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Effects and Mechanisms of Smartphone-Based Mindfulness Training on Emotional Experience

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EFFECTS AND MECHANISMS OF SMARTPHONE-BASED MINDFULNESS TRAINING ON EMOTIONAL EXPERIENCE

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University

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Abstract

Emotional well-being is an important component of mental and physical health that includes both positive emotions and an absence of emotional symptoms (e.g., depressive- and anxiety-related). In this study, we examine psychological mechanisms that help to explain the effects of an digital mindfulness-based intervention (MBI) on emotional states. We conducted a randomized controlled trial wherein undergraduate student participants vulnerable to decreased positive and increased negative affect received a 2-week smartphone-based MBI or a structurally equivalent coping control intervention. Emotional experience, including depressive feelings, anxiety, and happiness, as well as subjective social well-being, including loneliness and felt connection to others, was assessed at pre-intervention, post-intervention, and follow-up through ecological momentary assessment (EMA). Social behavior was examined using EMA, as well as smartphone call log data, assessing call frequency, duration, and missed calls. Contrary to expectations, participants in the mindfulness training group did not exhibit immediate improvements in emotional experience compared to the control group. However, mindfulness training effects were observed during a follow-up period, indicating sustained benefits over time. Despite not finding direct training effects on subjective social well-being, associations between subjective social well-being and subsequent emotional experience remained consistent. Exploratory analyses of mindfulness training effects on calling behavior did not reveal significant differences between the mindfulness and control groups. These findings underscore the complexity of evaluating digital MBIs' effects on emotional well-being and social functioning. Further research is needed to elucidate the underlying mechanisms, particularly concerning social well-being and behavior.

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Acknowledgements

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Vita

EDUCATION

2019–2024	**Virginia Commonwealth University** (Richmond, Virginia) PhD, Psychology (Social Psychology concentration), GPA: 4.0
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GRANTS & AWARDS

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	International Society for Contemplative Research Early Career Scholarship, 2023
	Society for Personality and Social Psychology Graduate Student Travel Award, 2023
	Mind & Life Award for Public Communication of Contemplative Research, honorable mention, 2022
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	VCU Graduate School, Travel Award, 2023
	VCU Business Services, International Student Scholarship, 2022–2023 ($5,000)
	VCU Psychology Department, Outstanding Graduate Student Teacher Award, 2022
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	ESCP Europe, Academic Excellence Scholarship (50%), 2010
	HSE University, Graduate Placement Exam Entrance Scholarship (50%), 2009

HSE University, Outstanding Academic and Service Achievement Award, 2009

HSE University, Undergraduate Placement Exam Entrance Scholarship (100%), 2005

PUBLICATIONS

Journal papers

Beloborodova, P., Dutcher, J. M., Villalba, D. K., Tumminia, M. J. Doryab, A., Creswell, K., Sefdigar, Y., Seo, W., Mankoff, J., Dey, A., Creswell, J. D., & Brown, K. W. (in press). College students' daily mind wandering is related to lower social well-being. *Journal of American College Health.* Preprint: https://doi.org/10.31234/osf.io/75p2r

Beloborodova, P. & Leontiev, D. (2024). Make your future job matter: A career calling intervention for college students. *Career Development Quarterly*, *71*(1), 63–76. https://doi.org/10.1002/cdq.12342

Brown, K. W., Berry, D., Eichel, K., **Beloborodova, P.**[‡¶], Rahrig, H., Britton, W. B. (2022). Comparing impacts of meditation training in focused attention, open monitoring, and mindfulness-based cognitive therapy on emotion reactivity and regulation: Neural and subjective evidence. *Psychophysiology*, e14024. https://doi.org/10.1111/psyp.14024

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Book chapters

Zheng, D., **Beloborodova, P.**[§¶], Arch, J., & Brown, K. W. (accepted). Emotional benefits of mindfulness. In K. W. Brown (Ed.), Handbook of Mindfulness. Guilford.

Beloborodova, P. & Brown, K. W. (2023). Mindfulness and basic psychological needs satisfaction. In R. Ryan & E. Deci (Eds.), Oxford Handbook of Self-Determination Theory. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780197600047.013.9

Other publications

Beloborodova, P. & Brown, K. W. (2024). Effects and mechanisms of smartphone-based mindfulness training on emotional experience. *Affective Science (Abstracts from the 2023 Annual Meeting of the Society for Affective Science).* https://doi.org/10.1007/s42761-023-00229-7

Beloborodova, P. (2016). [Review of the book Being Called: Scientific, Secular, and Sacred Perspectives, by D. B. Yaden, T. D. McCall, & J. H. Ellens (Eds.)]. *Voprosy Psikhologii*, *4,* 162–163.

PRESENTATIONS

* Undergraduate student mentee

Invited talks

Beloborodova, P. (2024, February). *Motivation and goals.* Department of Psychology, Colorado College (online).

Beloborodova, P. (2023, October). *Research funding beyond NIH and NSF grants.* Psychology Department, University of Missouri (Columbia, MO).

Beloborodova, P. (2023, September). *Getting funding and recognition in the US as an international student and scholar.* Department of Neuroscience, University of Wisconsin-Madison (Madison, WI).

Beloborodova, P. & Brown, K.W. (2023, April). *The mismeasurement of mindfulness: Evidence of a jangle fallacy in popular mindfulness scales.* Health and Human Performance Lab, Carnegie Mellon University (online).

Beloborodova, P. (2022, November). *Effects and mechanisms of smartphone-based mindfulness training on emotional well-being.* Health and Human Performance Lab, Carnegie Mellon University (online).

Conference presentations

Beloborodova, P. (2023, June). *Effects and mechanisms of smartphone-based mindfulness training on daily emotional well-being.* Plasticity of Well-Being Summer Workshop (Madison, Wisconsin).

Beloborodova, P. & Brown, K.W. (2023, May). *Mindfulness and satisfaction of basic psychological needs.* International Conference on Self-Determination Theory (Orlando, FL).

Beloborodova, P. & Brown, K.W. (2023, February). *Mindful states: A promoter of social and emotional well-being in college students.* Society for Personality and Social Psychology Annual Convention (Atlanta, GA).

Beloborodova, P. & Brown, K.W. (2023, February). *The mismeasurement of mindfulness: Evidence of a jangle fallