state-trait anxiety inventory (STAI; Laux et al., 1981), and the social interaction anxiety scale (SIAS; Heimberg et al., 1992), respectively.

EMA survey items

EMA surveys were delivered with the movisensXS app (Movisens GmbH) on an android smartphone. State anxiety was assessed with a 10-item short form of the STAI state anxiety subscale (Grimm, 2009) rated on a Likert scale from 1 ("not at all") to 8 ("totally"). Participants indicated the time of their most recent social interaction ("now", "within the last 30 min", "more than 30 min ago"). For social interactions ≤ 30 min ago, they answered the social interaction questionnaire (for a detailed item list, see Table S1). Otherwise, they answered a similarly structured activity questionnaire to prevent avoidance behaviour due to time savings (see Table S2). The social interaction questionnaire first assessed the type ("direct contact", "telephone call", "e-mail/letter", "SMS", "social media"; "private", "job-related"), the approximate start, and duration of the social interaction (slider scales with three anchors: "<1 min", "15 min", ">30 min"), and the quantity ("1" to "5 or more") and gender ("female", "male", "mixed") of the interaction partners. The familiarity of the interaction partners ("I know the other person/one of the other persons well.") was assessed continuously on a Likert scale ranging from 1 ("not at all") to 8 ("very"; Venaglia & Lemay Jr, 2017; Vogel et al., 2017), as the categorical measurement of familiarity in previous studies may overlook relations like estranged family members or familiar long-time colleagues. State social interaction anxiety was averaged from two items ("I worried about what the other person(s) thought of me", "I was worried that I would say or do the wrong things") rated on a Likert scale from 1 ("not at all") to 9 ("very"; Goodman et al., 2018; Kashdan et al., 2014). The final screen assessed ECG control variables (e.g., consumption of caffeine/nicotine/alcohol during the last hour).

Autonomic measures

HR and HRV were measured continuously with an ambulatory ECG, i.e., the movisens EcgMove4 sensor (Movisens GmbH, Karlsruhe, Germany). HR describes the number of heartbeats in beats per minute (bpm). In the presence of a stressor, HR is increased by vagal withdrawal and sympathetic activation (Schiweck et al., 2019; Schwerdtfeger & Friedrich-Mai, 2009). HRV is a quantitative marker of autonomic nervous system activity influenced by both sympathetic and parasympathetic activity (Camm et al., 1996; Thayer et al., 2012). It describes the fluctuation in the time intervals between adjacent heartbeats, which show less linearity and more spatial and temporal complexity in healthy individuals (i.e., higher HRV; McCraty & Shaffer, 2015; Shaffer & Ginsberg, 2017). Higher HRV relates to higher skills, engagement, and stress regulation in social situations (Appelhans & Luecken, 2006; Kemp & Quintana, 2013), including the adaptive regulation of HR (Kok & Fredrickson, 2010). This study's HRV measure is the root mean square of successive differences between heartbeats (RMSSD) measured in ms. RMSSD estimates vagal cardiac control, reflecting short-term parasympathetic variations. There is support that time-domain HRV measures like RMSSD show higher robustness to (motion) artefacts than frequency-domain HRV measures (Sheridan et al., 2020). RMSSD is an appropriate measure for long- and short-term time windows (Pham et al., 2021), and EMA research (Liu et al., 2021; Wrzus et al., 2013). For comprehensive guidelines, see Camm et al. (1996) or Quintana and Heathers (2014).

The ECG sensor was attached to a chest belt worn at the base of the sternum with direct skin contact of two dry electrodes. Participants were instructed to clean the skin beneath the electrodes with alcohol pads (70% isopropyl alcohol) prior to attachment. The sensor collected single channel ECG data (resolution = 12 bits, sampling rate = 1,204 Hz). Participants were asked not to consume a heavy meal, coffee, alcohol or tobacco, and to only drink low amounts of water in the two hours prior to the pre-session (Quintana & Heathers, 2014). All baseline ECG measurements were collected between 12 and 6 pm.

Data Analysis

EMA survey data curation

We screened the EMA survey data for invalid or incoherent data. Within-person variables were person-centred continuous, and between-person variables were grand mean-centred (Bolger & Laurenceau, 2013). We categorized the social interaction type into “direct” or “virtual”, and transformed consumption indications into binary variables (“yes”, “no”). Finally, we added a binary variable for the interaction partner quantity (“1”, “2 or more”) to account for the constitutional absence of mixed-gender social interactions with one person only.

ECG data curation and heart rate variability calculation

After visual inspection of ECG data, we applied the movisens DataAnalyzer software (version 1.13.8) to convert the ECG signals into HRV indices. The software uses an automated algorithm to detect artefacts. Its output is based on minute-by-minute calculations derived from 2-min segments. The DataAnalyzer detects R-peaks (Hamilton, 2002), marks signal amplitude and number of zero crossings per s outside a normal physiological range as artefacts, and filters invalid R-peaks and artefacts (Clifford et al., 2002; for more details, see supplement). Bodily movement (sampling rate = 64 Hz) was transformed into 1-min epochs.

ECG and EMA data were aligned and imported into R (version 4.2.0). We rounded ECG data to whole-minute values, excluded ECG segments labelled as invalid, and calculated mean scores for HR and RMSSD at baseline (first minute excluded). We calculated separate outlier detections for baseline and EMA values of HR and RMSSD. Values outside the upper and lower quartile by at least 1.5 times the interquartile range were removed (Tukey, 1977). 73.4% of rows had valid HR and RMSSD. We extracted mean HR and RMSSD values for each social interaction (time retrieved from slider scales, transformed to 1-min-intervals; first and last segment of time window excluded). The survey prompt marked the end of on-going social interactions. We removed social interactions shorter than 60 s. A natural logarithmic transformation was performed to correct for skewness (RMSSD). The final 96 participants provided a total of 1,536 valid observations, i.e., 16 social interaction assessments on average (SD = 5.08, range = 5-27).

Statistical analysis

Differences between male and female participants were calculated using *t*-tests. To test our hypotheses, we calculated three linear mixed models with participant as random intercept and state anxiety, HR, and RMSSD as dependent variables, respectively, using the ‘lme4’ package (Bates et al., 2015). All models were tested against a basic model without interactions. Model significance was calculated with the ‘lmerTest’ package (Kuznetsova et al., 2017), applying Satterthwaite’s method to estimate degrees of freedom and *p*-values. We assessed multicollinearity within the models by calculating variance inflation factors (VIF) with the ‘performance’ package (Lüdecke et al., 2021). The ‘sjPlot’ package provided ICC and R^2 (Lüdecke, 2015). We conducted simple slope analyses for significant interactions with continuous variables using the ‘interactions’ package (Long, 2019), and post hoc comparisons using pairwise *t*-tests (Bonferroni-corrected) for interactions with categorical variables.

First, as a manipulation check for the expected relationship between subjective anxiety and autonomic responses, we created two simple models with state anxiety as outcome, and HR and RMSSD during EMA as predictors respectively. We added essential autonomic control variables (caffeine, nicotine, alcohol, acceleration, baseline; see below).

Second, we created the main models. The HR and RMSSD models included the predictors participant’s gender (gender participant; two levels: female, male), familiarity (familiarity IP; centred within [cw]), and gender of the interaction partner (gender IP; three levels: female, male, mixed; reference: female), state social interaction anxiety (state SI anxiety; cw), trait social interaction anxiety (SIAS; centred between [cb]), and social interaction type (SI type; two levels: direct, virtual). HR and RMSSD are sensitive to a number of potential confounds

(Quintana & Heathers, 2014; Sheridan et al., 2020). Therefore, we included the following covariates: duration of the social interaction (SI duration; cw), interaction partner quantity (quantity IP; two levels: 1, 2 or more), consumption of caffeine, nicotine, and alcohol within the last hour (two levels each: yes, no), and movement acceleration (accel; mean, cw). To account for individual differences in autonomic baseline levels, the HR and RMSSD models further included HR and RMSSD at baseline (cb), respectively. The models included two interactions: gender participant x gender IP, and gender participant x familiarity IP. Model comparison with likelihood ratio tests indicated a better model fit of the interaction models (both *p*s' $< .001$).

The state anxiety model also included the predictors gender participant, gender IP, familiarity IP, state SI anxiety, SIAS, and SI type, and the interactions gender participant x gender IP, and gender participant x familiarity IP. As control variables, we only included SI duration, quantity IP, caffeine, nicotine, and alcohol, as we did not expect an effect of movement or baseline. The interaction effects were non-significant, and model comparison indicated no difference in model fit with or without the interactions ($p = .734$). Therefore, we chose the basic state anxiety model as main model.

Finally, we compared the main models to more complex (and less parsimonious) models. First, we added age (cb) and depression scores (ADS-K; cb) as additional control variables. Second, we integrated social interactions with romantic partners (two levels: yes, no) as potential confounding variable for gender IP effects. Third, we tested two additional control interactions (SI type x accel, gender IP x quantity IP) for the autonomic models. Age and ADS-K improved model fit for the anxiety model and were therefore added to the final anxiety model. There were no other significant improvements in model fit (all *p*s' $> .05$) and thus no other changes.

Results

Sample characteristics

The observations consisted of 78.4% direct and 21.6% virtual social interactions. 40.2% of social interactions took place with female, 29.5% with male, and 30.3% with mixed interaction partners. Overall, 42.5% of social interactions included two or more interaction partners (16.9% female, 12.1% male, 71.0% mixed). 57.5% of one-person social interactions were with female interaction partners. Sample characteristics and gender differences are reported in Table 2.1 (see Table S5 for correlations between HR, RMSSD, and trait questionnaires). Compared to men, women showed higher mean levels of HR during social interactions. Women also tended to show higher HR during baseline and higher depression scores (for numeric values, see Table 2.1).

Table 2.1

Characteristics of the total sample and the female and male participants.

	Total sample (N = 96)		Female subsample (n = 51)		Male subsample (n = 45)				
	M	*SD*	*M*	*SD*	*M*	*SD*	Sample comparison	*p*	Cohen's *d*
Age	25.17	4.12	24.55	4.06	25.87	4.12	$t(94) = 1.58$	.119	.322
BMI	23.13	3.62	21.93	3.62	24.50	3.12	$t(94) = 3.71$	<.001	.762
HR (baseline)	71.76	11.04	73.53	10.47	69.74	11.44	$t(94) = -1.70$	.093	.346
RMSSD (baseline)	47.52	23.79	48.69	25.29	46.18	22.16	$t(94) = -0.51$	.609	.105
HR (SI)	82.95	7.97	84.72	7.42	80.94	8.17	$t(94) = -2.38$	.019	.485
RMSSD (SI)	35.90	9.35	35.89	9.61	35.91	9.15	$t(94) = 0.01$	.991	.002
state anxiety	26.09	10.95	26.69	10.84	25.40	11.16	$t(94) = -0.57$	.568	.117
state SI anxiety	2.59	1.31	2.61	1.38	2.57	1.23	$t(94) = -0.16$	.876	.032
SIAS	20.41	10.85	20.04	11.04	36.62	9.61	$t(94) = .35$	.726	.072
ADS-K	10.14	4.17	10.88	4.44	9.29	3.70	$t(94) = -1.90$	.051	.390
STAI-Trait	37.16	10.12	37.63	10.63	36.62	9.61	$t(94) = -0.48$	.630	.099

Note. ADS-K = Allgemeine Depressionsskala; BMI = body mass index; HR = heart rate; RMSSD = the root mean square of successive differences between heartbeats; SI = social interaction; SIAS = Social Interaction Anxiety Scale; STAI = State Trait Anxiety Inventory; state SI anxiety = state social interaction anxiety.

State anxiety

The manipulation check confirmed a relationship between subjective and autonomic indicators of anxiety. Higher state anxiety correlated with higher HR during social interactions (β = .17, $p < .001$), but not to changes in RMSSD (β = -1.20, $p < .184$).

Details of the results for the state anxiety model are presented in Table 2.2 (left column). VIF (all ≤ 2.39) were in an acceptable range (Kutner et al., 2004). There was a main effect of familiarity IP (β = -0.94, $p < .001$; see Figure 2.1), indicating lower state anxiety after interacting with more familiar interaction partners.

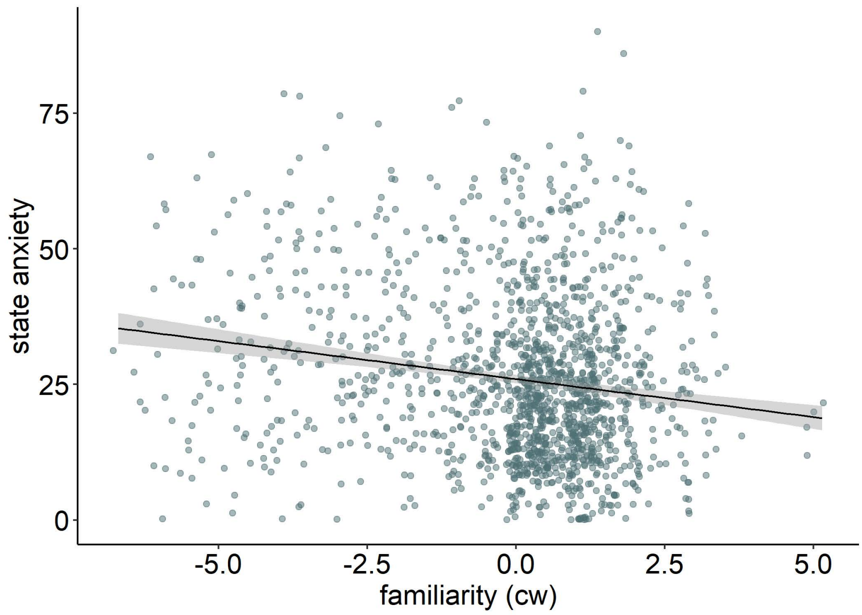

Figure 2.1 Main effect of familiarity (centred within, cw) on state anxiety. Shaded errors indicate 95% confidence intervals.

In addition, lower state anxiety was related to lower state SI anxiety (β = 1.96, $p < .001$), and state anxiety was lower during direct compared to virtual social interactions ($\chi^2(1) = 8.65$, $p = .003$). On the between-person level, state anxiety increased with age (β = 0.23, $p = .014$), trait SI anxiety (β = 0.56, $p = .021$), and depression scores (β = 1.20, $p < .001$). There were no significant gender effects.

Table 2.2

Linear mixed models examining the association of social interaction variables and participant variables with heart rate (HR), heart rate variability (RMSSD [ln]), and state anxiety.

Models	State anxiety			HR			RMSSD (ln)		
Fixed effects	est. (*SE*)	*t*	*p*	est. (*SE*)	*t*	*p*	est. (*SE*)	*t*	*p*
(Intercept)	13.41 (2.79)	4.80	<.001	79.69 (0.98)	81.70	<.001	3.54 (0.04)	86.35	<.001
Within-person effects									
familiarity IP[1]	-0.94 (0.16)	-5.99	<.001	0.24 (0.17)	1.40	.163	-0.03 (0.01)	-4.06	<.001
gender IP (f-m)	0.80 (0.79)	1.02	.308	2.13 (0.84)	2.53	.012	-0.05 (0.04)	-1.26	.207
gender IP (f-mix)	0.62 (1.07)	0.58	.562	2.83 (0.93)	3.04	.002	0.02 (0.04)	0.59	.553
state SI anxiety[1]	1.96 (0.22)	8.87	<.001	0.49 (0.16)	3.09	.002	-0.01 (0.01)	-1.96	.050
quantity IP (1-2 or more)	-0.63 (0.96)	-0.66	.508	0.97 (0.69)	1.41	.159	-0.08 (0.03)	-2.79	.005
SI type (direct-virtual)	2.34 (0.80)	2.94	.003	-2.57 (0.58)	-4.46	<.001	0.07 (0.02)	2.94	.003
SI duration[1]	-0.00 (0.00)	-2.42	.015	-0.00 (0.00)	-1.40	.161	0.00 (0.00)	2.06	.040
caffeine (yes-no)	-0.55 (0.80)	-0.68	.494	-0.56 (0.57)	-0.99	.325	0.04 (0.02)	1.77	.076
nicotine (yes-no)	0.72 (1.98)	0.36	.716	6.73 (1.40)	4.81	<.001	-0.21 (0.06)	-3.49	<.001
alcohol (yes-no)	-1.89 (1.28)	-1.48	.140	4.58 (0.91)	5.01	<.001	-0.11 (0.04)	-2.81	.005
accel[1]				121.88 (4.15)	29.39	<.001	-3.05 (0.18)	-17.20	<.001
Between-person effects									
gender participant (f-m)	0.14 (1.96)	0.07	.944	5.44 (1.34)	4.08	<.001	-0.10 (0.06)	-1.81	.071
SIAS[2]	0.23 (0.09)	2.46	.014	0.07 (0.06)	1.27	.205	-0.00 (0.00)	-1.49	.136
HR (baseline)[2]				0.43 (0.05)	7.78	<.001			
RMSSD (baseline) [2]							0.25 (0.05)	5.20	<.001
ADS-K[2]	1.20 (0.25)	4.72	<.001						
age[2]	0.56 (0.24)	2.30	.021						
Interactions									
familiarity IP[1] x gender participant (f)				-0.78 (0.22)	-3.55	<.001	0.05 (0.01)	5.10	<.001
gender participant (f) x gender IP (f-m)				-4.72 (1.16)	-4.07	<.001	0.15 (0.05)	3.08	.002
gender participant (f) x gender IP (f-mix)				-3.08 (1.05)	-2.92	.004	0.05 (0.05)	1.16	.246

ICC	0.39	0.33	0.32
Marginal R^2	0.20	0.44	0.23

Note. [1] person-centred; [2] grand mean-centred. accel = acceleration; ADS-K = Allgemeine Depressionsskala; f = female; IP = interaction partner; HR = heart rate; m = male; mix = mixed genders; RMSSD = root mean square of successive differences between heartbeats; SI = social interaction; SIAS = Social Interaction Anxiety Scale. state SI anxiety = state social interaction anxiety.

Heart rate

Details of the results for the HR model are presented in Table 2.2 (middle column). VIF (all $\leq$ 7.45) were in an acceptable range (Kutner et al., 2004). The HR results showed a significant main effect of state SI anxiety ($\beta = 0.49$, $p = .002$), representing higher HR with higher state social interaction anxiety. In addition, the main effect of SI type ($\chi^2(1) = 19.92$, $p < .001$) indicated lower HR during virtual vs direct social interactions. The main effect of the participant's gender ($\chi^2(1) = 16.61$, $p < .001$) reflected higher HR in women. The participant's gender also interacted with familiarity IP ($\chi^2(1) = 12.60$, $p < .001$; Figure 2.2A). Follow-up analyses for the simple slopes of familiarity for female and male participants revealed a negative slope for women ($\beta = -.54$, $p < .001$), but no effect for men ($\beta = .24$, $p = .163$).

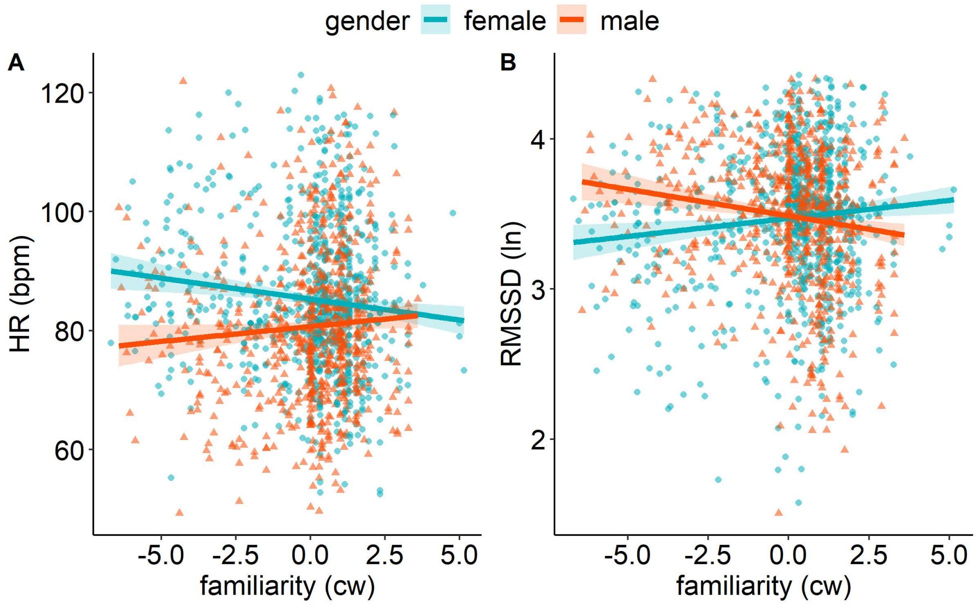

Figure 2.2 Prediction of HR (A) and RMSSD (ln; B) by familiarity x gender participant, i.e., in female (turquoise) and male (red) participants. Shaded errors indicate 95% confidence intervals. bpm = beats per min; cw = centred within.

Lastly, HR was affected by the interaction partners' gender ($\chi^2(2) = 11.26$, $p = .004$), but gender IP also interacted with the participant's gender ($\chi^2(2) = 18.30$, $p < .001$; Figure 2.3A). Pairwise *t*-tests revealed higher HR in women when interacting with female vs male IP ($t(1514) = 2.60$, $p = .005$). In contrast, men showed lower HR when interacting with female vs mixed IP ($t(1475) = -2.83$, $p = .015$), and tended to show lower HR when interacting with female vs male IP ($t(1507) = -2.13$, $p = .070$). Comparing male and female participants, men showed lower HR than women when interacting with female IP ($t(131) = -5.44$, $p < .001$).

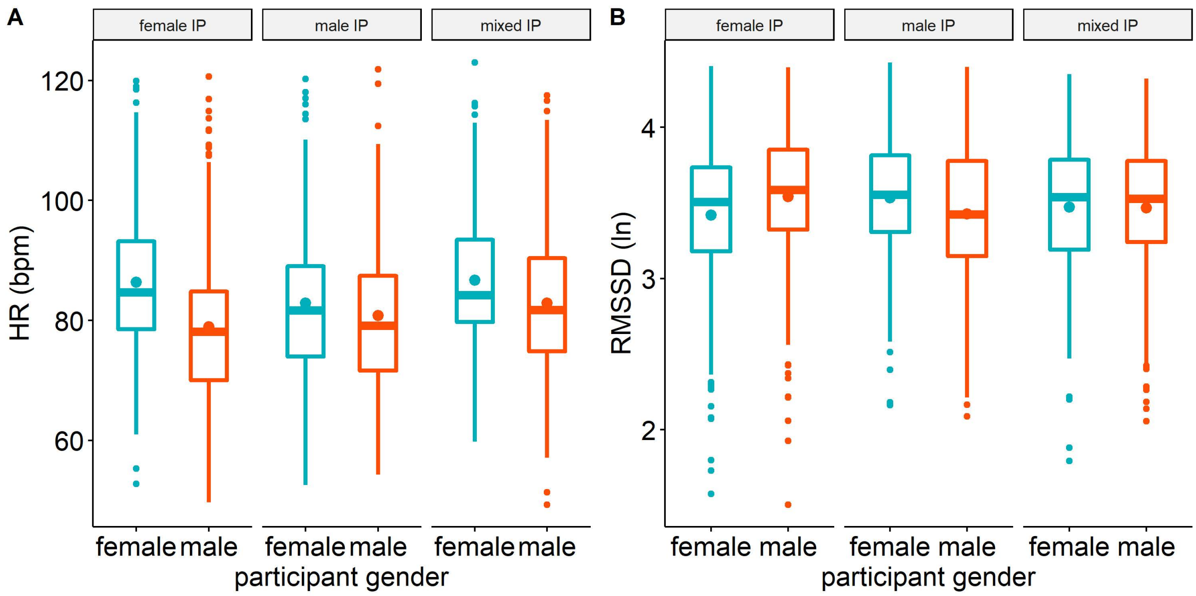

Figure 2.3 HR (A) and RMSSD (B) in female (turquoise) and male (red) participants in social interactions with female, male, and mixed interaction partners (IP). Dots within boxplots represent group mean, lines represent medians. bpm = beats per min.

Heart rate variability

Details of the results for the RMSSD (i.e., HRV) model are presented in Table 2.2 (right column). VIF (all ≤ 7.45) were in an acceptable range (Kutner et al., 2004). In accordance with the state anxiety model, RMSSD was higher (i.e., more adaptive) when participants interacted with more familiar interaction partners ($\beta = -0.03$, $p < .001$). In accordance with the HR results, RMSSD was higher during virtual vs direct social interactions ($\chi^2(1) = 8.62$, $p = .003$), and a marginal main effect for the participant's gender ($\beta = -0.10$, $p = .071$) indicated a tendency towards lower RMSSD in women. The participant's gender also interacted with familiarity IP ($\chi^2(1) = 25.99$, $p < .001$; Figure 2.2B). Simple slope analyses revealed a positive slope for women ($\beta = .02$, $p = .004$), but a negative slope for men ($\beta = -.03$, $p < .001$).

Due to the main effects of baseline and gender participant in the HR and RMSSD models, we additionally tested if baseline levels affected the gender participant x familiarity IP effects by testing the main models against a model with an additional three-way interaction (gender participant x familiarity IP x baseline). In the HR model, this interaction was neither significant ($\chi^2(1) = 0.04$, $p = .833$) nor improved model performance ($p = .691$). In the RMSSD model, the three-way interaction was significant ($\chi^2(1) = 9.76$, $p = .002$; see Figure 2.4) and improved model fit ($p = .005$). Separate simple slope analyses in the male and female subsample revealed a negative slope for men with low baseline RMSSD levels ($\beta = -0.06$, $p = .010$), indicating that the gender-specific negative relationship between familiarity and RMSSD in men was limited to those with low baseline RMSSD, while the positive relation in women was independent of baseline RMSSD.

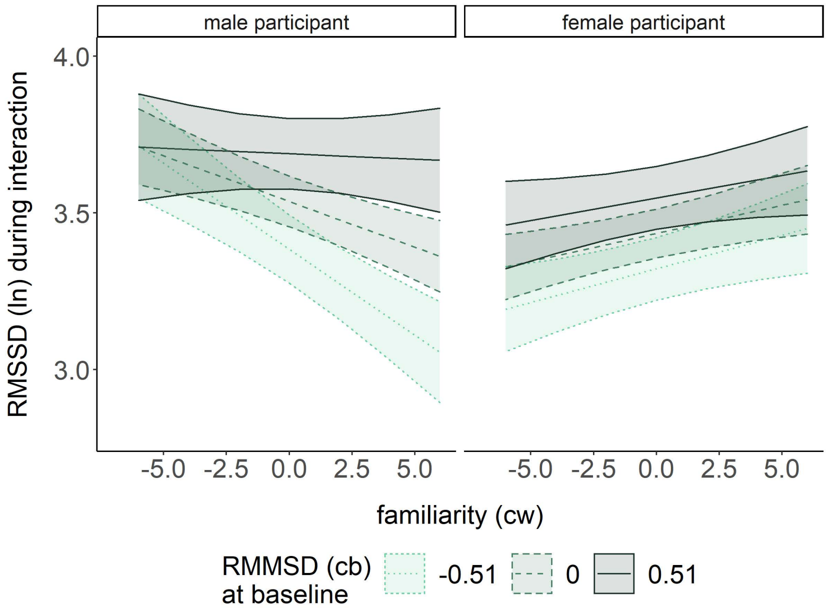

Figure 2.4 Prediction of RMSSD by familiarity in male (left panel) and female (right panel) participants at low (-1*SD*), medium, and high (+1*SD*) levels of baseline RMSSD. cb = centred between; cw = centred within.

Lastly, as for HR, gender IP interacted with the participant's gender ($\chi^2(2) = 9.54$, $p = .008$; Figure 2.3B). Pairwise *t*-tests revealed lower RMSSD in women when interacting with female vs male IP ($t(1515) = -0.11$, $p = .008$). There were no other significant contrasts (all *p*s' $\geq .220$).

Discussion

Overcoming limitations of previous social buffering studies in laboratory settings, this EMA study investigated how important characteristics of an interaction partner, such as their familiarity and gender, affect social buffering of state anxiety and related cardiovascular responses during real-life social interactions in women and men. Our results showed a decrease in state anxiety with increasing familiarity of the interaction partner (Figure 2.1), independent of the gender of the participant or interaction partner. In parallel, we assessed HR and HRV, i.e., cardiovascular responses related to subjective state anxiety ratings (see also Hamidovic et al., 2020; Kudielka et al., 2004). HR and HRV were more sensitive to gender differences than the subjective anxiety ratings. Specifically, our results showed a decrease in HR and an increase in HRV with increasing familiarity of the interaction partner in women, but not in men (Figure 2.2).

This finding of decreased HR and increased HRV when women interact with familiar partners is in accordance with previous findings of stronger social buffering effects in women (Qi et al., 2021; Reddan et al., 2020). On the one hand, it could mean that women benefit more from the presence of a familiar interaction partner than men. Alternatively, men might have engaged in more adaptive autonomic regulation when confronted with less familiar interaction partners. Previously, men, but not women, have shown adaptive HRV in negative social situations (e.g., negative social evaluation; Vanderhasselt et al., 2018) as well as more adaptive stress responses after receiving social support from strangers (Kirschbaum et al., 1995). As social interactions with less familiar interaction partners could be perceived as (more) negative (Reis et al., 2011), this could translate to more adaptive responses in men and less autonomic emotion regulation in women during such situations. Unfamiliar interaction partners could therefore have affected women more negatively than men, similar to evidence of a higher vulnerability of women to stress-induced hyperarousal (Bangasser et al., 2018; Kudielka et al., 2004). In this study, women also showed higher autonomic arousal than men, represented in higher HR during social interactions. Thus, in comparison to women, men's need for social buffering may have been smaller as their cardiac arousal was already lower, leading to the lack of autonomic social buffering effects of familiarity in men.

However, the exploratory finding of HRV-reducing effects of familiarity in men at lower (i.e., less adaptive) baseline HRV levels refutes this argument, as the maladaptive familiarity effect particularly emerged for those men more likely to require social buffering (Appelhans & Luecken, 2006; Schwerdtfeger & Friedrich-Mai, 2009). At the same time, even women with higher (i.e., more adaptive) baseline HRV profited from the social buffering effect of familiarity, further supporting the gender-specific effect. Overall, the observed reductions of state anxiety scores and autonomic responses with increasing familiarity are in line with previous laboratory and EMA findings (Holt-Lunstad et al., 2003; Hur et al., 2019; Schwerdtfeger et al., 2020). Extending these previous results, our findings show that in everyday life, the presence of a familiar interaction partner has a differential effect on cardiovascular responses of women vs men.

Evidence regarding gender effects in social buffering have been largely conflicting, from stronger social buffering effects in women (Qi et al., 2021; Reddan et al., 2020), vice versa (Kirschbaum et al., 1995; Well & Kolk, 2008), to no gender difference in social buffering (Lepore, 1992; Shahrestani et al., 2015). Most previous studies primarily focused on the participant's gender, while the gender of the interaction partner was either kept constant (Kirschbaum et al., 1995; Qi et al., 2021) or was not included in the main analyses (Well & Kolk, 2008). The present findings are novel in that they show that social buffering effects in everyday life are shaped by the gender of both the participant and their interaction partners. In greater detail, our results showed stronger autonomic social buffering effects if participants interacted with persons from the opposite gender (Figure 2.3). In women, this was reflected in decreased HR and increased HRV in the presence of male compared to female interaction partners (Phillips et al., 2006; Phillips et al., 2009). Similarly, men showed lower HR in the presence of female interaction partners compared to mixed-gender social interactions.

Previous studies investigating opposite-gender effects often focussed on romantic partners (Kirschbaum et al., 1995; Monin et al., 2019; Phillips et al., 2006). Importantly, entering romantic relationship as a control variable into our models neither improved model fit nor distinguished the opposite-gender social buffering effects, which rules out the assumption that these effects were mainly driven by the romantic partner. Men's reduced HR when interacting with women agrees with other results on social buffering effects of female interaction partner in men only (Glynn et al., 1999; Kirschbaum et al., 1995; Monin et al., 2019), while the stronger social buffering effect in women in the presence of a male interaction partner is in contrast to anxiety-buffering effects of female dyads found in the laboratory (Glynn et al., 1999; Qi et al., 2021). This could have different causes relating to methodology. For instance, conclusions on same vs opposite-gender social buffering effects from previous laboratory studies may be limited, as many of them only investigated two-person interactions and did not compare all possible gender constellations, e.g., investigating same-gender (Qi et al., 2021) or opposite-gender dyads (Kirschbaum et al., 1995), but not both. Factors like role expectations (Robinson & Wise, 2003) could also be more salient and influential in laboratory compared to EMA settings and bias participants' experience and behaviour, e.g., female participants wanting to fulfil expectations of getting along with other women and thus acting accordingly (Eagly & Wood, 1991, 2012).

With our EMA approach, we were able to assess everyday-life social interactions with a variety of male and female interaction partners (e.g., differing in quantity, familiarity). Extending previous studies, this allowed us to investigate the effects of social interactions with multiple interaction partners and in different gender constellations outside the laboratory, thus identifying an opposite-gender social buffering effect in everyday-life social interactions. Note that men's lower HR with female compared to mixed interaction partners hints towards higher anxiety-related responses during mixed-gender social interactions. This aligns with previous findings on such differential effects (Greenfield et al., 2013; Leaper, 2019), including stronger anxiety induction by same vs mixed-gender social partners (Allen et al., 2014; Duchesne et al., 2012). Future research should look more closely into factors influencing the diverse effects of same vs mixed-gender social interactions in everyday life.

Our study revealed differential effects of interaction partner gender and familiarity on men's and women's autonomic responses, but not on their state anxiety assessed with a validated questionnaire. The finding of differences in autonomic responses, but not subjective anxiety scores is in line with previous findings showing social buffering effects on the autonomic, but not the subjective level (Glynn et al., 1999; Kirschbaum et al., 1995; Phillips et al., 2009). It is possible that anxiety-altering effects of gender only emerged on the autonomic level because they were suppressed or misconceived on the subjective level. Factors like social norms could cause participants not to admit to gender-related differences in state anxiety (Biel & Thøgersen, 2007; Cislaghi & Heise, 2020).

The results of the current study show that EMA combining smartphones and wearable sensors is a useful and sensitive tool to investigate the effects of complex social interactions in everyday life. In the current study, we used this set-up in healthy participants with relatively low anxiety. Future studies should validate our findings with clinical samples (e.g., from the anxiety-disorder spectrum). Moreover, our participants interacted more frequently with familiar vs unfamiliar interaction partners. A study including more social interactions with unfamiliar interaction partners could confirm the stability of the familiarity effects.

In summary, the present EMA study provides novel insights into gender-dependent changes in anxiety-related autonomic responses during social contacts. Based on our results, social contacts with more familiar male interaction partners could be best suited to help reduce anxiety-related autonomic responses in women, e.g., during therapeutic interventions. At the same time, female interaction partners (or practitioners) may be best suited for anxiety reductions in men, while their familiarity might be disregarded. In conclusion, our study underlines the importance of considering the gender of patients and clinicians in therapeutic interventions.

Implications for study 3

In contrast to study 1, the more complex and naturalistic social setting of study 2 showed social buffering effects of everyday-life social interactions, represented in anxiety-reducing effects of more familiar interaction partners as well as reduced autonomic responses when interacting with the opposite gender. What is more, our EMA study revealed that the autonomic effects of familiarity were gender-dependent, as only women showed reduced HR and increased HRV with more familiar interaction partners. These results underline the importance of considering gender when investigating the effects of social presence and interaction. Moreover, taking research from lab to life, study 2 replicated previous social buffering effects found in other laboratory settings.

In accordance with the majority of previous social buffering research, studies 1 and 2 focused on effects of the presence of social contact (i.e., social influence and social interaction). In contrast, study 3 was designed to investigate how the absence of social contact in everyday life affects individuals' mental health, including their anxiety. What happens when social contact is not available, and which factors might influence how anxious a person feels? Using online surveys, we aimed to answer this question in study 3 by investigating loneliness, social isolation, related social factors, and state anxiety in the context of social distancing.

Construction and validation of a scale to measure loneliness and isolation during social distancing and its effect on mental health

Marthe Gründahl[1], Martin Weiß[1], Lisa Maier[1], Johannes Hewig[2], Jürgen Deckert[1], Grit Hein[1]

[1]Translational Social Neuroscience Unit, Department of Psychiatry, Psychosomatics and Psychotherapy, Center of Mental Health, University of Würzburg, Würzburg, Germany

[2] Institute of Psychology, Department of Psychology I: Differential Psychology, Personality Psychology and Psychological Diagnostics, University of Würzburg, Würzburg, Germany

Corresponding authors:
Prof. Dr. Grit Hein, Translational Social Neuroscience Unit, Department of Psychiatry, Psychosomatics and Psychotherapy, Center of Mental Health, University of Würzburg, Margarete-Höppel-Platz 1, 97080 Würzburg, Germany. Email: Hein_G@ukw.de

Marthe Gründahl, Translational Social Neuroscience Unit, Department of Psychiatry, Psychosomatics and Psychotherapy, Center of Mental Health, University of Würzburg, Margarete-Höppel-Platz 1, 97080 Würzburg, Germany. Email: Gruendah_M@ukw.de

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Abstract

A variety of factors contribute to the degree to which a person feels lonely and socially isolated. These factors may be particularly relevant in contexts requiring social distancing, e.g., during the COVID-19 pandemic or in states of immunodeficiency. We present the Loneliness and Isolation during Social Distancing (LISD) Scale. Extending existing measures, the LISD scale measures both state and trait aspects of loneliness and isolation, including indicators of social connectedness and support. In addition, it reliably predicts individual differences in anxiety and depression. Data were collected online from two independent samples in a social distancing context (the COVID-19 pandemic). Factorial validation was based on exploratory factor analysis (EFA; Sample 1, $N = 244$) and confirmatory factor analysis (CFA; Sample 2, $N = 304$). Multiple regression analyses were used to assess how the LISD scale predicts state anxiety and depression. The LISD scale showed satisfactory fit in both samples. Its two state factors indicate being *lonely and isolated* as well as *connected and supported*, while its three trait factors reflect general *loneliness and isolation*, *sociability and sense of belonging*, and *social closeness and support*. Our results imply strong predictive power of the LISD scale for state anxiety and depression, explaining 33 and 51% of variance, respectively. Anxiety and depression scores were particularly predicted by low dispositional *sociability and sense of belonging* and by currently being more *lonely and isolated*. In turn, being *lonely and isolated* was related to being less *connected and supported* (state) as well as having lower *social closeness and support* in general (trait). We provide a novel scale which distinguishes between acute and general dimensions of loneliness and social isolation while also predicting mental health. The LISD scale could be a valuable and economic addition to the assessment of mental health factors impacted by social distancing.

Keywords: Loneliness, social isolation, social distancing, depression, anxiety.

Introduction

Increases in loneliness (i.e., a subjective lack of social connection) and social isolation (i.e., an objective lack of social interactions) have repeatedly been listed among important risk factors for mental and somatic illness (e.g., Elovainio et al., 2017; Hawkley & Cacioppo, 2010; Masi et al., 2011). The prevalence of loneliness in the population is high, with 15–30% experiencing chronic, long-term (trait) loneliness and 60–80% experiencing occasional, short-term (state) loneliness (Hawkley & Cacioppo, 2010). Therefore, it is crucial to detect high levels of loneliness early and to intervene as soon as possible, as loneliness is associated with mental health issues such as stress, depression, anxiety, self-harm, and even suicide (Beutel et al., 2017; Campagne, 2019; Döring & Bortz, 1993).

At present, several well-established measures of loneliness and isolation exist, such as the De Jong Gierveld Loneliness Scale (De Jong Gierveld & Van Tilburg, 1999) and the UCLA Loneliness Scale (Russell et al., 1980; Russell, 1996). These scales measure loneliness and isolation based on the dispositional need for social contact, but do not differentiate this trait from currently felt (i.e., state) loneliness. This state-trait distinction is often overlooked in previous literature, yet important (Heinrich & Gullone, 2006; Henriksen et al., 2019). Although both have been related to diminishments in mental health (Heinrich & Gullone, 2006; Wright et al., 2006; Zhong et al., 2016), state and trait loneliness appear to be related to different aspects of mental health. That is, while trait loneliness is a stable predictor of mental health outcomes (i.e., anxiety and depression; Cacioppo et al., 2006; Hawkley & Cacioppo, 2010; Heinrich & Gullone, 2006), state loneliness can predict the individual reaction to a specific incidence of social isolation, e.g., social distancing (Abad et al., 2010; Hoffart et al., 2020). In general, predictions of mental health are worse for a person scoring high on trait loneliness than for a person scoring low on trait loneliness (Cacioppo et al., 2006; Hawkley & Cacioppo, 2010; Heinrich & Gullone, 2006), but this does not necessarily mean that this person suffers more from acute (state) loneliness. Instead, it is possible that long-term (trait) lonely people are better equipped to cope with acute situations of loneliness and social isolation because they are used to a lack of social contact. In contrast, for a person with low trait loneliness, acute (state) loneliness may incite stronger mental health problems because this person is used to the stabilizing effect of social contact and support. A mere assessment of trait loneliness (based on existing questionnaires, De Jong Gierveld & Van Tilburg, 1999; Russell et al., 1980; Russell, 1996) only predicts mental health in general, regardless of reactions to acute lack of social contact in a given situation. A mere assessment of state loneliness only predicts situational mental health outcomes in reaction to an acute lack of social contact (e.g., due to social distancing), regardless of the individual's dispositional need for and access to social contact. Thus, our studies focused on developing an instrument that assesses loneliness and isolation on both the state and the trait level, and tested its predictive power for important dimensions of mental health, i.e., anxiety and depression.

The necessity to assess loneliness and isolation on the state and trait level is particularly obvious in times of social distancing, i.e., during the reduction of physical proximity and direct social contacts. Social distancing is prominent in the current COVID-19 pandemic (Douglas et al., 2020; Fiorillo & Gorwood, 2020; Khanna et al., 2020), but is also used in many other clinical contexts to prevent virus or disease transmission, e.g., in response to seasonal influenza outbreaks (Ahmed et al., 2018; Shim, 2013) or as a pre-emptive intervention for severely ill individuals (Reluga, 2010; Tacconelli, 2009). For instance, patients suffering from cancer (Kersun et al., 2013) or severe immunodeficiency (Lesko et al., 1984) may need to socially distance from others to protect their weakened immune system from additional strain. Social distancing could even refer to solitary confinement, which in essence corresponds to isolating a person from contact with others (Gilmartin et al., 2013). Social distancing in all its forms can enhance loneliness and related declines in mental health (Abad et al., 2010; Fiorillo & Gorwood, 2020; Gammon, 1999; Hoffart et al., 2020). It prevents individuals from fulfilling their need for social contact and connectedness, thus increasing feelings of loneliness and social isolation (Bu et al., 2020; Hoffart et al., 2020). To sensitively predict the effect of social distancing-induced loneliness, social isolation and mental health, both state and trait dimensions need to be assessed and put in relation to each other.

Previous literature has presented loneliness and social isolation as either convergent or distinct constructs (Jong Gierveld et al., 2006; Valtorta et al., 2016). Social isolation can be divided into two aspects that focus on objective and subjective aspects of isolation, respectively: social disconnectedness and perceived isolation. Objective aspects (social disconnectedness) focus on physical separation from others, i.e., the observable absence of social contacts. Subjective aspects (perceived isolation) capture how a person perceives the (un)availability of social support, companionship, and emotional closeness to others (Cornwell & Waite, 2009a, 2009b). Similar to perceived isolation and sometimes used synonymously (Cacioppo & Hawkley, 2009), the concept of loneliness refers to the subjective dimensions of social isolation, to feeling disconnected and lacking meaningful companionship and integration. One's social relationship network is perceived as inadequate, and there is a discrepancy between the desire for social connection and the perception of one's actual relationships (Lee & Cagle, 2017). Based on these theoretical similarities, this study presumes a convergent and fluent conceptualization of perceived isolation and loneliness. Thus, we focus on these subjective perceptions of loneliness and social isolation in the context of social distancing, i.e., during an objective reduction in social contacts. Notably, physical separation from others does not necessarily lead to loneliness. Instead, there are important inter-individual differences to this relation (Jong Gierveld et al., 2006). For instance, those who have small social networks or rarely participate in social activities still might not feel lonely if the contacts they have match their needs. At the same time, people may be socially active and part of several social groups, but nevertheless feel lonely, left out or isolated, if their relationships lack emotional closeness and support (Cornwell & Waite, 2009b; Hawkley & Cacioppo, 2010; Jong Gierveld et al., 2006; Lee & Cagle, 2017).

Social isolation, loneliness and their effect on mental health relate to a number of factors. As presented above, the perception of social support, i.e., having people to rely on who may provide care, value and love (Liu et al., 2016), is an important aspect in the definition and measurement of loneliness and social isolation (Cornwell & Waite, 2009b; Lee & Cagle, 2017; Russell et al., 1980). In social distancing contexts, lower levels of social support are associated with increases in loneliness (Bu et al., 2020; Groarke et al., 2020; Liu et al., 2016; Segrin & Passalacqua, 2010). In general, perceived social support, stable social relationships and face-to-face interactions have been found to reduce loneliness and isolation (Cornwell & Waite, 2009b; Segrin & Passalacqua, 2010) and enhance mental health (Cohen, 2004; Sacco & Ismail, 2014; Thoits, 2011; Uchino, 2009). Another important factor are individual differences in extraversion, a personality trait representing sociability and the enjoyment and appreciation of engaging in social contacts (Buecker et al., 2020; McCrae & Costa, 1987; Soto & John, 2017). Higher extraversion relates to lower levels of loneliness (Buecker et al., 2020) and positive mental health, including psychological and social wellbeing (Lamers et al., 2012). In contrast, anxiety in social interactions and related avoidance of social situations are associated with decreases in mental health (Heimberg et al., 1992; Moitra et al., 2008) and increases in loneliness (Lim et al., 2016). However, during social distancing, those with a predisposition to seek social engagement (i.e., extraverts) might suffer more from limited access to direct social contacts, resulting in higher state loneliness and isolation (Gubler et al., 2020). At the same time, a dispositional tendency to avoid social contacts (i.e., social anxiety) could prevent increases in state loneliness and isolation, as social contact restrictions agree with dispositional tendencies to avoid contacts. Thus, the relation of extraversion and social anxiety with loneliness, isolation and mental health during social distancing is unclear.

The effect of social distancing on loneliness and isolation could depend on its extent. In times of social distancing, continued access to close contacts should protect against loneliness and impaired mental health (Groarke et al., 2020; Kovacs et al., 2021). As social distancing particularly targets distancing from high-risk persons (Sen-Crowe et al., 2020), individuals who were regularly in contact to high-risk persons before the social distancing context might particularly miss these contacts, leading to an increase in loneliness. Virtual communication and virtual interactions could be an important substitute for face-to-face contacts during social distancing. Virtual interactions were shown to reduce both loneliness and depression (Shaw & Gant, 2004) and provide an alternative medium to maintain social support and a sense of belonging in social distancing contexts and in general (Banerjee & Rai, 2020; Naslund et al., 2016). Finally, gender and age should be considered when investigating loneliness, social isolation and mental health. Younger age leads to a higher prevalence in anxiety (Bandelow & Michaelis, 2015; Mahoney et al., 2015) and depression, at least in high-income countries (Bromet et al., 2011; Kessler & Bromet, 2013). Regarding loneliness and age, findings are ambiguous, implying either a decrease (Barreto et al., 2021), a U-shaped relation (lowest level in middle-aged individuals; Luhmann & Hawkley, 2016), or an increase (Yang & Victor, 2011) of loneliness with age. Regarding gender, previous findings imply a lower prevalence of loneliness (Barreto et al., 2021), but a higher prevalence for depression and anxiety (Leach et al., 2008; McLean & Anderson, 2009; Nolen-Hoeksema & Hilt, 2009) in women compared to men.

Previous research indicates that loneliness is a risk factor for later loneliness, social isolation, and impaired social functioning and connectedness (Cacioppo et al., 2006; Hawkley & Cacioppo, 2010; Heinrich & Gullone, 2006). It is therefore likely that the degree of acute (state) loneliness and isolation caused by social distancing is affected by pre-existing (trait) loneliness and isolation and (lack of) access to social support and integration. Next to these dispositional factors, current access to social support could reduce acute loneliness and isolation. Given its strong predictive relation with mental health measures, a reliable state-trait measure of loneliness and isolation in the context of social distancing is vital to detect and predict negative psychological effects of social distancing measures. An economic yet comprehensive assessment with one single instrument would facilitate timely intervention to protect and enhance wellbeing and prevent long-term health consequences (Galea et al., 2020).

Here, we introduce the Loneliness and Isolation during Social Distancing (LISD) Scale which differentiates between state and trait variables. Its two subscales assess (1) general feelings of loneliness and social isolation along with the dispositional need and availability of social contacts and support (i.e., on the trait level) and (2) acute feelings of loneliness and isolation along with the current situational context, including social contacts and support (i.e., on the state level). The LISD scale was validated during a social distancing context (i.e., the COVID-19 pandemic) and linked to important dimensions of mental health (i.e., anxiety and depression).

We hypothesized that high scores in LISD traits assessing loneliness and isolation are positively related to LISD state scores representing loneliness and isolation during social distancing. That is, the stronger a person's general feelings of loneliness and isolation and related dispositional need for social contact, the stronger (i.e., the more negative) this person's acute loneliness and isolation. At the same time, LISD traits representing social support and connectedness should relate negatively to these LISD state scores. The stronger the perceived social support and connectedness, the lower the state loneliness and isolation. Moreover, greater habitual and acute use of virtual interactions, and more stable access to social contacts (trait and state) should also reduce state loneliness and isolation.

The relationship between state and trait loneliness and isolation may be influenced by individual differences in extraversion and social anxiety. Inspired by previous literature (Gubler et al., 2020), we predicted that extraverts may be more negatively affected by social distancing due to their preference for social participation, resulting in higher state loneliness and isolation. In contrast, as social anxiety is related to the tendency to avoid social contacts (Heimberg et al., 1992), socially anxious individuals may show lower levels of loneliness and isolation.

Finally, we hypothesized that both state and trait indicators of loneliness and isolation predict mental health outcomes during acute situations of social distancing. Thus, higher scores on loneliness and isolation were expected to relate to higher self-rated state anxiety and depression. Indicators of social withdrawal and avoidance were also expected to relate to higher anxiety and depression scores. In contrast, higher levels of perceived social support, perceived social connectedness and extraversion as well as continued access to social contacts should relate to lower anxiety and depression.

Methods

Construction of the LISD scale

Scale construction followed a deductive approach. Items were selected based on literature research, already established instruments, and our own theoretical considerations (see e.g., Boateng et al., 2018). Two researchers (first and last author) pooled 54 potential items based on theoretical considerations, content validity and psychometric properties (e.g., Boateng et al., 2018). Selected items related to loneliness and isolation (e.g., state/trait: "I lack companionship."), social support and connectedness (state: "There are people I can talk to."), social withdrawal (trait: "I like spending a lot of time by myself."), extraversion (trait: "I am an outgoing person."), and specific characteristics of social contacts in the context of social distancing, like the contact to people from the high-risk group or the use of virtual communication (state: "I maintain contacts via telephone/internet/app."). Items for the assessment of state and trait loneliness and isolation were taken from or inspired by the (revised) University of California Los Angeles (UCLA) Loneliness Scale (Döring & Bortz, 1993; Russell et al., 1980) and the Social Isolation Scale (Cornwell & Waite, 2009b). For the assessment of social support and connectedness as well as social anxiety and avoidance, we consulted the Multidimensional Scale of Perceived Social Support (MSPSS; Zimet et al., 1988), the Social Interaction Anxiety Scale (SIAS; Heimberg et al., 1992; Mattick & Clarke, 1998), and the Social Avoidance and Distress Scale (SADS; Watson & Friend, 1969). Some items were modified to improve their fit (e.g., inversed phrasing). Lastly, we constructed items relating to sociodemographic and behavioral indicators of isolation and the social distancing context (see also Supplementary Table 1). These items considered individual differences in the need for social contact (e.g., trait: "Regular contact is important to me.") and the need for face-to-face interactions (e.g., trait: "It is good for me to talk to friends and family in person."). We also included items to assess (a lack of) contact to people from high-risk groups (state: "I miss the personal contact with people belonging to the high-risk group.").

The resulting scale consisted of a state and a trait section (i.e., subscale). The pooled items were assigned to the state or trait subscale based on theoretical considerations, being considered more appropriate to measure acute (state) aspects and effects of the social distancing context (e.g., "I am unhappy being so withdrawn.") or dispositional (trait) aspects like extraversion (e.g., "I am an outgoing person."). In the state section, participants are asked via instruction to indicate how each item describes their feelings and experiences "at the current time" (e.g., "I'm alone too often.", "There are people I can talk to."). In the trait section, participants are asked to indicate how each item describes their feelings and experiences "in general," not (only) at the current time (e.g., "I am lonely.", "No one really knows me well."). The items are evaluated on a 5-point Likert-scale ranging from "strongly agree" to "strongly disagree". Items were included, modified or excluded based on multiple evaluations. The authors and a panel of five psychologists and five laymen of different ages (Min = 26, Max = 72) evaluated the items regarding their redundancy, clarity and relevance in the context of social distancing (i.e., current COVID-19-related restrictions in March 2020). The evaluation panels were interviewed on their thoughts about each scale item, screened for possible misunderstandings, and asked for reasons for their responses. Based on their feedback, one item was deleted, four were modified, one was replaced by a similar item with a better fit, and four items were added (e.g., to assess an individual's disposition to attend social events). Three loneliness and isolation items from the state scale were also added to the trait scale in response to the panel's feedback. The final scale for validation by exploratory factor analysis (EFA) consisted of 40 items (17 state, 23 trait items; see Supplementary Table 1 for the complete item list and their sources). This scale was once again presented to the panel group to validate that the changes actually responded to their critical suggestions.

Validation of the LISD scale

Samples

For the validation of the LISD scale, we collected data from two independent samples and conducted an exploratory (EFA) and a confirmatory factor analysis (CFA). Data were collected online using German nationwide (www.clickworker.com) or local online platforms. The survey targeted the general population without specific requirements. After the first COVID-19-related, lockdown in Germany, the first sample completed the LISD scale within 2 weeks under mild social distancing restrictions (starting from June 25, 2020). The second sample completed the scale under stricter COVID-19-related, lockdown conditions, i.e., under tightened social distancing restrictions (starting from December 11, 2020). This allowed us to test the reliability of the scale in two independent samples across two different situational contexts. Exclusion criteria were age < 18, text input without meaning, insufficient data as indicated by response bias (e.g., straight-lining), a statement by the participant (validation question), very small (speeding) or large answering times as indicated by the median-based relative speed index (TIME_RSI ≤ 2; see Leiner, 2019), and additional attention check questions (Abbey & Meloy, 2017). Multivariate outliers (Sample 1: $n = 15$; Sample 2: $n = 14$)

in the LISD scale were identified via Mahalanobis distance (Sample 1: χ^2 [40] = 73.40; Sample 2: χ^2 [30] = 59.70) and excluded (threshold .001; Tabachnick & Fidell, 2014).

For the first sample, we collected data from 343 adults. Ninety-nine participants had to be excluded based on the criteria above, including four dropouts. For the second sample, we collected data from 361 adults and excluded 57 data sets, including 12 dropouts and three participant exclusions due to failed attention checks (see Table 3.1 for sample characteristics and Supplementary Table 7 for an extended sample comparison).

Sample size considerations were based on recommendations from the literature, e.g., minimum sample sizes of 100 (Hair et al., 2010) to 200 (Boomsma, 1982) or a recommended five to 10 observations per estimated parameter (Bentler & Chou, 1987; Hair et al., 2010). The final sample sizes are considered sufficient for EFA and CFA analyses (see e.g., Hair et al., 2010; Tabachnick & Fidell, 2014). While no statistical a priori power analysis was conducted, sensitivity power analyses with α = 0.05 and power (1-β) = 0.80 showed that both samples were large enough to detect small single regression effects with effect sizes of f^2 = 0.03 (t = 1.97).

Table 3.1

Characteristics of study samples.

	Sample 1 (*N* = 244)	Sample 2 (*N* = 304)	Group comparison	*p*-value
Age (*SD*)	28.65 (10.59)	40.52 (12.06)	t(540.16) = -12.24	< .001
Female[a]	79.1%	37.2%	$\chi^2(3) = 96.86$	< .001
Employed	45.1%	69.1%	$\chi^2(1) = 31.10$	< .001
Student	55.3%	18.8%	$\chi^2(1) = 77.97$	< .001
Average number of contacts per day (*SD*)	13.58 (33.66)	6.83 (18.46)	t(347.57) = 2.78	.006
Stayed at home to avoid social contacts [last 2 weeks][b] (*SD*)	3.12 (1.19)	4.01 (.99)	t(472.57) = −9.37	< .001
Avoided physical contact [last 2 weeks][b] (*SD*)	4.37 (.97)	4.65 (.71)	t(432.28) = −3.82	< .001

Note. [a] 1 = identifying as female, 2 = identifying as male; no other gender identification option was chosen. [b] Items range from 1 = “strongly disagree” to 5 = “strongly agree”.

Measures of mental health, social support and sociability

For the assessment of mental health, we used well established clinical measures of anxiety and depression. Individual differences in anxiety were assessed using the trait scale of the State-Trait Anxiety Inventory (STAI; Laux et al., 1981; Spielberger & Gorsuch, 1983) and a 6-item short form of the STAI state scale (Marteau & Bekker, 1992). Individual differences in depression were assessed using the 2-item Patient Health Questionnaire (PHQ-2; Kroenke et al., 2003) and the simplified Beck Depression Inventory (BDI-V; Schmitt et al., 2003). We included the MSPSS (Zimet et al., 1988) and the SIAS (Heimberg et al., 1992; Mattick & Clarke, 1998) as indicators of convergent validity for factors measuring social support or social anxiety and avoidance, respectively. As indicators of sociability and social engagement, we used the extraversion subscale of the NEO-Five Factor Inventory (NEO-FFI; Borkenau & Ostendorf, 2008; Costa & McCrae, 1992) and the sociability subscale of the 10-item shyness and sociability scales for adults (German: "Schüchternheits- und Geselligkeitsskalen für Erwachsene", SGSE; Asendorpf, 1997).

Data Analysis

Exploratory and confirmatory factor analyses

All analyses were conducted in R (version 4.0.3; R Core Team, 2020). We computed means, standard deviations, and ranges for the items and subscales of the LISD scale. There were no missing values as the online survey did not allow incomplete responses on the LISD scale and clinical questionnaires. For each clinical questionnaire, a total and (if applicable) subscale score was calculated for each participant. From this, we derived means, standard deviations, ranges, and indicators of internal consistency (Cronbach's α, McDonald's ω).

EFA was computed for the state and trait scale separately, similar to previous validations of instruments divided into a state and trait subscale with different instructions (Dunn et al., 2014; Ree et al., 2008). The EFA were calculated using the R package "psych" (Revelle, 2017). We used principal axis factor analysis for factor extraction. We chose principal axis factor analysis because it is recommended for studies with the primary goal to identify latent dimensions (factors) represented in a scale's items (Hair et al., 2010). Moreover, it does not include distributional assumptions (e.g., multivariate normality; Fabrigar et al., 1999), accounts for specific and error variance (Hair et al., 2010), and is robust regarding unequal factor loadings or factors with few indicators (Briggs & MacCallum, 2003; De Winter & Dodou, 2012). The CFA on the resulting factor solutions (2 state factors and 3 trait factors) were also computed separately using the R package "lavaan" (Rosseel, 2012). For EFA, the determination of number of factors and dimensionality of the LISD scale was guided by parallel analysis and minimum average partial (MAP)-test, and supported by inspection of the scree plot (Bühner, 2011; Tabachnick & Fidell, 2014). Oblique rotation (promax) was applied to account for correlated factors. Initial assumption checks of EFA and CFA included the Bartlett test of sphericity ($p < 0.05$), the Kaiser Meyer Olkin criterion (KMO, or Measure of Sampling Adequacy [MSA], > 0.50; Field et al., 2012; Hair et al., 2010), and tests for acceptable multivariate normal distribution and linearity of the data (Tabachnick & Fidell, 2014). The determinant of the item correlation matrix was assumed to be small, but > 0.00001. The proportion of very small ($r > .30$) and very large ($r > .70$) correlations in the bivariate item correlation matrix was checked to exclude singularity and multicollinearity, respectively (Backhaus et al., 2016; Field et al., 2012). Items with a skewness > 2.0 ($n = 2$) were excluded from factor analysis (Muthén & Kaplan, 1985).

Several criteria determined a stepwise item reduction throughout EFA. First, items with communalities $h^2 \leq 0.20$ were excluded from the unrotated factor solution (Child, 2006; Samuels, 2017). After rotation, items with primary factor loadings of < 0.35 were also removed, as recommended for sample sizes of approximately $N = 250$ (Hair et al., 2010). In case of multiple factor loadings, items with a difference between loadings of $\Delta < 0.20$ were excluded when also showing a communality of $h^2 < 0.50$ (Hair et al., 2010; Tabachnick & Fidell, 2014). We computed internal consistency (Cronbach's α) for each LISD factor. Cronbach's α coefficient estimates the total variation in the scale shared by the included items. Values above 0.70 are considered acceptable indicators of overall scale reliability (Kline, 2014; Nunnally, 1978). Items were excluded throughout the EFA if their exclusion considerably increased Cronbach's α (Field et al., 2012). Lastly, we considered item discrimination (exclusion criteria: $r_{it} < 0.30$) and item difficulty (exclusion criteria: $P < 0.20$ and $P > 0.80$) within each factor (Bortz & Döring, 2015; Kline, 2013; Trakman et al., 2017). There were a number of borderline exclusion indications, i.e., items with values just above or below an exclusion threshold (e.g., communality), especially on the trait scale which originally contained more items than the state scale (23 vs. 17 items, respectively). In these cases, the exclusion decision was based on (1) the unambiguousness of the other exclusion criteria and (2) the individual item's value with regard to the scale's content and to its factor. That is, if there was not just one but several marginal exclusion criteria for one item, it was more likely to be excluded. In addition, items were not excluded if this would result in too few items per factor (a minimum of three items is recommended; Hair et al., 2010).

The two (state and trait) factor matrices resulting from EFA were then considered for factor content interpretation and labelling (Hair et al., 2010; Tabachnick & Fidell, 2014). The comparative fit index (CFI; Bentler, 1990), root mean square error of approximation (RMSEA; Steiger, 1990) and root mean square of the residuals (RMSR; Jöreskog & Sörbom, 1980) served as model fit indices. For CFA, we inspected the standardized root mean square of the residuals (SRMR; Hu & Bentler, 1999). CFI values > 0.95 indicate reasonable model fit (Hu & Bentler, 1999), but a more liberal cutoff of 0.90 is also frequently accepted (Hopwood & Donnellan, 2010; Perry et al., 2015). For RMSEA, RMSR and SRMR, low values are desirable. RMSEA values < 0.06 indicate excellent fit and values < 0.10 moderate fit (Bryant & Yarnold, 1995; Thompson, 2004). RMSR values ≤ 0.08 and SRMR values < 0.10 are acceptable (Hu & Bentler, 1999). CFA target models were the 2-factor solution (12 items) for the state scale and the 3-factor solution (14 items) for the trait scale from EFA. Maximum likelihood (ML) estimation was applied. For CFA, we also examined the 90% confidence interval of the RMSEA (Kline, 2014) and modification indices. A χ^2 difference test was calculated for comparison of the CFA target models to a 1-factor-model (state and trait total score, respectively) and to an alternative trait model resulting from inspection of modification indices. The corresponding Akaike information criterion (AIC) and Bayesian information criterion (BIC) are reported. The use of modification indices is a data-driven approach recommended to respecify models with poor fit, but needs to be carefully applied and theoretically justified (MacCallum, 1986; Perry et al., 2015; Saris et al., 2009).

The factor correlations provided by EFA and CFA represent the relations between state and trait loneliness and social isolation, social support, social interaction anxiety and extraversion in the context of social distancing. Due to related item exclusions throughout EFA, the influence of virtual communication was considered minor and not further investigated. Additionally, for inspection of convergent and discriminant validity of the LISD scale, and the role of social support and connectedness, sociability, and social interaction anxiety, we calculated Pearson correlations of the LISD factors with the relevant questionnaire scores described above (MSPSS; extraversion subscale of NEO-FFI; sociability subscale of SGSE; SIAS). These relations also served as justifications for the factor labels chosen based on the EFA factor solution. As one factor resulting from factor analyses (i.e., state factor 2) included an item taken from the MSPSS ("There is a special person with whom I can share my joys and sorrows.”), we excluded this item from the MSPSS sum score for this single correlation to avoid an artificially high correlation.

Regression analyses

To assess the predictive strength of the LISD scale for clinical outcome variables, we calculated multiple regressions, using the R-package “stats” (R Core Team, 2020). Results were visualized with the “ggplot2” package (Wickham, 2009). Variance inflation factors (VIFs) were calculated with the “car” package (Fox & Weisberg, 2018) to check for collinearity (Sheather, 2009). For each target variable (i.e., depression and anxiety), three regression models with decreasing parsimony were compared. Model fit was compared using Analysis of Variance (ANOVA). Predictor variables for model 1 were the five LISD factors without interactions; for model 2 the LISD factors, age, gender, and social distancing compliance without interactions; and for model 3 the LISD factors, age, gender, social distancing compliance, and their interactions. All continuous predictors in our regressions were z-standardized (age, questionnaire scores, LISD factors). The remaining two categorical predictors were converted into binary items: Gender (identifying as female/male; no other option selected) and compliance to social distancing (yes/no). We created the two outcome variables from standardized state questionnaire scores based on their construct’s theoretical relation and their Pearson correlations in the present sample. STAI state anxiety serves as the outcome variable “anxiety”. The outcome variable “depression” represents the mean score of PHQ-2 and BDI-V ($r = 0.72$, $p < 0.001$).

Results

Exploratory Factor analysis

Two items from the state scale were excluded due to high skewness (> 2.0). All other assumptions were fulfilled satisfactorily (Bartlett: $\chi^2[105] = 1484.39$, $p < 0.001$; MSA = 0.9).

For the state scale, the EFA led to a 2-factor-solution with 12 items (i.e., five items were excluded; for item means, standard deviations, and factor loadings, see Supplementary Table 2). Both parallel analysis and MAP test suggested two factors, supported by the visual inspection of the scree plot. The fit was satisfactory (CFI = 0.97, RMSR = 0.03, RMSEA = 0.06). The fit of the off-diagonal values was 0.99. The two factors correlated with $r = 0.56$. State factor 1 included nine items and explained 32% of variance. Based on its items which were partly inspired or taken from the UCLA Loneliness Scale (e.g., "I lack companionship.", "I feel isolated from others"), it was labeled "lonely and isolated". State factor 2 included three items (e.g., "There are people I can talk to.") and explained 18% of variance. We inverted this factor and labeled it "connected and supported", representing that social relations have not deteriorated in the present context, but that there is someone to talk to and provide support (Lee & Cagle, 2017; Zimet et al., 1988). Internal consistency was high for state factor 1 ($\alpha = 0.87$, $\omega = 0.92$) and acceptable for state factor 2 ($\alpha = 0.67$, $\omega = 0.71$).

For the trait scale, the EFA led to a 3-factor-solution with 14 items (i.e., nine items were excluded; for item means, standard deviations, and factor loadings, see Supplementary Table 3). Parallel analysis suggested three factors and the MAP test two factors, but the visual inspection of the scree plot also indicated a 3-factor solution. The fit was satisfactory (CFI = 0.97, RMSEA = 0.06, RMSR = 0.03). The fit of the off-diagonal values was 0.99. Trait factors 1 and 2 correlated with $r = -0.34$, factors 1 and 3 with $r = 0.67$, and factors 2 and 3 with $r = -0.50$. Trait factor 1 included five items and explained 24% of variance. Based on its items which were partly inspired or taken from the UCLA Loneliness Scale (e.g., "I am lonely", "I feel left out".), it was labeled "loneliness and isolation". Trait factor 2 included five items (e.g., "I find it easy to relax with other people."), explained 19% of variance and was labeled "sociability and sense of belonging". While *sociability* represents extraversion (McCrae & Costa, 1987), a *sense of belonging* refers to generally feeling in tune and having a lot in common with the people one is surrounded by (Lee & Cagle, 2017). Trait factor 3 included four items (e.g., "There is no one I feel close to.") and explained 12% of variance. It was inverted and then labeled "social closeness and support". Its items capture perceived general access to social *support* (Zimet et al., 1988) and emotional *closeness*, i.e., feeling close to and known by one's social relations as opposed to having superficial relations (Cornwell & Waite, 2009a; Lee & Cagle, 2017). Internal consistency was good for trait factor 1 ($\alpha = 0.85$, $\omega = 0.87$) and trait factor 2 ($\alpha = 0.82$, $\omega = 0.85$), and acceptable for trait factor 3 ($\alpha = 0.77$, $\omega = 0.80$).

All items provide acceptable discrimination and difficulty indices (see Supplementary Tables 2, 3). Factor correlations of EFA and CFA are presented in Table 3.2. Correlations regarding construct and criterion-related validity of the LISD scale were considered sufficient to continue to CFA. Items on virtual communication were excluded throughout EFA (e.g., state item: "I keep in touch via telephone/internet/app."; trait item: "It is good for me to talk to friends and family via telephone/internet/app."; exclusion criteria: communality < 0.20).

Table 3.2

Pearson correlations of the five LISD factors for the EFA (Study 1, *N* = 244) and CFA (Study 2, *N* = 304) sample.

LISD factor	Study	*M*	*SD*	α	Ω	state 1	state 2	trait 1	trait 2
state 1: lonely & isolated	1	2.47	.84	.88	.92	-			
	2	2.81	.87	.90	.93				
state 2: connected & supported	1	4.31	.72	.67	.71	−.51***	–		
	2	3.79	.82	.62	.68	−.54***			
trait 1: loneliness & isolation	1	2.13	.81	.85	.87	.66***	−.63***	–	
	2	2.61	.93	.87	.88	.73***	−.60***		
trait 2: sociability & sense of belonging	1	3.85	.73	.82	.85	−.08	.29***	−.37***	–
	2	3.28	.78	.83	.87	.23***	.12*	−.14*	
trait 3: social closeness & support	1	4.25	.70	.77	.80	−.35***	.63***	−.67***	.44***
	2	3.73	.84	.81	.84	−.25***	.60***	−.56***	.49***

Note. LISD = Loneliness and Isolation during Social Distancing Scale.
**p* < .05, ****p* < .001.

Confirmatory factor analysis

The state and trait factor models resulting from EFA were tested via CFA in an independent sample. The initial assumption check for CFA provided satisfactory results. For CFA of the 2-factor state model, the fit indices were CFI = 0.86, SRMR = 0.08 and RMSEA = 0.13, with a 90% confidence interval of 0.12 to 0.14. The comparison with the 1-factor-model showed a significant difference in χ^2 (χ^2_{diff} (1) = 14.62, $p < 0.001$), with $AIC_{2\text{-factor}}$ = 9,775.9 compared to $AIC_{1\text{-factor}}$ = 9,788.6 and $BIC_{2\text{-factor}}$ = 9,913.5 compared to $BIC_{1\text{-factor}}$ = 9,922.4. The state items and their means, standard deviations, and factor loadings are presented in Supplementary Table 4. Cronbach's α and McDonald's ω are 0.90 and 0.93 for state factor 1, and 0.62 and 0.68 for state factor 2, respectively.

In the CFA of the 3-factor trait model, one item (“I lack companionship.”) from trait factor 1 produced several high modification indices. It was removed after careful consideration (e.g., closeness in content to other factor 1 items; lowest factor loading on factor 1; cross-loading and low communality in EFA; equivalent state item with higher properties). The resulting model showed a significant difference in χ^2 ($p < 0.001$) compared to the original model and was therefore selected ($AIC_{reduced}$ = 9,925.3, $AIC_{original}$= 10,718.6; $BIC_{reduced}$ = 10,081, $BIC_{original}$ = 10,886). The fit indices were CFI = 0.92, SRMR = 0.09 and RMSEA = 0.09, with a 90% confidence interval of 0.08 to 0.11. The trait items and their means, standard deviations, and factor loadings are presented in Supplementary Table 5. The 1-factor solution provided poor fit indices (CFI = 0.53, SRMR = 0.19, RMSEA = 0.22) and further model comparison was therefore discarded. Cronbach’s α and McDonald’s ω are 0.87 and 0.88 for trait factor 1, 0.83 and 0.87 for trait factor 2, and 0.81 and 0.84 for trait factor 3.

Factor means, standard deviations and correlations for the first (EFA) and second (CFA) sample are shown in Table 3.2. Indicators of loneliness and isolation (state 1, trait 1) correlate positively with each other and negatively with both being *supported and connected* (state 2) as well as *social closeness and support* in general (trait 3; all $p < 0.001$, see Table 3.2 for r-values). Correlations notably differ between samples only on trait factor 2 (*sociability and sense of belonging*). Here, the correlation with being *lonely and isolated* (state 1) is positive in Sample 2 ($r = 0.23$, $p < 0.001$) but non-significant in Sample 1 ($r = −0.08$, $p = 0.189$). In contrast, Sample 2 shows weaker correlations of *sociability and sense of belonging* with being *connected and support* (state 2; Sample 1: $r = −29$, $p < 0.001$, Sample 2: $r = 0.12$, $p = 0.043$) and trait *loneliness and isolation* (trait 1; Sample 1: $r = −0.37$, $p < 0.001$, Sample 2: $r = −0.14$, $p = 0.013$).

Finally, we inspected selected correlations to validate the LISD factors’ labeling and convergent validity (see also Supplementary Table 6 for a complete list of correlations for convergent and discriminant validity). Factors indicating social support, connectedness and closeness correlated positively with perceived social support (e.g., state factor 2 [*connected and supported*] and MSPSS, $r = 0.57$, $p < 0.001$; item “There is a special person with whom I can share my joys and sorrows.” excluded from MSPSS sum score) and extraversion (e.g., trait factor 3 [*social closeness and support*] and extraversion [NEO-FFI], $r = 0.53$, $p < 0.001$). The convergent validity of trait factor 2 (*sociability and sense of belonging*) is represented in its high positive correlation with the Big Five’s extraversion dimension ($r = 0.80$, $p < 0.001$) and the SGSE's sociability subscale (r = 0.76, p < 0.001), as well as its negative correlation with social interaction anxiety (SIAS; r = −0.68, p < 0.001).

Relationship between LISD scores and mental health dimensions

The regression analyses presented below focus on the second sample (CFA; N = 304) as it represents a more heterogeneous sample (nationwide recruitment, see also Table 3.1). Most importantly, during this time of enhanced restrictions, social distancing compliance was higher and the number of daily social contacts was lower.

Table 3.3

Multiple regression analyses for predicting state anxiety.

	Model 1			Model 2		
Model statistics						
Adjusted R^2	.33			.33		
F	30.57***			19.73***		
(df)	(5, 298)			(8, 295)		
Standardized regression weights (β), effect sizes (η_p^2) and variance inflation factors (VIF)						
	β	η_p^2	VIF	β	η_p^2	VIF
LISD state 1	.26**	.03	3.08	.27**	.03	3.26
LISD state 2	−.10	.01	2.09	−.10	.01	2.11
LISD trait 1	.28**	.03	3.32	.26**	.03	3.38
LISD trait 2	−.25***	.06	1.67	−.25***	.05	1.77
LISD trait 3	.06	.00	2.43	.04	.00	2.51
Age				.01	.00	1.10
Gender (female)				.15	.01	1.05
Compliance (yes)				−.22	.01	1.03

Note. LISD state 1 = "lonely and isolated"; LISD state 2 = "connected and supported"; LISD trait 1 = "loneliness and isolation"; LISD trait 2 = "sociability and sense of belonging"; LISD trait 3 = "social closeness and support"; VIF = variance inflation factor. State anxiety was measured with a 6-item short form of the State-Trait Anxiety Inventory's (STAI) state scale (Marteau & Bekker, 1992). ** < .01, *** < .001.

Model statistics, regression weights, effect sizes, and VIFs for multiple regression analyses with anxiety as outcome variable are reported in Table 3.3. The predictors for model 1 (LISD factors) and 2 (LISD factors, age, gender, social distancing compliance) showed acceptable VIFs below 5 which indicates low collinearity (Sheather, 2009). In contrast, model 3 (LISD factors, age, gender, social distancing compliance, and their interactions) shows VIFs > 10. Moreover, model comparison (ANOVA) showed that the inclusion of interactions (model 3) did not improve model fit (model 1: F [18, 280] = 1.31, p = 0.178; model 2: F [15, 280] = 1.29,

p = 0.211). Model 3 is therefore not reported (but see Supplementary Table 9 for reports on all three models).

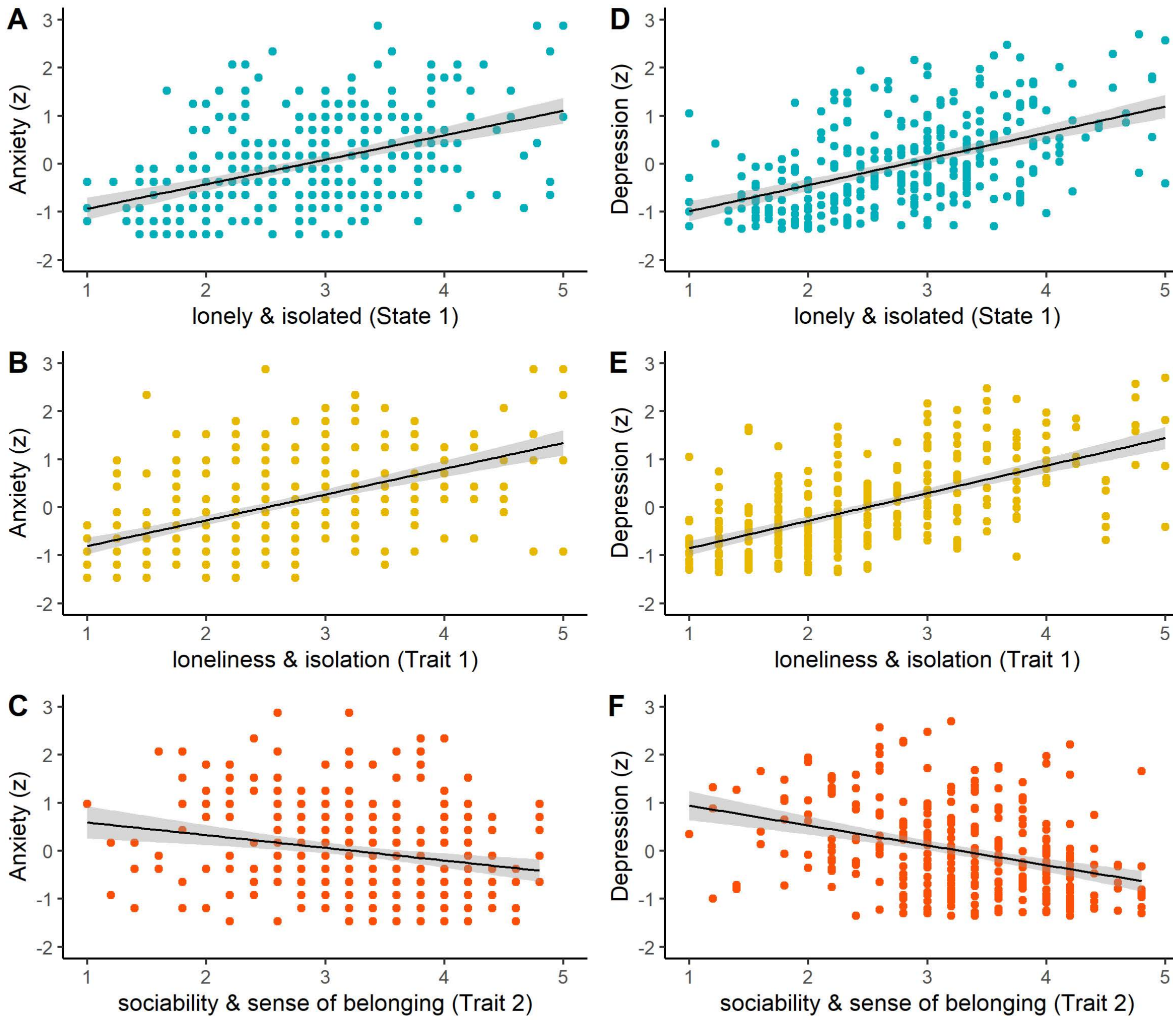

Figure 3.1 Relationships between raw LISD factor scores and z-standardized scores of anxiety (left column) and depression (right column) for **(A,D)** lonely and isolated (State 1; $p = 0.002$ / $p < 0.001$), **(B,E)** loneliness and isolation (Trait 1; $p = 0.001$; $p = 0.020$), and **(C,F)** sociability and sense of belonging (Trait 2; both $p < 0.001$). The shaded areas indicate standard errors of the mean.

Regression analyses for model 1 revealed a significant positive relationship of anxiety with loneliness and isolation as a state (LISD state 1; β = 0.26, *SE* = 0.08, $p = 0.002$; Figure 3.1A) and trait (LISD trait 1; β = 0.28, *SE* = 0.09, $p = 0.001$; Figure 3.1B). Furthermore, anxiety was negatively related to trait *sociability and sense of belonging* (LISD trait 2; β = −0.25, *SE* = 0.06, $p < 0.001$; Figure 3.1C). The LISD factors alone explained 32.8% of variance (adjusted R^2) in state anxiety. The more complex model (model 2) did not improve prediction performance (F [3, 295] = 1.43, $p = 0.234$). See Figure 3.1 for a visualization of significant predictors for anxiety.

Table 3.4

Multiple regression analyses for predicting depression.

	Model 1			Model 2		
Model statistics						
Adjusted R^2	.51			.51		
F	64.25***			40.43***		
(df)	(5, 298)			(8, 295)		
Standardized regression weights (β), effect sizes (η_p^2) and variance inflation factors (VIF)						
	β	η_p^2	VIF	β	η_p^2	VIF
LISD state 1	.39***	.10	3.08	.38***	.10	3.26
LISD state 2	−.10†	.01	2.09	−.10†	.01	2.11
LISD trait 1	.16*	.02	3.32	.15*	.02	3.38
LISD trait 2	−.37***	.16	1.67	−.36***	.15	1.77
LISD trait 3	−.25	.00	2.43	−.04	.00	2.51
Age				−.01	.00	1.10
Gender (female)				.12	.01	1.05
Compliance (yes)				−.07	.00	1.03

Note. LISD state 1 = "lonely and isolated"; LISD state 2 = "connected and supported"; LISD trait 1 = "loneliness and isolation"; LISD trait 2 = "sociability and sense of belonging"; LISD trait 3 = "social closeness and support"; VIF = variance inflation factor. Depression is indicated by the mean score of the 2-item Patient Health Questionnaire (PHQ-2; Kroenke et al., 2003) and the simplified Beck Depression Inventory (BDI-V; Schmitt et al., 2003).
† < .10, * < .05, *** < .001.

Model statistics, regression weights, effect sizes, and VIFs for multiple regression analyses with depression as outcome variable are reported in Table 3.4. The predictors for model 1 and 2 showed acceptable VIFs below 5. Model 3 again showed some VIFs > 10 and did not improve model fit (model 1: F [18, 280] = 1.33, p = 0.165; model 2: F [15, 280] = 1.42, p = 0.135). It is therefore not reported (but see Supplementary Table 11 for reports on all three models).

Regression analyses with the LISD factors as predictors (model 1) also revealed a significant positive relationship of depression with state 1 (β = 0.39, *SE* = 0.07, p < 0.001; Figure 3.1D) and trait 1 (β = 0.16, *SE* = 0.07, p = 0.020; Figure 3.1E). A negative correlation was found with *sociability and sense of belonging* (LISD trait 2; β = −0.37, *SE* = 0.05, p < 0.001; Figure 3.1F). Moreover, there was a marginally significant relationship with being *connected and supported* (LISD state 2; β = −0.10, *SE* = 0.05, p = 0.078). Once again, the more complex model (model 2) did not improve prediction performance (F [3, 295] = 0.87, p = 0.457). The LISD factors explain 51.1% of variance in depression. See Figure 3.1 for a visualization of (marginally) significant predictors for depression.

Exploratory regression analyses with Sample 1 (EFA) underline the predictive strength of the LISD factors for mental health indices even under less severe social distancing conditions. The LISD factors explain 21.5% of variance in anxiety and 39.5% of variance in depression (see Supplementary Tables 8 and 10 for model statistics, regression weights, effect sizes, and VIFs).

Discussion

This article presents the Loneliness and Isolation during Social Distancing (LISD) Scale, a measure for the assessment of loneliness and isolation during times of social distancing on the state and trait level. The final scale consists of 12 state and 13 trait items on five factors: *lonely and isolated* (state), *connected and supported* (state), trait *loneliness and isolation*, trait *sociability and sense of belonging*, and trait *social closeness and support*. Based on exploratory and confirmatory factor analyses, the factor solutions showed satisfactory fit in two independent and diverse samples. With the exception of *connected and supported,* all scales exhibit high reliability. In addition to convergent and discriminant validity assessed with established measures, state and trait LISD factors show strong predictive value for indicators of mental health, particularly depression. Our results underline our scale's adequacy for measuring mental strain in relation to loneliness and isolation. To the best of our knowledge, our LISD scale is the first to distinguish between state and trait aspects of loneliness and social isolation. Importantly, our analyses underline the expected gain in knowledge provided by the state-trait distinction. Extending previous findings lacking such a distinction, they imply a stronger mental health-depriving effect of state than trait loneliness and isolation in the context of social distancing.

Scale construction and validity

The satisfactory fit indices derived from factor analyses in two heterogeneous samples are promising regarding the applicability of the LISD scale. The EFA's 2-factor state and 3-factor trait solutions' fit were confirmed in the second sample. The labeling of the state factor *lonely and isolated* and trait factor *loneliness and isolation* is supported by their items' origin from previous scales assessing loneliness and social isolation (e.g., the UCLA Loneliness Scale; Russell et al., 1980). Some items even explicitly address loneliness and isolation, i.e., "I feel isolated from others" and "I feel lonely". The high positive correlation of perceived social support with state factor *connected and supported* and trait factor *social closeness and support* justifies their "social support" labeling. The distinction between "connected" and "closeness" is based on the remaining items' content (e.g., "I feel that my relationships with friends have deteriorated." vs. "There is no one I feel close to.") and their theoretical relevance for individual differences in loneliness and isolation (Cornwell & Waite, 2009b; Jong Gierveld et al., 2006; Lee & Cagle, 2017). Note that despite high convergent validity, insufficient reliability of *connected and supported* implies that this factor may need additional items with higher reliability. The remaining factor *sociability and sense of belonging*'s items represent a tendency to seek social engagement and a feeling of belonging there. Convergent validity and support for its labeling as a "sociability" factor are provided in *sociability and sense of belonging*'s positive correlations with extraversion (NEO-FFI) and sociability (SGSE), and a negative correlation with shyness (i.e., a construct negatively associated with sociability; Asendorpf & Wilpers, 1998). Moreover, two of its items were previously used to measure social avoidance and distress ("I often find social occasions upsetting."; "I find it easy to relax with other people.", inverted coding; Watson & Friend, 1969). Low scores on these items should therefore indicate a tendency towards social engagement.

The original scale for EFA contained a number of items that were included to target additional aspects related to social distancing. While other social distancing-specific items (e.g., "Regular contact is important to me.") were excluded throughout EFA, the effect of the (lack of) contact to people from the high-risk group was included in the factor *lonely and isolated*. Despite their potential importance (Baker et al., 2018; Banerjee & Rai, 2020; Naslund et al., 2016), items related to virtual communication (e.g., "I keep in touch via telephone/internet/app.") were excluded due to low communalities. Future studies should investigate the potential effect of virtual communication further, using more objective measures of virtual interactions and contacts such as app usage times.

In accordance with previous literature (Bu et al., 2020), positive factor correlations imply that pre-existing general loneliness and social isolation are a risk factor for feeling lonely and isolated in an acute context of social distancing. Furthermore, previous findings suggest that acute loneliness is dependent on the social context (Van Roekel et al., 2015). Negative correlations between the LISD factors measuring social factors (e.g., social closeness and support) with the LISD factors measuring loneliness and isolation indicate that social support, connectedness and closeness protect against loneliness and isolation, both on a state and trait level. This is in accordance with research on social distancing measures throughout the COVID-19 pandemic (Kovacs et al., 2021). The researchers found a loneliness-increasing effect of having less than five close relations and a loneliness-decreasing effect of face-to-face interactions and longer and more frequent interactions with emotionally close relations (Kovacs et al., 2021). Notably, the LISD scale allows to assess these factors and relations in an economic way, using just 25 items while also distinguishing between dispositional and acute influences on the degree of acute loneliness and isolation (as well as anxiety and depression). In contrast, previous researchers had to use multiple measures (e.g., single items on sociodemographic and social network information combined with other questionnaires without state-trait distinction, Kovacs et al., 2021).

Although our findings imply a protective role of *sociability and sense of belonging* against trait loneliness and isolation as well as anxiety and depression, its relationship with state loneliness and isolation is less clear. Correlations between the LISD factors point in the same direction across both samples, with one exception: While playing a protective role in the exploratory first sample, *sociability and sense of belonging* were associated with higher *lonely and isolated* scores in the confirmatory second sample. The second sample's greater variance in sociodemographic factors, particularly their higher age, could contribute to this difference to the younger and more homogeneous first sample (see e.g., Tomaka et al., 2006). However, note that the first sample was collected during milder social distancing, with less compliance to social distancing measures and a higher frequency of daily contacts. It is likely that more sociable individuals were still able to fulfill their need of social contacts to a sufficient level, thus feeling less lonely (Cornwell & Waite, 2009b; Jong Gierveld et al., 2006). This could have been denied to the second sample due to strict restrictions which encouraged staying at home, closed public places, and discouraged group gatherings and contacts beyond households (Wieler et al., 2021). As a result, more sociable individuals grew lonelier and more isolated as they could not satisfy their pronounced need for social engagement. Besides sociability, losing a sense of belonging due to restricted contacts could also play a role here. Although usually functioning as a protective factor against loneliness (Thoits, 2011), it may be too strongly impaired by social distancing and therefore unable to protect against acute loneliness and isolation. Social interaction anxiety (SIAS) was associated with higher state and trait loneliness and isolation. However, the *sociability and sense of belonging* factor includes negatively loaded items representing social interaction anxiety, avoidance and distress. For instance, a high score for the factor's item "I often find social occasions upsetting." led to lower *sociability and sense of belonging*, which in turn related to lower *lonely and isolated* scores in the second sample. A trait tendency to avoid social gatherings and to feel uncomfortable among other people could therefore protect against loneliness during strict contact restrictions (but not at times of milder restrictions). In line with previous findings regarding a nationwide lockdown (Gubler et al., 2020), our findings imply that strict social distancing circumstances may have a stronger impact on more sociable and socially integrated persons regarding acute loneliness and isolation. Thus, social distancing may overshadow the generally loneliness-reducing effects of sociability, extraversion, and a sense of belonging (Buecker et al., 2020; Lamers et al., 2012).

Prediction of anxiety and depression

The LISD scale shows strong predictive strength for mental health dimensions, i.e., anxiety and depression. The high proportions of explained variance (33% for anxiety, 51% for depression) revealed by multiple regression analyses show that in the context of social distancing, the 25-item LISD scale can predict mental health in an efficient way, particularly regarding increases in depression. Regression models with just the five LISD factors as predictors showed that in a phase of strict social distancing measures (Sample 2), being *lonely and isolated* predicts higher state anxiety and depression with a small and moderate effect, respectively. Higher *loneliness and isolation* on a trait level shows a similar, but smaller effect. Note that a measure without the state-trait distinction may have overlooked the strong effect of acute feelings of loneliness and isolation. In addition, the trait factor *sociability and sense of belonging* predicted lower levels of anxiety and depression, with a moderate and large effect, respectively.

Regression analyses show the value in distinguishing between state and trait aspects of loneliness and isolation in the context of mental health. Both anxiety and depression increase with higher scores in *lonely and isolated,* and *loneliness and isolation*. This risk-enhancing role of loneliness and isolation for anxiety and depression is in accordance with previous literature (Beutel et al., 2017; Masi et al., 2011), including research involving social distancing (Fiorillo & Gorwood, 2020; Hoffart et al., 2020). In addition, however, our results imply a higher predictive strength of state compared to trait loneliness and isolation for increases in depression during times of social distancing. This suggests a more important role of acute compared to perpetual loneliness and isolation in predicting mental health. Differentiating between state and trait aspects refines our understanding of loneliness and social isolation (Morgan & Burholt, 2020), as in other assessments of emotion and personality with a state-trait distinction, e.g., measurements of anxiety and anger (Spielberger & Reheiser, 2009).

In contrast to their positive relation with loneliness and isolation, anxiety and depression decrease with higher *sociability and sense of belonging* trait scores. The protective role of *sociability and sense of belonging* against depression and anxiety agrees with previous findings regarding a mental health-enhancing role of extraversion (Lamers et al., 2012) and sense of belonging (Sacco & Ismail, 2014; Thoits, 2011). Note that the negative relation to depression and anxiety is in contrast to *sociability and sense of belonging*'s concurrent positive relation to feeling *lonely and isolated.* Based on our results, an individual who generally seeks and appreciates social contacts and feels like having a lot in common with the people around them (i.e., someone scoring high on *sociability and sense of belonging*) feels more lonely and isolated during strict social distancing conditions (than someone scoring low on *sociability and sense of belonging*). However, this person is also expected to report lower levels of depression and anxiety. Thus, although being linked to acute loneliness and isolation which usually relates to higher depression and anxiety, extraversion appears to retain its established mental health-enhancing effect (Lamers et al., 2012; Sacco & Ismail, 2014; Thoits, 2011) in a strict social distancing context. This may be supported by the positive correlation of *sociability and sense of belonging* with *social closeness and support*, which in turn is a protective factor against both state and trait loneliness and isolation and increased depression and anxiety.

Depression was marginally reduced by higher *connected and supported* scores. Apart from this, *connected and supported* and *social closeness and support* remained non-significant predictors in our regression models. This is surprising as social support was strongly associated with lower depression and anxiety in previous research (Cohen, 2004; Marroquín et al., 2020; Thoits, 2011). Despite this finding, we believe that identifying a lack of social support, closeness and connectedness (e.g., with low scores on the LISD scale's *connected and supported* and *social closeness and support* factors) is still relevant to both loneliness and mental health in the context of social distancing. Previous psychiatric research has underlined the crucial role of sufficient access to social contacts, activities, support and integration in protecting against loneliness and poor mental health (Perese & Wolf, 2005; Sheridan et al., 2015). The negative association of LISD factors assessing loneliness and isolation (state and trait) with the LISD factors assessing social connectedness, closeness and support (state and trait) visible in factor correlations implies that interventions supporting socialization could be effective in reducing loneliness and social isolation. Based on the present findings and previous research on the link between loneliness and mental health (Beutel et al., 2017; Perese & Wolf, 2005), this should in turn lead to a lower risk of decreases in mental health. The support of socialization is particularly challenging in times of social distancing. It could be achieved by the enabling of appropriately distanced in-person meetings or by organized, targeted use of virtual communication tools (Choi et al., 2020; Pantell, 2020; Williams et al., 2021), for example with phone or video calls by volunteers (Jawaid, 2020). This may require social distancing-related tailoring of technology-based interventions, telemedicine consultations and teletherapy, and may even require the provision of technological devices to those lacking financial resources (Baker et al., 2018; Choi et al., 2022; Jawaid, 2020; Williams et al., 2021).

The additional integration of other factors (i.e., compliance, gender, age) did not improve model performance, further supporting the scale's predictive value and economy. Although generally being associated with both loneliness and mental health, the inclusion of age and gender did not improve model fit. Against expectations, the individual compliance to social distancing also did not play a role in predicting anxiety and depression. However, the percentage of compliance was high (82.2%). Possibly, even if a person did not comply with social distancing, their social contacts did, exposing them to restricted social contacts all the same. Moreover, higher proportions of explained variance in the second sample compared to explorative regression analyses in the first sample underline the risk-enhancing role of social contact restrictions for mental health problems in the context of loneliness and isolation (Ebrahimi et al., 2021; Liu et al., 2020; Marroquín et al., 2020). Note, however, that the first and second sample also differed on other aspects (e.g., occupation), prohibiting definite conclusions on the effect of more strict contact restrictions.

The positive associations of LISD state and trait loneliness and isolation with depression and anxiety further establish loneliness and social isolation as crucial covariates of decreases in mental health (Beutel et al., 2017; Elovainio et al., 2017; Hawkley & Cacioppo, 2010), particularly in the context of social distancing (Hoffart et al., 2020; Liu et al., 2020). At the same time, *sociability and sense of belonging* is associated with lower depression and anxiety levels (but also with higher state loneliness and isolation during strict social distancing conditions). However, based on our analyses, we cannot draw directional conclusions for these relationships. That is, for example, *sociability and sense of belonging* might not protect against depression, but be deprived by depression. Still, our findings underline the strong associations between depression and anxiety with loneliness, isolation, sociability, and a sense of belonging. Consequently, the LISD scale's assessment of state and trait indicators of loneliness, social isolation and associated factors could provide a more refined identification of loneliness-related covariates of poor mental health in clinical and therapeutic settings to better integrate them into therapeutic interventions (e.g., Internet-Based Cognitive Behavior Therapy for Loneliness; Käll et al., 2020; Trad et al., 2020). In the context of social distancing, increases in loneliness seem inevitable, and previous work has already highlighted the relevance of measuring loneliness and isolation in the context of social distancing for the protection and enhancement of wellbeing and mental health (Galea et al., 2020; Liu et al., 2020). The LISD scale can be applied to identify those individuals particularly vulnerable to mental health-depriving effects of social contact restrictions, both on a dispositional and situational level (i.e., high levels of loneliness and isolation, low levels of sociability and sense of belonging). In the therapeutic setting, this could enable the clinician to individualize interventions by explicitly targeting these aspects. Besides factors directly related to the prediction of anxiety and depression, intervention strategies targeting the improvement of (perceived) social support, closeness and connectedness could reduce state and trait levels of loneliness and isolation. If successful, this could indirectly reduce the risk of decreases in mental health.

Limitations and Outlook

As all new instruments, our scale, and in particular one of its factors (*connected and supported*), should be validated in independent studies. The LISD scale was constructed based on state-of-the-art criteria for item selection and scale validation (EFA, CFA). The state factor solution's SRMR indicates acceptable fit, while RMSEA and CFI lie slightly outside the targeted ranges. However, these criteria alone are not sufficient to make a general judgment about the quality of a scale (Hopwood & Donnellan, 2010; Perry et al., 2015), and other indicators of validity (e.g., convergent validity) were satisfying. Each factor's internal consistency was acceptable or high after EFA, supporting their adequacy for the CFA analyses.

After CFA, only one factor's reliability (*connected and supported*) was below the recommended value of > 0.70 ($\alpha = 0.62$, $\omega = 0.68$). This may have been due to the small number of items (i.e., three) and the breadth of the construct (i.e., social support and connectedness) that this short factor aims to measure (Stanley & Edwards, 2016). Importantly, although only with marginal significance, the factor *connected and supported* tended to predict (lower) depression levels along with the other factors of the scale. Note that although the labeling of the factors *lonely and isolated* and *loneliness and isolation* is supported by their items' adaption from the established UCLA Loneliness Scale, future studies should assess their convergent validity by including an independent loneliness measure.

Fluctuations of infection waves and related governmental restrictions including social distancing and nationwide lockdowns prevented data collection under equal social distancing restrictions for EFA and CFA, respectively. Moreover, the distribution of gender and the mean age (but not the age span) differed between samples. This could have reduced the applicability of the EFA factor solution to the second data set. However, despite the differences between the sample regarding age and the situational context (milder vs. more severe phase of the COVID-19 pandemic in Germany), our results show a good fit of the LISD scale. Although originally validated in a less heterogeneous sample with less social distancing behavior, the factor solution was still largely confirmed in the second sample, and the relation between LISD factors and mental health dimensions (i.e., depression, anxiety) could be replicated. Note however that our study targeted healthy participants. A validation of the factor structure in a clinical sample would allow further insight into the applicability among the general public, psychiatric patients and beyond. In addition, a longitudinal assessment under mild and strict social distancing conditions would allow more concise conclusions on the effect of the extent of social distancing, e.g., regarding the relation of *sociability and sense of belonging* with acute loneliness and isolation. This would also allow for a validation of the differentiation of state and trait items and factors via test-retest reliability. While trait factors should remain stable, we would expect higher variability in the two state factors.

Lastly, we would like to point out a limitation that frequently occurs in the literature when reporting results from different questionnaires. The questionnaires we used for the assessment of anxiety and depression utilize different instructions, therefore assessing feelings and experiences in slightly diverse time windows, i.e., "in the current moment" (STAI state), "over the last 2 weeks" (PHQ-2), or as a "current attitude toward life" (BDI-V). A common time frame would be more precise.

In conclusion, we developed and validated the Loneliness and Isolation during Social Distancing (LISD) Scale which assesses state and trait factors of loneliness and isolation in times of social distancing. For the first time, acute and dispositional aspects of loneliness and isolation can be measured in parallel and with just one instrument. Moreover, the LISD scale can help predict mental health outcomes, i.e., depression and state anxiety.

Data Availability Statement

The final LISD Scale (English and German version) and the datasets presented in this study are publicly available in the following online repository: https://osf.io/ezdgt.

Ethics Statement

The studies involving human participants were reviewed and approved by the Ethics Committee of the Institute of Psychology of the Faculty of Human Sciences, Julius-Maximilians-University of Würzburg, Würzburg, Germany. The participants provided their written informed consent to participate in this study.

Author Contributions

MG, JH, JD, and GH contributed to conception and design of the scale and study. MG and LM programmed the survey and collected the data. MG and MW performed data curation and statistical analyses with input from LM and supervised by GH. MG and MW wrote the manuscript with input from GH. LM, JH, and JD contributed to the manuscript revision. All authors read and approved the submitted version.

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Supplementary Material

The Supplementary Material for this article can be found online at:
https://www.frontiersin.org/articles/10.3389/fpsyt.2022.798596/full#supplementary-material

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

3 General Discussion

3.1 Summary

The studies presented in this dissertation investigated the role of social contact for anxiety and related autonomic responses by taking psychosocial research "from lab to life". This was achieved by applying three different methodological approaches. The first study included a laboratory-based learning paradigm with fear-inducing stimuli, fear ratings, and SCR measurements. The second study applied EMA in participants' daily life to capture characteristics of social interactions, and related changes in state anxiety and cardiovascular responses with smartphone-based surveys and portable ECG sensors. The third study was composed of two independent online surveys which delivered questionnaires for the assessment of state anxiety, loneliness, and social isolation in a naturalistic context of limited social contact (social distancing). The results imply that social buffering depends on factors including the extent of social contact (minimal vs. more complex), the familiarity of the interaction partner, and the gender of the persons involved. During times of limited social contact, lower state anxiety related to lower feelings of loneliness and social isolation on a state and trait level as well as higher trait sociability and sense of belonging. The main findings regarding influences of social contact on anxiety-related responses are illustrated in Figure A.

Study 1 included a pain relief learning paradigm conducted in the laboratory. Based on previous works that had revealed the social buffering effects of social presence in fear-inducing situations, we expected lower fear-related responses when another person was involved in pain induction (but not directly present) as compared to conditions without social influence. However, as illustrated in Figure A, results showed that the reductions in autonomic responses (SCR) and increases in fear ratings towards the conditioned stimulus ($_{relief}$CS) following pain relief learning were independent of social involvement. The autonomic response towards the painful stimulation (US) also did not differ between social and non-social conditions. Returning to this dissertation's first research question, results from study 1 thus suggest that mere social involvement without direct physical presence or social interaction does *not* suffice to produce fear-reducing social buffering effects.

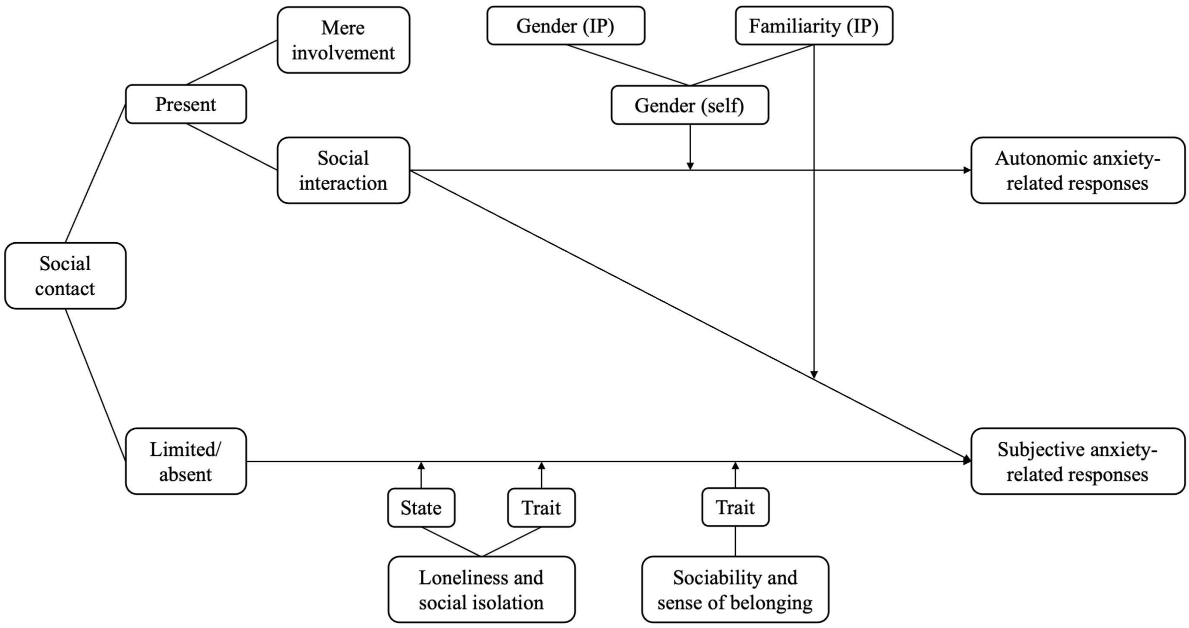

Figure A. The influence of social contact and related social factors on anxiety-related responses as implied by the three studies included in this dissertation. IP = interaction partner; self = participant. Note: the relation between "limited/absent" and "autonomic anxiety-related responses" was not tested.

Expanding previous works, studies 2 and 3 reveal and replicate factors of social contact in daily life that relate to inter- and intra-individual differences in subjective and autonomic indicators of anxiety. Overall, study 2 tested the transferability of previous laboratory-based social buffering effects to the more complex social contact of daily life involving social interactions. In particular, we expected that anxiety-related responses would be shaped by the gender of the participant and his or her interaction partners, and that more familiar interaction partners would lead to lower anxiety. Not only did this EMA study find social buffering effects of familiarity and gender on anxiety-related responses, but it additionally revealed important gender-related and outcome-specific differences (see Figure A). Firstly, social buffering in everyday life was influenced by the familiarity of the interaction partner, but this effect partly depended on the participant's gender. Subjective anxiety was lower in both men and women following social interactions with more familiar interaction partners, but only female participants showed corresponding buffering effects on the autonomic level (lower HR, higher HRV). Secondly, study 2 implies opposite-gender social buffering effects, such as lower HR in women interacting with male compared to female interaction partners, and in men interacting with female compared to mixed-gender interaction partners. Thus, regarding the second main research question, study 2 demonstrates that social buffering *does* take place outside the laboratory in everyday-life social interactions, with differential anxiety-related responses depending on the interacting individuals' familiarity and gender.

Study 3 investigated anxiety-reducing and anxiety-enhancing social and personal factors during a period of limited social contact in daily life via online surveys. State anxiety as well as social distancing-related state and trait loneliness, social isolation, and additional factors referring to social integration and support were captured at two single time points with clinical questionnaires and the newly developed LISD scale. As expected, acute loneliness and social isolation during limited social contact were associated with higher state anxiety levels. On a dispositional level, the association of lower anxiety with higher levels of trait sociability and sense of belonging as well as lower trait loneliness and isolation represented social buffering-like effects (see Figure A). Contrary to our hypotheses, social support and gender did not play a dominant role. In light of this dissertation's third general research question, study 3 shows that increased feelings of loneliness and social isolation and lower dispositional sociability and sense of belonging may predict higher anxiety in the absence of social contact.

In sum, this dissertation's three studies illustrate that the impact of social contact on anxiety-related subjective and autonomic responses depends on various factors. Minimal social contact without direct physical presence or communication may not suffice to alleviate imminent fear-related responses. At the same time, anxiety-reducing effects of more complex social interactions in everyday life depend on the interaction partners' gender and familiarity. When social contact is reduced or absent, subjective anxiety differs in relation to an individual's feelings of loneliness and isolation and other factors related to social integration. In combination with previous findings on social buffering effects, the present studies underline that the potential impact of social contact on anxiety-related measures should not be neglected − neither in the laboratory, nor in everyday life.

3.2 Implications

First and foremost, this dissertation presents further evidence that humans are, in fact, social beings who are frequently involved in and benefit from social contact (Cacioppo & Cacioppo, 2014; Cohen, 2004; Frith & Frith, 2007). Study 2's numerous observations show that social contact is a frequent and inevitable aspect of daily life: in 74.7% of the answered prompts, social interactions had taken place either at that moment or within the preceding 30 minutes. Study 3 further underlines the importance of social contact in daily life by demonstrating mental health deprivations when social contact and integration were insufficient or lacking, as represented by the association between loneliness and social isolation with enhanced state anxiety and depressive symptoms.

Until now, most social buffering-related research was conducted in the laboratory. This dissertation aimed to examine potentially response-buffering social factors in diverse social settings inside and outside the lab. The results lead to important implications regarding the extent and components of social contact and their effect on subjective and autonomic fear and anxiety-related responses. The indications, conclusions, and outlook regarding social buffering effects, their measurement, and their real-life applications derived from the present works may be of relevance for psychological and clinical research and practice aiming for the enhancement of mental health.

3.2.1 The extent of social contact

Social contact is complex, and its form and extent can vary momentously (Hall, 2018; Hennessy et al., 2009; Lee & Cagle, 2017; Marco-Pallarés et al., 2010). As shown throughout this dissertation, these variations impact the "when" and "how" of social buffering effects. Study 1 implies that minimalistic social involvement does not alter fear-related responses. At the same time, study 3 indicates that social contact can relate to subjective anxiety even when it is absent. This link is reflected by state anxiety's relation to inter-individual differences in factors associated with loneliness, social isolation, and related indicators of social integration. Finally, study 2 suggests that more substantial social contact (i.e., social interaction) generates inter- and intra-individual differences in anxiety-related responses moderated by factors like familiarity and gender.

In more detail, as implied by study 1, mere social involvement without direct physical presence or interaction was not sufficient to produce reductions in subjective and psychophysiological responses − at least not in an imminent, fear-inducing context with painful stimulation as aversive stimulus. In this laboratory paradigm, potential social buffering effects would have been reflected in lower fear and pain responses (Che et al., 2018; Hennessy et al., 2009; Kikusui et al., 2006) and/or inhibited fear learning (immunization; Golkar & Olsson, 2016) in the social-influence condition where another person was allegedly involved in the prevention of pain induction compared to the non-social conditions (self-influence, no-influence). Instead, neither the autonomic pain relief responses (reduced SCR) towards the $_{relief}$CS, nor the enhanced SCR towards the painful stimulation itself supported the hypothesis of social buffering as they did not differ between social and non-social conditions. Subjective fear learning after the learning and the test phase was also comparable between conditions. The only group difference was the lower autonomic fear responses in the self-influence compared to the no-influence condition during the early test phase. This effect did not apply to the social-influence group, however, as their responses were similar to those of the other two groups.

Study 1 presented no evidence that mere social involvement produces social buffering effects. This implies that social contact needs to be more extensive to generate social buffering effects. In conjunction with previous indications of social buffering effects, results from study 1 suggest that social buffering requires immediate physical presence (Kleck et al., 1976; McClelland & McCubbin, 2008; Qi et al., 2021) and/or communication (Hein et al., 2018; Heinrichs et al., 2003; Roberts et al., 2015), as the minimalistic social setting did not lead to fear reductions. It is not unlikely that a social buffering effect would emerge with alterations to the paradigm. Firstly, seating the confederate in the same room may induce social buffering effects, as in previous research where physical presence resulted in reductions in fear responses in comparison to non-social conditions (McClelland & McCubbin, 2008; Qi et al., 2021). However, this could increase the additional influence of other social variables (e.g., the perceived similarity of the other person; Qi et al., 2020). Secondly, the use of more explicit social support could result in social buffering effects (Hein et al., 2018; Roberts et al., 2015). In study 1, the social-influence participants were told that the confederate would try to learn to suppress their pain. Although this social involvement was intended to be perceived as helpful and supportive and therefore expected to reduce pain-related responses (Che et al., 2018; Hein et al., 2018), such implicit forms of social support previously produced weaker social effects than explicitly expressed social support (Che et al., 2018). Moreover, the social influence may not have been perceived as positive or helpful after all, as the other person did not always "succeed" in preventing the painful stimulation. Such ambiguity or uncertainty in social contact could even lead to higher pain responses (Krahé et al., 2013). More positive and unambiguous perception of the social contact, and thus, reduced pain and fear-related responses could for instance be achieved by the inclusion of feedback on the social partner's continued effort to prevent the participant's painful stimulation (e.g., a visualisation of a success rate). Finally, social effects were potentially weakened by unfamiliarity with the other person (Eisenberger, 2013; Krahé et al., 2013). Other social settings without social presence indicate social buffering effects of familiar social partners. For instance, fear learning was less successful when the CS consisted of a picture showing familiar socially supportive figures as compared to a picture showing strangers (Hornstein & Eisenberger, 2018). Such findings suggest that an inclusion of familiar as well as unfamiliar partners into study 1's protocol could bring further insight regarding the (lacking) social buffering effects of minimalistic social contact (but introduce additional confounding factors, see "3.3 Methodology in lab and life: Lessons learned"). In sum, however, study 1 demonstrates that the presence of minimalistic, indirect social contact did not produce social buffering effects on SCR or fear ratings.

In contrast to study 1's lack of social buffering effects of minimal social contact without imminent physical presence on fear-related responses, study 3 implies that social effects on anxiety *can* emerge without physical presence. Combined with previous research, study 3 suggests that general access to and inclusion into social contact might have anxiety-reducing effects during times of restricted social contact. When social contact is limited in everyday life, the remaining social contacts may not fulfil a person's social needs (Cornwell & Waite, 2009b) and therefore lead to acute feelings of loneliness and social isolation (Bu et al., 2020; Cornwell & Waite, 2009b; Hoffart et al., 2020; Lee & Cagle, 2017). These are in turn related to higher levels of state anxiety (Abad et al., 2010; Santini et al., 2020). Study 3's validated distinction between acute (state) and general (trait) factors of loneliness and social isolation through the LISD scale extends these findings. The similar yet distinct positive relation of state and trait loneliness and isolation to state anxiety illustrates that even when a person does not generally suffer from loneliness and isolation, acute loneliness and isolation can still positively correlate with increased anxiety levels. As loneliness and social isolation are characterized by an objective and subjective lack of social contact, connection, and integration, this indicates "reverse" social buffering effects, i.e., anxiety-*enhancing* effects of state loneliness and social isolation in the *absence* of social contact (but note that the causality of this implication remains unclear, see "3.3 Methodology in lab and life: Lessons learned"). At the same time, lower levels of trait loneliness and social isolation as well as higher trait sociability and sense of belonging may buffer against higher state anxiety once social contact is limited (see also, Hoffart et al., 2020; Lamers et al., 2012; Santini et al., 2020; Thoits, 2011). Here, the significance and omnipresence of social relations in our everyday lives becomes clear once more: both previous and current social contacts, whether present or absent, were associated with how anxious the participants felt in a given moment. The relation of higher loneliness and isolation to higher state anxiety is in accordance with our hypotheses. Yet, LISD factors indicating general and acute social support (trait social closeness and support, state connected and supported) were not directly associated with lower state anxiety levels in the absence of social contact. This implication is in contrast to our hypotheses and previous findings of social buffering effects of social support (Cohen, 2004; Marroquín et al., 2020; Thoits, 2011) and should be validated in future studies.

To conclude, a reduction of imminent, fear-related responses may require social presence (study 1). In the absence of social contact, state anxiety levels may be buffered by other factors in relation to social contact, i.e., lower loneliness and social isolation as well as higher sociability and sense of belonging (study 3). Earlier findings showed that social buffering effects particularly emerge when social contact becomes more complex, e.g., through communication with varying interaction partners. Compared to social presence, social interaction was previously associated with stronger social buffering effects (e.g., provision of social support; Heinrichs et al., 2003; Taylor, 2011; Thorsteinsson & James, 1999). In line with this, study 2 examined components of everyday-life social interactions that led to differences in anxiety-related responses, revealing an especially influential role of gender.

3.2.2 The components of social contact

3.2.2.1 Gender and familiarity

Previous research has repeatedly shown gender-dependent social buffering effects (Kirschbaum et al., 1995; Phillips et al., 2009; Qi et al., 2021; Well & Kolk, 2008). This dissertation's first study could not provide implications regarding gender effects as we only measured female dyads (gender was not targeted, but controlled for). The inclusion of mixed-gender samples in the subsequent studies proved to be a valuable alteration. In particular, the results of study 2 underline the importance of considering the gender of both parties involved in social contact (participants and their interaction partners) when investigating social buffering effects.

Most previous findings on same-gender and opposite-gender social buffering emerged in laboratory studies in specific social settings or tasks (Glynn et al., 1999; Kirschbaum et al., 1995; Phillips et al., 2009; Qi et al., 2021). Study 2 sought to extend these laboratory findings by measuring various types of social interaction using EMA. The opposite-gender interaction partner effects revealed by study 2 are based on multiple assessments per participants collected in various social situations. Therefore, they are assumed to represent overarching gender effects on HR and HRV in our participants' everyday-life social interactions. This has implications regarding the inconsistent previous findings on gender effects, i.e., same-gender, female-gender, or opposite-gender social buffering effects (Glynn et al., 1999; Hahn et al., 2012; Monin et al., 2019; Phillips et al., 2009). Possibly, same-gender and female-gender effects observed in previous studies emerge only in specific social situations, such as an anxiety-inducing situation requiring social support (Glynn et al., 1999; Phillips et al., 2009). It has been suggested that women are more likely to give and to perceive social support, and that social support provided by women may be more efficient (Monin et al., 2019; Taylor, 2011; Thoits, 2011), which could lead to response-buffering effects of female compared to male interaction partners in the context of social support. In contrast, in social contexts in which physical attraction plays a role, opposite-gender interactions may be more arousing and anxiety-inducing than same-gender interactions (Beidel et al., 1985; Hahn et al., 2012; Powers et al., 2006). It is possible that study 2's observations also encompassed specific situations where such gender effects were present (e.g., anxiety-reduction by female interaction partners in social situations aiming for the reception of social support), but that these effects were not strong enough to alter the overall opposite-gender buffering effect. Future EMA studies on social interactions should therefore examine potential context-dependent deviations from the overall opposite-gender effect by testing whether the social context (e.g., a situation requiring social support, being on a date, having lunch with a colleague) interacts with the gender of the persons involved. For now, however, the results of study 2 together with previous findings indicate that opposite-gender social buffering effects represent a phenomenon present in both lab and life, whereas other gender effects found in laboratory settings such as same-gender social buffering effects may not extrapolate to everyday-life social interactions.

The presence of familiar others can enhance mental health and reduce anxiety (Eisenberger, 2013; Holt-Lunstad et al., 2003; Mascret et al., 2019). In this dissertation, the expected response-reducing effect of familiarity on subjective anxiety has been further established in a sample of young and healthy participants engaged in everyday-life social interactions. Furthermore, a novel finding extends previous research: the expected familiarity-related autonomic changes depended on gender, implying that the autonomic (but not the subjective) social buffering effect of familiarity is limited to women. This suggests that women could particularly profit from seeking out more familiar interaction partners, while they would also be more negatively affected by unfamiliar interaction partners (see also "3.4 Real-world applications"). Keeping in mind that anxiety and fear are closely related, the influential role of familiarity on female participants' anxiety-related responses in study 3 supports the assumption that the confederate's unfamiliarity (and female gender) could have contributed to the lack of social buffering effects on fear-related responses in the female participants in study 1. Here, the social condition only included female participants paired with an unfamiliar female stranger. Based on study 2 and previous laboratory-based research, it is plausible to hypothesize that social influence by a more familiar person would have resulted in social buffering effects like reduced pain (Krahé et al., 2013) and fear-related responses (Mascret et al., 2019). As study 2 targeted much more complex social situations and assessed anxiety rather than fear, the transferability of its findings to study 1 needs to be treated with caution. Nonetheless, future studies should test whether social influence by a more familiar person would result in the expected social buffering effects in the pain relief paradigm.

In contrast to the gender-specific findings of study 2, study 3 demonstrates a negligible role of gender in the prediction of state anxiety compared to the predictive strength of social distancing-related loneliness and social isolation. Despite a repeatedly reported higher prevalence of anxiety in women compared to men in previous research (Leach et al., 2008; McLean & Anderson, 2009), female participants did not show higher anxiety levels in study 3, and adding gender (alongside age and social distancing compliance) as a predictor of state anxiety to the five LISD factors did not improve model fit. However, other research conducted during social distancing (Marroquín et al., 2020) as well as other contexts in which social contact was lacking (Beutel et al., 2017) did find gender-specific differences in mental health, including higher anxiety levels in women. Similar to anxiety, study 3 also found no gender differences in loneliness and social isolation. Here, previous results are inconsistent as well. There are findings of higher loneliness in women than men (Beutel et al., 2017; Victor & Yang, 2012) including the context of social distancing (Hoffart et al., 2020), but other samples showed higher loneliness in men vs. women (Barreto et al., 2021), or no gender differences (Geirdal et al., 2021). The lacking impact of gender on anxiety and loneliness implied by study 3 should be validated in future research, e.g., using more fine-grained assessments via EMA.

3.2.2.2 Interaction medium

Although not the primary focus of studies 2 and 3, their results provide important data regarding the effect of in-person and virtual social contacts on anxiety-related responses. The majority of previous research on social buffering effects focussed on dyadic social contact taking place in person (e.g., Phillips et al., 2006; Qi et al., 2020; Well & Kolk, 2008). Nowadays, however, a growing number of social interactions takes place virtually, e.g., via phone and video calls, messaging apps, internet chats, or social media platforms (Chayko, 2014; Verduyn et al., 2021). While researchers and clinicians have expressed concerns regarding the potential health-reducing effects of internet and social media usage (Keles et al., 2020; Kelly et al., 2018; Primack et al., 2017), other studies suggested mental health-enhancing effects of virtual social contact (Naslund et al., 2016; Sahi et al., 2021; Shaw & Gant, 2004).

Similar to in-person contacts, virtual social interactions can lead to decreases in depression, anxiety, stress, and loneliness, as well as to increases in well-being and social support (Forsman & Nordmyr, 2017; Nabi et al., 2013; Shaw & Gant, 2004). However, previous findings suggested that social buffering effects are stronger in direct compared to virtual contacts (Kesselring et al., 2021; Schwerdtfeger et al., 2020) and that beneficial effects of face-to-face social interactions like increased social belonging and lower depressive symptomology may not transfer to virtual interactions (Sacco & Ismail, 2014; Weiß et al., 2022). In study 2 of this dissertation, the average subjective anxiety of participants was higher after virtual compared to in-person social interactions. At the same time, however, anxiety-related autonomic responses were more adaptive (lower HR, higher HRV) during virtual social interactions. Nevertheless, study 2's main analyses demonstrate that the gender and familiarity-dependent social buffering effects apply to both in-person and virtual social interactions. Exploratory analyses with extended interaction models also showed no difference between virtual and in-person social interactions in relation to the gender- and familiarity-related social buffering effects. The present findings are supported by recent studies showing buffering effects of more familiar interaction partners on subjective measures during virtual social interactions, including lower levels of negative affect and stress (Tibbetts et al., 2021), and implying that social support provided via virtual interaction may be as effective as face-to-face social support in reducing subsequent stress responses (Kothgassner et al., 2019). In today's digital age where virtual communication is frequently used in both private and job-related contexts (Meier & Reinecke, 2021; Naslund et al., 2020; Wang et al., 2020), it becomes increasingly important to define to what extent social buffering effects that were observed in in-person social contact can translate to virtual contacts. With study 2, we extend the scope of familiarity and gender-related social buffering effects to virtual social interactions.

Previous research stated that virtual social interactions could be an important substitute when in-person social contact is unavailable. Virtual interactions can provide access to social connection and support and thus protect against loneliness and mental health deprivations (Naslund et al., 2016; Shaw & Gant, 2004), at least as long as digital social tools are not used excessively (Dailey et al., 2020; Rosenthal et al., 2021; Shensa et al., 2016). Yet, study 3 does not provide evidence for a prominent role of virtual social contact in times of social distancing. Items from the original LISD scale referring to virtual interactions (e.g., "I maintain contacts via telephone/internet/app.") only showed low communality during EFA and were excluded. The low communality implied that variance regarding the use of virtual social interaction (as measured by these items) was only mildly associated with social distancing-related loneliness, social isolation, and related social factors (Hair et al., 2010). Other findings during the COVID-19 pandemic also showed none or inconsistent effects with respect to virtual interaction, particularly in comparison to the well-being and mental health-enhancing effects of in-person social contacts (Newson et al., 2021; Rudert & Janke, 2022; Sun et al., 2022). In contrast, other studies could find associations of more frequent virtual communication with lower levels of loneliness or higher levels of well-being and mental health during the COVID-19 pandemic (Meier et al., 2021; Sahi et al., 2021; Shufford et al., 2021). Integrating more aspects of virtual interactions including quantity, quality, aim, and involved interaction partners could provide valuable additional insights into the potential impact of virtual interaction on mental health-related factors. This could be achieved by use of EMA and/or advanced technological measures, such as app usage times for messaging, calls, and social media apps (Weiß et al., 2022; Wetzel et al., 2021).

3.2.3 Discrepancies between subjective and autonomic measures

This dissertation examined both subjective and autonomic anxiety-related responses. Anxiety and fear relate to cognitive and affective states as well as physiological changes (Hamm, 2020; Lonsdorf et al., 2017; Öhman, 2008). Moreover, impaired psychophysiological functionality and reactivity like threat-based cognitions and maladaptive physiological reactivity are important correlates of anxiety disorders (Hyde et al., 2019). Researchers and clinicians have thus repeatedly underlined the necessity to observe both subjective and autonomic correlates of fear and anxiety in order to achieve an integrative understanding of the mechanisms underlying and altering fear, anxiety, and their health-related consequences. This can in turn contribute to the development of diagnostic, preventive, and therapeutic measures (Hamm, 2020; Hyde et al., 2019). Multidimensional assessments are particularly relevant because subjective and autonomic (as well as behavioural) outcomes of fear and anxiety do not always converge. Increases in subjective anxiety may not be accompanied by increased physiological arousal, and physiological responses towards a threat may not correspond with conscious experiences and reports of increased fear or anxiety (LeDoux & Brown, 2017; Lonsdorf et al., 2017; Taschereau-Dumouchel et al., 2022). Likewise, researchers have found differential subjective and autonomic anxiety-related responses in the context of social buffering (Ditzen et al., 2008; Glynn et al., 1999; Kirschbaum et al., 1995; Phillips et al., 2009).

This dissertation also revealed discrepancies between subjective and autonomic indicators of fear and anxiety. Study 1 showed pain relief learning on an autonomic level but fear learning on a subjective level. These results correspond to previously found differences between changes in subjective and autonomic fear-related responses (Andreatta et al., 2012; Green et al., 2020; Haddad et al., 2012) and illustrate that there are different dimensions to fear which can be differentially affected by external factors and processes (e.g., painful stimulation, fear conditioning; Lonsdorf et al., 2017). In study 2, virtual social interactions led to higher reports of state anxiety but lower autonomic arousal (HR) than in-person social interactions. Here, too, differences in autonomic anxiety indicators did not correspond to subjective anxiety levels. The divergent subjective and autonomic responses during virtual interactions may partly account for previous inconsistent findings regarding mental health-related effects of virtual contact (Keles et al., 2020; Kothgassner et al., 2019; Primack et al., 2017; Tibbetts et al., 2021). Importantly, study 2 further revealed discrepancies in autonomic and subjective social buffering effects. Familiarity decreased subjective anxiety in all participants, but corresponding adaptive autonomic responses were only evident in women. At the same time, the opposite-gender social buffering effects emerged on the autonomic level only, whereas subjective anxiety was again unaffected by gender. These findings indicate that different social and personal factors affect diverse dimensions of anxiety during social contact. It has been suggested that such discrepancies in subjective and autonomic anxiety-related responses may be traced back to differential underlying neural processes, e.g., regarding conscious and non-conscious experiences of fear and anxiety (LeDoux & Brown, 2017; Savage et al., 2021). Other possible explanations include cognitive biases that may hinder the awareness of autonomic arousal, such as gender-related stereotypes and social norms regarding the behaviour of men or women in social groups. For instance, regarding study 2, a male participant may not admit to anxiety in social interactions with other men as he might want to fulfil stereotypes of masculinity (Cislaghi & Heise, 2020; Stewart et al., 2021). These assumptions are speculative, however, and need to be targeted in future research.

Taken together, the present findings emphasize the importance of considering both subjective and autonomic responses when investigating human emotion and experiences, including anxiety and related social buffering effects (Bradley & Lang, 2000; Pine & LeDoux, 2017). To combine diverse subjective and physiological assessments, the present works could be extended to other measures, including neural responses, to best understand social buffering (Hamm, 2020).

3.3 Methodology in lab and life: Lessons learned

This dissertation applied different methodological approaches to the investigation of social contact and its impact on anxiety-related responses. Over the course of my doctoral project, I was confronted with various advantages and challenges of each method. Key learning experiences and implications are outlined below.

Study 1 allowed for high experimental control. Still, the restrictive design of the laboratory paradigm also posed challenges. In the "lab", the experimental procedure should be comparable between conditions except for the construct of interest that is experimentally manipulated (Wilhelm et al., 2012). In our case, this construct was the influence on the occurrence of painful stimulation (a fear-inducing stimulus) by another person, oneself, or the computer. This manipulation was crucial to this dissertation's aim of investigating social buffering. However, including an additional person in the social-influence condition meant integrating (social) factors which would not be present in the other two conditions where no one else was involved. Characteristics of the confederate, like their gender (Qi et al., 2021), familiarity (Hornstein et al., 2016; Mascret et al., 2019), or the participant's sympathy towards her (Koenig et al., 2017) could produce additional social effects, both within the condition as well as compared to the other two conditions. It is possible that previous studies which did find effects of social presence overlooked confounding social factors such as verbal or non-verbal interactions between participants, confederates, and/or researchers prior to or during the procedure (Kikusui et al., 2006; Krahé et al., 2013). To keep these influences at a minimum, we included the same young woman as confederate, prevented interactions between participant and confederate (greeting only), and seated them in separate rooms. The resulting high internal validity and comparability between conditions strongly support study 1's implication that mere social involvement does not suffice for producing social buffering effects. Despite this valuable strength, I learned that the reduction of social confounders also reduced the social extent of the social-influence condition. In "real life", social contact is much more complex (Junghaenel & Stone, 2020). Our decisions in favour of internal validity may thus have undermined social buffering effects as well as the external validity of our results as they came at the cost of the extent and authenticity of the social setting. Furthermore, study 1 focussed on fear-related responses to a specific stimulus. Turning towards social buffering in daily life, anxiety might be a more appropriate indicator of social buffering in everyday-life social experiences without experimental control and with more contextual influences, given that it represents a more diffuse and longer-lasting threat response (LeDoux & Pine, 2016; Öhman, 2008). As a consequence, I would adapt study 1's paradigm in future research to include a "more social" condition and examine changes in subjective anxiety as well as fear. Such a paradigm could encompass a more familiar interaction partner and/or a confederate that is present in all conditions, including the self-influence and no-influence condition (e.g., another person supposedly undergoing the same procedure). Moving forward in my doctoral project, however, the limited external validity of study 1's social condition and social setting as well as the potential relevance of additional social factors supported the decision to use EMA for the investigation of anxiety-related responses in more complex and authentic everyday-life social interactions.

Study 2 demanded a considerable amount of devotion and time to penetrate the complexity of planning, executing, and analysing an EMA study. EMA's numerous advantages, including their fine-grained observations and high ecological validity, demand substantial commitment and resources (Junghaenel & Stone, 2020; Wilhelm et al., 2012). EMA studies, particularly those including physiological measurements, require thorough planning and implementation of the study procedure, adequate measures to support sufficient compliance and motivation of participants (e.g., careful design of EMA survey length and items), and a tolerance for data loss. Oftentimes, they also call for technologically advanced and comparatively costly materials. While providing invaluable possibilities for within- and between-person analyses, the complex psychophysiological EMA data sets demand sophisticated data curation and statistical analyses like linear mixed modelling to account for their hierarchical multi-layered structure and missing data (Conner & Mehl, 2015; Junghaenel & Stone, 2020; Wilhelm et al., 2012). Finally, data collection itself takes time: seven days were needed per participant (pre-session, 5-day smartphone assessment, post-session), and the number of concurrent assessments was limited by the study material (five ECG sensors). In hindsight, the effort was worthwhile because study 2 provides novel evidence of gender-specific social buffering effects in everyday-life social interactions won from fine-grained, ecologically valid observations of both cognitive and autonomic anxiety responses. Participants from study 2 reported acceptable participant burden and showed high compliance across the five-day assessment. Based on our participants' feedback, the burden could be further reduced in the future by installing the survey app on the participants' smartphone rather than a study smartphone (given sufficient data protection; Burke et al., 2017). As most German households own a smartphone (88.1% in 2022; Statistisches Bundesamt, 2022), this would be a feasible alteration without extensive risk for selection bias. Lastly, note that most previous research on social buffering effects has focused on between-person effects, such as the provision of social support by persons of different genders (Glynn et al., 1999), or the interaction with familiar vs. less familiar social partners (Eisenberger, 2013). Study 2 demonstrated that there is more to social buffering than mere between-subject effects, as its results and implications are based on both within and between-subject comparisons of various social situations. In sum, the chosen study design and length were successful, and the modern methodology of EMA was confirmed as a valuable opportunity to take psychosocial research from lab to life.

Study 3 was designed and conducted during the first year of the COVID-19 pandemic, where social distancing measures restricted physical contact between individuals (Benke et al., 2020; Marroquín et al., 2020). This presented a unique opportunity for investigating anxiety and related social factors during limited social contact in daily life without experimental manipulation. As the social contact restrictions also hindered contact between researchers and participants, our online surveys provided a convenient and economic alternative to both EMA and laboratory research. Thanks to established online platforms (e.g., soscisurvey.de, surveymonkey.com), online surveys are comparatively easy to set up. However, although being well-suited for our purposes of collecting everyday experiences in a context of social restrictions, challenges arose from the online surveys' restricted experimental control. We could control for speeding and inattentiveness, but not for other confounding factors like distracting background noises (Maniaci & Rogge, 2014). Another demanding task was the recruitment of representative samples. The EFA sample was recruited in the areas of three German cities. We enhanced heterogeneity and external validity by restraining from age restrictions (apart from mandatory adulthood) and using different recruitment media, but the restriction of data collection to local regions still limited the sample's heterogeneity. As a consequence, we decided to collect the CFA sample on a Germany-wide participant recruitment platform. The more diverse second sample (e.g., regarding location and educational level) enhanced the generalizability of our findings. However, a sample with an equal gender distribution could have provided more conclusive results regarding gender-related effects. Note also that the scale validation required cross-sectional data collection in two independent samples. While this allowed for interesting indications on a correlational level, we cannot derive causational conclusions regarding the relationship between anxiety and loneliness-related factors. These issues could be resolved in future longitudinal study designs with equal gender distributions (Krosnick et al., 2014; Maniaci & Rogge, 2014). Nevertheless, the online surveys allowed us to collect data from relatively heterogeneous subclinical samples, which is not as easily achievable with in-person data collection, particularly when social contact is restricted.

In conclusion, all three methodological approaches applied in this dissertation comprised advantages, challenges, and disadvantages. EMA emerged as the most promising method, while inflicting the least limitations regarding the assessment of authentic social contact. This does not mean that laboratory and online designs are inferior to EMA in all respects. Instead, based on previous works and my personal experiences, they should be complemented with EMA to provide a more detailed and ecologically valid insight into the respective construct of interest.

3.4 Real-world applications

3.4.1 Reducing anxiety in everyday life

Overall, this dissertation emphasizes the significance of social contact for mental health. Social buffering effects found in studies 2 and 3 as well as previous works can be regarded as support for advantageous effects of social contacts in daily life (Eisenberger, 2013; Hennessy et al., 2009; Taylor, 2011), while their absence and related social isolation and feelings of loneliness can have detrimental effects (Beutel et al., 2017; Lee & Cagle, 2017).

Summarizing implications outlined above, study 2 indicates that anxiety reductions in everyday-life social interactions could be achieved by seeking out familiar interaction partners. This may be particularly effective in women, where familiar interaction partners should buffer autonomic as well as subjective anxiety-related responses. For men, social contacts to reduce autonomic responses should preferably involve female interaction partners. Moreover, study 3 implies that when social contact is limited or absent in daily life, sociable and socially integrated individuals should show lower anxiety levels. In everyday life, the LISD scale could serve as a convenient tool to reveal individuals at risk for elevated anxiety levels: those high in state and trait loneliness and social isolation, and those low in trait sociability and sense of belonging. Based on study 3's results, preventive measures against anxiety during limited social contact in everyday life could target loneliness-related aspects, particularly state loneliness and isolation and trait sociability and sense of belonging. There are a variety of measures previously shown to reduce loneliness and isolation and enhance social belonging that are applicable in daily life, such as physical exercise (Dowd et al., 2014; Shankar et al., 2011), engagement in virtual interactions (Sheridan et al., 2015; Thoits, 2011; Williams et al., 2021), and pet ownership (Bussolari et al., 2021; Gee & Mueller, 2019). However, to support their potential usefulness, a longitudinal study design should first determine the causational relationship between the LISD factors and state anxiety to clarify whether measures for decreasing loneliness and isolation could prevent increases in anxiety (and depression), or whether interventions aiming for anxiety reduction (e.g., psychoeducation, behavioural training; Bandelow et al., 2017; Kaczkurkin & Foa, 2015) could reduce loneliness and isolation.

3.4.2 Clinical significance

The implications for everyday life reported above ought to be tested in clinical samples. If replicated, the social buffering factors revealed in this dissertation could represent promising targets for therapeutic interventions. Given the high comorbidity of anxiety disorders with other psychiatric disorders (Kessler et al., 2015; Newby et al., 2015), the inclusion of anxiety-reducing factors of social contact into anxiety disorder treatment could also result in other symptom reductions, including depressive symptoms (Daniel-Watanabe & Fletcher, 2021; Hamm, 2020).

The subclinical samples of studies 2 and 3 did not show gender differences in overall state anxiety levels. Yet, previous research with patients suffering from anxiety disorders has repeatedly shown more severe symptoms and illness-related impairment in women compared to men (Christiansen, 2015; McLean et al., 2011). This leads to the interesting question whether the gender-related social buffering effects on anxiety-related responses in study 2 also apply to samples with more severe anxiety levels. Previous clinical findings already suggest a role of gender in the context of anxiety, related disorders, and their treatment. For instance, women paired with male therapists were less likely to drop out of therapeutic intervention than men paired with male therapists (Cottone et al., 2002; Korobkin et al., 1998). Findings on therapist and client gender effects on therapy outcome were inconsistent, with some studies finding stronger symptom reductions for female therapists (in both male and female patients; Bhati, 2014; Kirshner et al., 1978), for same-gender therapists, or no gender effects on therapy outcome (Bohart & Wade, 2013; Huppert et al., 2001; Miller et al., 2013). Moreover, to the best of my knowledge, familiarity effects of therapists and other patients have not yet been the focus of clinical research. An investigation of study 2’s social buffering effects in a clinical sample could hence provide valuable new insights. For instance, the successful clinical replication of the familiarity-related social buffering effects would imply that more involvement of familiar everyday-life social partners into therapeutic treatment could help reduce anxiety-related responses, including women's cardiovascular responses. Possibly, enhancing the familiarity of therapists and fellow patients (e.g., by repeated meetings and/or the sharing of personal information) could also lead to reductions in anxiety. Note that interventions for anxiety disorders aim to provide help for potentially anxiety-inducing situations, e.g., through psychoeducation and cognitive and behavioural training (Bandelow et al., 2017; Kaczkurkin & Foa, 2015). Given a replication of study 2 in a clinical sample, interventions for women could target tools and strategies to reduce anxiety responses during social interactions with less familiar and/or female interaction partners (i.e., the more anxiety-inducing interaction partners). For men, mixed-gender social interactions may be particularly beneficial.

The relationship between loneliness-related factors (included in the LISD scale) and mental health should also be validated in clinical samples with higher anxiety levels. Loneliness and social isolation are well-known risk factors for anxiety and depression (Beutel et al., 2017; Masi et al., 2011). If the relationship between loneliness and state anxiety detected in study 3 was replicated and its causality clarified, interventions for the reduction of anxiety when social contact is absent could specifically integrate loneliness-related measures (or vice versa, depending on the causational relationship). Again, the LISD scale could serve as a short and economic assessment tool to identify individual factors that enhance the risk of higher anxiety levels in a patient. This assessment could even be achieved online without the need of an in-person meeting, which could be of particular use in patients that are highly isolated due to somatic illnesses (Abad et al., 2010; Kersun et al., 2013).

Finally, another interesting question for social buffering-related clinical research is the potentially substitutional role of virtual social contact when in-person social contact is lacking (Baker et al., 2018; Banerjee & Rai, 2020; Naslund et al., 2016). Recent discussions stemming from the unique contact restrictions during the COVID-19 pandemic concern the transferability of in-person therapeutic interventions to virtual settings like Skype or Zoom calls (Simpson et al., 2021). The demand for and application of virtual/remote therapy increased, and recent studies reported either comparable or lower effectiveness of virtual vs. in-person interventions (Inchausti et al., 2020; Puspitasari et al., 2021; Smith et al., 2020). Keeping in mind the important role of gender and familiarity in both in-person and virtual social interactions implied by study 2, future clinical studies should investigate social buffering effects of familiarity and gender on anxiety in offline and online therapeutic interventions. If the social buffering effects of study 2 also applied to virtual interactions in clinical patients, virtual interaction and/or treatment could provide an economic intervention method for anxiety reduction.

3.5 Limitations

Before presenting the general outlook and conclusions of this dissertation, I need to point out some limitations in addition to the method-related challenges discussed above.

Firstly, while fear and anxiety are closely related, they are not the same (Daniel-Watanabe & Fletcher, 2021; LeDoux & Pine, 2016; Öhman, 2008). Their conceptual differences should hence always be considered when comparing fear-related responses like in study 1 with anxiety-related responses like those of studies 2 and 3. Social buffering effects on fear-related responses do not necessarily apply to anxiety-related responses and contexts, and vice versa. Accordingly, assumptions drawn between fear and anxiety-related findings (e.g., the unfamiliarity of the social partner may have prevented social buffering effects in study 1) should be treated with caution and need to be validated in future studies.

Secondly, study 1 did not include male participants or confederates and thus cannot provide implications regarding potential opposite-gender social buffering effects as evident in study 2 and previous research (Kirschbaum et al., 1995; Monin et al., 2019; Phillips et al., 2006; Phillips et al., 2009). It is possible that social involvement would have led to social buffering in opposite-gender pairings (male participants with female confederates, female participants with male confederates). This assumption could be validated by future studies with diverse gender pairings. Apart from the social manipulation, social buffering in study 1 could also have been prevented by the choice of fear induction (painful stimulation with air-pressure). Possibly, the fear induction was not strong enough to require social buffering effects on fear-related responses, or not intense or long-lasting enough to affect subsequent relief responses (Hostinar et al., 2014; Leknes et al., 2008; Lonsdorf et al., 2017). Future research should consider similar experimental settings with different gender constellations, alternative pain stimulation, increased intensity or duration of the aversive stimulation, or even an alternative fear induction method (e.g., visual or auditory stimuli).

Thirdly, study 3's investigation of loneliness and social isolation and their relation to state anxiety was limited to the context of COVID-19-related social distancing. The COVID-19 pandemic is known to have had a broad negative effect on humans' social lives (Kovacs et al., 2021; Long et al., 2022) as well as their physical health, mental health, and overall well-being (Fiorillo & Gorwood, 2020; Leung et al., 2022). This could reduce the valid extrapolation of the present results to other contexts of limited social contact. Consequently, the LISD scale and its relation to anxiety should be validated in different contexts of limited social contact (e.g., social distancing measures in response to epidemics, isolated hospital visits due to illness). Note also that study 3 did not include autonomic measurements due to the social distancing-related restrictions which prevented contact between participants and researchers. Future research should examine how the LISD factors relate to autonomic anxiety-related responses such as HR and HRV. Such studies should also inspect the coherence between subjective and autonomic measures of anxiety in the context of limited social contact (see "3.2.3 Discrepancies between subjective and autonomic measures").

Fourthly, there are factors that could further increase experimental control in studies 2 and 3. For instance, researchers have discussed the benefits of controlling for respiration (Quintana & Heathers, 2014) and speech (Beda et al., 2007; Houtveen & de Geus, 2009) when investigating HRV and HR. The physiological correlates of speech could result in higher autonomic activity during in-person compared to virtual written interaction. As a solution, future studies' ECG analyses should additionally control for the influence of respiration rates assessed by sensors (Quintana & Heathers, 2014) and verbal speech, e.g., captured by mobile sensing (Harari et al., 2017; Wang et al., 2018). Regarding study 3, important limitations include the online surveys' lack of control over distracting noise, persons nearby, and other contextual factors which could influence the (in)attentiveness and (un)disturbedness of participants (Maniaci & Rogge, 2014). To solve this, additional items assessing contextual factors (e.g., current location, persons nearby) could be included into the surveys and analyses. Smartphones could provide more objective measures through mobile sensing (Harari et al., 2017), but this would exclude computer-based assessments. Alternatively, voice or video calls with the experimenter during survey completion could provide additional control (Perry et al., 2021).

Fifthly, research on gender effects is often limited to binary gender categories (female and male; Heck et al., 2017), and many previous findings on opposite-gender social buffering effects were derived from dyads with heterosexual romantic partners (Kirschbaum et al., 1995; Monin et al., 2019; Phillips et al., 2006). This dissertation also focussed on binary gender categories, guided by an enhanced comparability to previous studies. However, the neglect of diverse gender identifications and sexual orientations often present in gender-related research could produce biased findings. For instance, given the potential role of physical attraction (Beidel et al., 1985; Hahn et al., 2012), it is not unlikely that opposite-gender social buffering effects from research with heterosexuals do not apply to homosexuals. The consideration of all gender categories and sexual orientations would therefore enrich gender-related investigations of anxiety and social contact (Heck et al., 2017; Richards et al., 2016; Thorne et al., 2019). Fortunately, inclusion of diverse gender categories and sexual orientations into research is growing (Badgett et al., 2021; Scandurra et al., 2019). For example, recent social distancing-related studies with sexual minorities revealed lower psychosocial well-being compared to heterosexuals (Baumel et al., 2021) as well as reduced mental health symptoms in relation to lower levels of social support and integration (Jones et al., 2021).

Lastly, although participant recruitment included broad public advertisement, the majority of participants in studies 1 and 2 as well as study 3's EFA sample were university students. This can be traced back to the main location of the research (27% of the population in the city of Würzburg, Germany are university students; Zeit Campus, 2022) as well as the age span of studies 1 and 2 (18-35 years) which was set to limit age effects on autonomic responses, i.e., SCR (Barontini et al., 1997; Gavazzeni et al., 2008), HR (Umetani et al., 1998; Valentini & Parati, 2009), and HRV (Quintana & Heathers, 2014; Shaffer & Ginsberg, 2017). To enhance their generalizability, the present results should be complemented by studies with other samples, e.g., differing in age as well as socioeconomic and educational backgrounds. For instance, follow-up projects of study 2 target the effects of social interactions in adult psychiatric (affective and anxiety disorders) and chronic pain patients (Bortezomib-induced peripheral neuropathy, complex regional pain syndrome) without age limitations and with age-matched healthy control groups.

3.6 Outlook

This dissertation provides important suggestions for future studies on social buffering effects with subclinical and clinical samples. Main indications for future research already outlined above include alterations to the social setting of study 1 (e.g., gender of the social partner), the consideration of additional context and personal factors in study 2 (e.g., aim of the social interaction), and longitudinal assessments to determine the causational relationship between loneliness-related factors and state anxiety during limited social contact (study 3). Returning to the main results illustrated in Figure A, future research should examine those paths which remain unexplored, including the effects of limited social contact on autonomic responses, the role of gender during mere social involvement, and moderating effects of additional social factors.

The social buffering-related implications of studies 2 and 3 require validation in clinical samples. Note that previous anxiety-related investigations often included active anxiety or fear induction. Yet, in clinical samples with patients suffering from severe anxiety disorders, extra fear or anxiety inductions could deteriorate the already deprived mental or physical health of the participants and should therefore be avoided (Raugh et al., 2019). In the context of study 2, it could hence be worthwhile to additionally capture specific anxiety-inducing contexts that occur in daily life. For instance, EMA assessments could encompass social interactions during or following the occurrence of a panic attack in patients suffering from panic disorder (Helbig-Lang et al., 2012). In the context of social distancing, events of interest could be an upcoming operation in socially isolated patients (Bailey, 2010). Such event-specific assessments of social contact and its anxiety-buffering factors could provide additional implications for preventive and therapeutic measures.

Based on the present as well as previous research, EMA shows great potential for future clinical investigations of anxiety-related social buffering effects. It enables researchers and clinicians to measure symptoms of interest when they naturally occur, such as experiences of social anxiety patients while or after being exposed to distressing social situations in daily life (e.g., public speaking; Helbig-Lang et al., 2016). The high ecological validity of such real-life investigations is of high value to clinical research and practice, since a central aim of clinical and therapeutic intervention is improved functioning and well-being in patients' everyday lives (Kazdin & Blase, 2011; Kolovos et al., 2016). In the opinion paper published throughout the earlier stages of my doctoral project(Appendix A; Gründahl et al., 2020), we have outlined that Ecological Momentary Interventions (EMI) show great promise for therapeutic interventions and clinical research. Using EMA methodology, EMI provide psychiatric treatment in daily life, e.g., through tailored interventional programs conveyed via smartphone apps. They can also serve as an assessment tool, for instance by collecting mood and anxiety levels of patients across long periods of time (Linardon et al., 2019; Myin-Germeys et al., 2018; Myin-Germeys et al., 2016; Van Ameringen et al., 2017). EMA and EMI further present vast opportunities for research and intervention in regard to social buffering effects. Smartphones, which enable voice and video communication, could be utilized to initiate social interactions, both with daily life social contacts and with researchers or clinicians. Moreover, mobile sensing and app tracing can directly capture the occurrence of virtual interactions (e.g., telephone calls, messenger chats; Weiß et al., 2022; Wetzel et al., 2021), while voice functions can objectively assess in-person conversations taking place in proximity to the smartphone (Harari et al., 2017;

Wang et al., 2018). Again, a combination of smartphone-based EMA and EMI with psychophysiological assessments could bring further insight into the relationship between subjective and autonomic anxiety-related responses. In conclusion, I strongly encourage the use of EMA and EMI in future clinical studies and practice to comprehensively validate the implications inferred from previous and this dissertation's studies in clinical samples, and to investigate and provide social buffering-related interventions to anxiety patients (e.g., access to opposite-gender social interactions; loneliness interventions during limited social contact).

Without doubt, researchers should continue to validate laboratory findings in everyday-life settings. In turn, they could take research "from life to lab" to validate implications of EMA studies in a setting with higher control regarding confounding variables (Wilhelm et al., 2012). While external validity and social authenticity would decrease in comparison to EMA research, an important advantage of a laboratory-based validation would be the enhanced control regarding confounding contextual factors and autonomic measurements (Boucsein, 2012; Quintana & Heathers, 2014; Raugh et al., 2019). Concerning this dissertation, a replication of study 2's gender- and familiarity-dependent social buffering effects under more controlled circumstances would strengthen their real-world implications. Physical and contextual factors like movement, consumption of food or alcohol, background noises, and visual stimuli could be controlled for through standardized instructions and assessment locations. Complex and carefully designed paradigms would be needed to create authentic and valid social interaction situations whilst keeping the social interactions reproducible and similar between conditions and participants, e.g., when integrating multiple interaction partners differing in familiarity and gender. Researchers could manipulate familiarity through tasks (e.g., sharing personal information), or include different interaction partners from the participants' real social network (e.g., friends, colleagues). Standardized interaction instructions, e.g., concerning the duration and topic of conversation, could enforce comparability between conditions. Alternatively, EMA could also be combined with an online paradigm. As shown in previous research, laboratory paradigms with social manipulations can be programmed and conducted as online studies (see e.g., Iotzov et al., 2022; Voit et al., 2021). Social interaction settings can be constructed online by use of modern communication technology like computer and smartphone-based microphones and cameras (Perry et al., 2021). Video communication between researcher and participant could again provide control regarding contextual and other confounding factors. Still, experimental control would be lower in online vs. laboratory research, as factors like the location of the assessment cannot be standardized (Maniaci &

Rogge, 2014). If, however, a laboratory setting is not possible (e.g., due to contact restrictions), EMA or laboratory research translated into online settings could depict a valuable and economic alternative.

In sum, based on my experiences throughout this doctoral project, I recommend future research to strive for the investigation of social contact and its subjective and autonomic anxiety-related effects in healthy as well as clinical samples and in diverse social settings. Multimethod approaches with different psychophysiological measurements and experimental approaches have great potential for providing more extensive and conclusive insights into the concept of social buffering.

3.7 Conclusion

Throughout this dissertation, I investigated human social contact and its impact on anxiety and related autonomic responses in different social settings (see Table A, Figure A). The results once again underline the influential role of social contacts in our daily lives (Cacioppo & Cacioppo, 2014; Frith & Frith, 2007). Social contact is frequent in healthy individuals' everyday life and can buffer or enhance anxiety-related responses depending on specific social interaction partner characteristics (study 2). When social contact is lacking, humans feel lonely and isolated, which in turn is associated with higher state anxiety levels as reported in online questionnaires. Here, general sociability and sense of belonging might buffer anxiety (study 3). In contrast to more complex interactions, social involvement without direct physical presence or communication does not result in social buffering effects (study 1).

In the long run, if externally validated with additional variables and in clinical samples, the social buffering effects found in this dissertation could be integrated into everyday life and outpatient psychiatric interventions, e.g., implemented via smartphone-based EMI. Treatment could be tailored to characteristics of the individual (e.g., their gender) and other persons involved in their social contacts (e.g., family members, clinicians). In addition, the mental health-enhancing effects of social contact could be more thoroughly integrated into daily routines and psychiatric prevention and intervention, for instance, by enforcing the occurrence of anxiety-reducing social contacts (e.g., with the opposite gender). Researchers and clinicians could determine and target anxiety-enhancing situations more specifically. For instance, they could provide support and anxiety-reducing strategies for women, especially when interacting with unfamiliar and/or female interaction partners. When social contact is limited, the LISD scale could be consulted to identify protective and risk factors for elevated anxiety levels, which could in turn be targeted by preventive measures and interventions.

By taking research from lab to life, the experimental studies presented in this dissertation considerably expand the understanding of the diverse effects of social contact on subjective and autonomic anxiety-related responses. While exposing limits of social buffering in a minimalistic social setting, the present findings also demonstrated the presence of social buffering effects in everyday-life social interactions in dependence of the gender and familiarity of the persons involved, and discovered anxiety-buffering factors even when social contact was restricted. On the whole, this dissertation demonstrates the magnitude of social buffering, a concept which is key to human existence.

4 References

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Appendix A: Opinion paper

Three Questions to Consider Before Applying Ecological Momentary Interventions (EMI) in Psychiatry

Marthe Gründahl[1], Jürgen Deckert[1], Grit Hein[1]

[1]Translational Social Neuroscience Unit, Department of Psychiatry, Psychosomatics and Psychotherapy, Center of Mental Health, University of Würzburg, Würzburg, Germany

Corresponding author:

Marthe Gründahl, Translational Social Neuroscience Unit, Department of Psychiatry, Psychosomatics and Psychotherapy, Center of Mental Health, University of Würzburg, Margarete-Höppel-Platz 1, 97080 Würzburg, Germany. Email: Gruendah_M@ukw.de

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Introduction

The umbrella term Ecological Momentary Intervention (EMI) labels a group of methods that provide clinical treatment via mobile devices in individuals' daily lives. The development and application of EMI are continuously increasing (1–3), related to the emergence of smartphone apps and the widespread availability of the internet (4, 5). Today, EMI applications are offered as treatment of various different psychological and psychiatric disorders including anxiety disorders, depression, obsessive-compulsive disorders, and posttraumatic stress disorders (2, 4, 6). EMI are often based on clinically evaluated psychotherapeutic treatments, e.g., cognitive behavioral therapy (CBT) (2), and apply therapeutic activities, assignments, and skills outside the clinical/therapeutic setting, i.e., in individuals' natural environment (7, 8). There are estimates that 70–85% of US citizens in need of mental health care do not receive it, and that these numbers might even be higher worldwide (9). EMI has the potential to reduce this treatment gap by providing interventions to individuals with little or no prospects of receiving regular clinical, face-to-face treatment. By providing wider access to mental health care, EMI may have financial benefits, potentially reducing the need for clinical care and hospitalization. Finally, EMI allows clinicians to monitor and individualize a therapeutic intervention, with patients actively included in the treatment process, thus resulting in higher treatment compliance and better interaction between patients and clinicians (10).

With all the potential benefits of EMI in mind, we propose that clinicians should ask the following three questions before integrating EMI into the therapy of psychological and psychiatric disorders. 1) Is the efficacy of the EMI application proven by randomized controlled trials, as per the criterion for all accredited therapies (especially those covered by health insurance)? 2) Does the EMI application consolidate the effects of face-to-face therapy, for example by reducing the risk of relapse? 3) Does the EMI application provide additional measures of therapy outcomes that are more accurate than traditional evaluation methods (e.g., clinical interviews and questionnaires)?

Evidence from randomized controlled trials

Randomized controlled trials (RCT) are seen as the gold standard in medical research that should be applied to all treatment methods to prove their efficacy [(11, 12) but see Grossman and Mackenzie (13) for a critical approach]. In RCTs, patients are randomly assigned to an experimental group that receives a certain treatment, or one or more control groups that receive a placebo or no treatment. The power of the conclusions gained from an RCT depends on the quality of the placebo treatment. In the ideal case, the control group receives a non-potent treatment that otherwise is identical to the experimental group. Regarding EMI applications, most RCT studies compared experimental groups that receive EMI treatment [usually combined with "therapy as usual [TAU]" or at least weekly face-to-face feedback (14)] and control groups that only receive TAU (15, 16).

A recent systematic review of EMI applications for major depressive disorder (MDD) by Colombo et al. (5) included seven EMI studies. The authors argue in favor of EMI's clinical efficacy and feasibility in treating MDD. However, the review only included four different EMI, and only two RCTs on their efficacy (5). Thus, the generalizability of these findings is questionable. A meta-analysis by Linardon et al. (4) included more data and a statistical analysis of effect sizes. Based on 66 RCTs of mental health EMI applications in clinical and non- clinical samples, they reported a reduction of stress and depressive and anxiety symptoms with small to medium effects (Hedge's g between 0.28 and 0.58). Such evidence suggests that EMI applications can indeed have systematic effects on important aspects of mental health (4). Given that they are effective, it is now crucial to understand which components of the EMI drive the effect. Most of the existing popular EMI applications for depression and anxiety include a variety of treatment components such as psychoeducation, assessment, relaxation, mindfulness, and meditation (17). Some of the individual components have been proven effective in isolation, but it is unclear if they drive the overall effect of the EMI application and how they interact with the other components.

To understand the mechanism behind EMI effects, RCTs need to systematically test the effect of individual components against each other. For example, Burton et al. (15) found a reduction of depression symptoms through regular use of an EMI application ("Help4Mood") in which patients interact with a customized virtual agent that guides them through daily mood questionnaires (15). To specify this effect, a group of patients using the current EMI version (virtual agent plus daily mood reflection) should be compared with patients that interact with the same virtual agent, but answer neutral questions that are unrelated to psychiatric symptomes.

Notably, it has been suggested that RCTs may not be the gold standard for the evaluation of increasingly smartphone-based EMI (3) because of their long duration and high financial costs (6, 18). However, given that a successful evaluation in RCTs is required before the official release of other medical treatments, these standards should also be applied to EMI.

Evidence for consolidation of face-to-face therapy effects

Face-to-face therapy is efficient in treating current psychiatric symptoms, for example in reducing depression or anxiety at the time of the consultation. However, maintaining these effects and preventing relapse is challenging (19). Because they can be integrated into patients' everyday life, EMI applications have the potential to consolidate face-to-face treatment effects, to prevent relapse and thus to increase the periods between face- to-face consultation (4, 7, 20). Up to this point, evidence for the efficacy of EMI in preserving face-to-face therapy effects is scarce (21–23).

There are some follow-up investigations on internet-based and smartphone-based EMI (4). For instance, a review by Andersson et al. (21) investigated 14 studies (n = 902) on internet-based, guided EMI with Cognitive Behavioral Therapy (CBT) elements for mental health improvement, with follow-up assessments between 2 and 5 years. They reported an average 50% symptom improvement from baseline and large within- group effects, with a pre- to follow-up effect size of Hedge's g = 1.52. However, the included studies and their effect sizes were heterogeneous, and overall results might thus be overestimated. Välimäki et al. (20) investigated effects of internet-based EMI on stress, depression, and anxiety in youth. Fifteen RCTs (n = 4979) were included into meta-analysis. Results suggest short-term improvement of mental health and reduction of depression and anxiety, but were questionable regarding long-term effectiveness due to a limited number of follow-up assessments. Only two studies reported significant long-term (>6 months) improvement of depression symptoms, while no mid- or long- term effects were evident for anxiety, mood, and feelings (20). More follow-up assessments are needed.

Long-term effects of EMI apps have mainly been assessed in relatively short follow-up periods of 4 weeks to 3 months (4, 24). However, there are single studies with promising long-term results. A small study on the combination of a well-being app and face-to-face counseling in university students (n = 38) with moderate anxiety or depression showed clinically relevant reductions in symptoms that were still evident after 6 months (25). Economides et al. (19) investigated long-term effects of an EMI app ("Ascend") with evidence-based treatment components in 102 patients. They found anxiety-reducing effects to last up to 6 months (Hedge's g = 0.91), and depressive-reducing effects to last up to 12 months after the initial 8-week EMI treatment (Hedge's g = 1.14). Notably, these results show uncontrolled effect sizes and would have greatly profited from the comparison to a control group, i.e., an RCT.

Overall, the length of follow-up periods varies greatly and is often considered too short (4, 21, 26), resulting in a lack of sufficient evidence on EMI long-term treatment effects. Moreover, there is a lack of longitudinal studies that compare the effects of face-to-face treatments with the effects of the same face-to-face treatments in combination with EMI.

Optimization of therapy outcome measures

Currently, the efficacy of EMI applications is mostly evaluated based on patients' self-reports and thus not different from the evaluation of classical face-to-face therapies. In most cases, questionnaires or reports on mental health outcomes are filled in prior to and after the intervention (e.g., 27, 28), sometimes with additional follow-up assessments (e.g., 19, 29). While self- reports are necessary to gain insights into the subjective perception and evaluation of symptoms, they are potentially confounded by biases (30). For example, there is a response bias in favor of positive responses (i.e., acquiescence, saying "yes") compared to negative responses (saying "no"; 31, 32). Moreover, patients may feel obliged to indicate a reduction of symptoms after the EMI to justify their own effort or to please the clinician (e.g., 31, 32).

It is well known that the onset and symptomology of mental health disorders like depression and anxiety are associated with various biomarkers (35). For example, MDD is associated with decreased high frequency heart rate variability (HF-HRV), both at rest and in response to challenges (36); increased cortisol levels during stress recovery (37); and decreases in skin conductance (38). Anxiety disorders, too, are associated with decreased HF- HRV (36). They also relate to high sensitivity of skin conductance to general anxiety change. Phobias are particularly associated with high cardiovascular activity (38). In combination with self-reports, these and other biomarkers can predict the onset and severity of psychiatric conditions (5, 39), and thus should be used to verify therapy outcomes.

A small-sampled clinical EMI study on stress and anger management in veterans (27) used mobile cardiovascular and electrodermal measurements to indicate physiological stress. Both the control group (n = 6) and the experimental group (n = 10) received standard CBT for 8 to 10 weeks. An EMI app with physiological stress assessment (skin conductance, heart rate, cortisol) was integrated into the experimental group's CBT. If stress was detected, the app initiated an alert and presented exercises for stress reduction. Results suggest that the combined vs standard intervention was more efficient in reducing stress, anxiety, and anger. Notably, however, only 4 experimental and 3 control participants completed follow-up assessments (27).

Botella et al. (40) investigated the feasibility and efficacy of an internet-based CBT-EMI for the prevention and treatment of depression and adjustment disorders in 60 unemployed men at risk of developing depression. The sensor group (n = 19) received 6 to 10 weeks of EMI with additional physiological and activity sensor assessment (electrocardiography, electroencephalography, and actigraphy) providing graphic feedback. The intervention group (n = 22) received EMI without sensors. The control group (n = 19) received no treatment. Overall, EMI related to stronger improvement in clinical variables. This effect was more pronounced in the sensor group, with medium effect sizes for depression, affect, and stress, and a small effect size for anxiety. The intervention group showed small effect sizes for all outcomes except depression (medium). In sum, EMI allows the development of physiological and behavioral outcome parameters in addition to classical psychometric scores. The combination of EMI and physiological measures is thus promising in MDD, anxiety, and beyond, but its potential and risks as well as ethical aspects need further investigation (41).

Conclusion

In summary, there is mounting evidence via randomized controlled trials of the efficacy of EMI applications, but a lack of evidence that EMI applications consolidate face-to-face treatment effects, for example, prevention of relapse. Moreover, the EMIs have not yet reached their full potential in providing more objective therapy outcome measures, for example by systematically assessing physiological changes in the course of the EMI. In the light of these findings, we answer our first question (Evidence from randomized controlled trials)? with a cautious “Yes,” and our second and third questions (Evidence for consolidation of face-to-face therapy?/Optimization of therapy outcome measures)? with an optimistic “Not yet.” Given the intense research activities in the field, the state of EMI evidence regarding our three questions should be regularly reviewed and recommendations for their application in the clinical praxis should be updated.

Author contributions

MG and GH wrote the manuscript. JD amended the manuscript.

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Conflict of interest

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Contributions at conferences

06/2022 — 47th Annual Conference of Psychology and the Brain (PuG), Freiburg, Germany. Poster title: “Measuring the effect of familiarity on state anxiety and related changes in heart rate (HR) and heart rate variability (HRV) in everyday life”

11/2021 — 22nd Congress of the Gesellschaft für Angstforschung e.V. (GAF), Göttingen, Germany. Poster title: „Soziale Interaktion, Angst und das Herz: Eine Ecological Momentary Assessment-Studie“

09/2021 — 3rd International Congress of the World Association for Stress-Related and Anxiety Disorders (WASAD) 2021, Vienna, Austria. Poster title: “Anxiety and cardiovascular response in everyday social interactions”

07/2021 — 7th Conference of the Society for Ambulatory Assessment (SAA) 2021, Zurich, Switzerland, virtual conference. Poster title: “The effect of social interactions on anxiety and cardiovascular responses”

11/2020 — 2020 Congress of the Deutsche Gesellschaft für Psychiatrie und Psychotherapie, Psychosomatik und Nervenheilkunde e.V. (DGPPN), virtual conference. Poster title: „Identifying predictors for compliance to COVID-19-related safety behaviours in young adults“

10/2020 — 2nd Joint Congress of the AGNP e.V. and the DGBP e.V. (Arbeitsgemeinschaft für Neuropsychopharmakologie und Pharmakopsychiatrie; Deutsche Gesellschaft für Biologische Psychiatrie), Berlin, Germany, virtual conference. Poster title: „The Effect of Social Influence on Relief Learning”

Individual author contributions

"Dissertation Based on Several Published Manuscripts"

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Participated in	**Author Initials,** Responsibility decreasing from left to right				
Study Design Methods Development	MA	GH	LR	MG	
Data Collection	LR	MG	MJH		
Data Analysis and Interpretation	MG	MA	LR	GH	
Manuscript Writing Writing of Introduction Writing of Materials & Methods Writing of Discussion Writing of First Draft	 MG MG MG MG	 LR MA GH LR	 GH LR LR GH	 MA GH MA	 MJH MJH MJH

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Participated in	**Author Initials,** Responsibility decreasing from left to right				
Study Design Methods Development	MG	GH			
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Manuscript Writing Writing of Introduction Writing of Materials & Methods Writing of Discussion Writing of First Draft	 MG MG MG MG	 MW KS MW MW	 GH MW GH KS	 KS GH KS	 JD JD JD

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Study Design Methods Development	MG	GH	LM	JD	JH
Data Collection	MG	LM			
Data Analysis and Interpretation	MG	MW	LM	GH	JH
Manuscript Writing					
Writing of Introduction	MG	MW	GH	KS	JD, JH
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Figure	**Author Initials,** Responsibility decreasing from left to right				
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Figure 1	MG	GH	LR	MA	
Figure 2	MA	MG	GH	LR	
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Figure	**Author Initials,** Responsibility decreasing from left to right				
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Figure 4	MG	MW	GH		

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Figure	**Author Initials,** Responsibility decreasing from left to right				
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Table 2	MG	MW	GH		
Table 3	MG	MW	GH		
Table 4	MG	MW	GH		
Figure 1	MW	MG	GH		

Explanations (if applicable):

I also confirm my primary supervisor’s acceptance.

Marthe Gründahl

Doctoral Researcher’s Name Date Place Signature

Affidavit

I hereby confirm that my thesis entitled "From Lab to Life: Investigating the Role of Social Contact for Anxiety and Related Autonomic Responses" is the result of my own work. I did not receive any help or support from commercial consultants. All sources and / or materials applied are listed and specified in the thesis.

Furthermore, I confirm that this thesis has not yet been submitted as part of another examination process neither in identical nor in similar form.

Marthe Gründahl	…………………………………..	…………………………………..
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Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, die Dissertation „Vom Labor ins Leben: Die Erforschung der Rolle von sozialem Kontakt für Angst und damit verbundene autonome Reaktionen" eigenständig, d.h. insbesondere selbstständig und ohne Hilfe eines kommerziellen Promotionsberaters, angefertigt und keine anderen als die von mir angegebenen Quellen und Hilfsmittel verwendet zu haben.

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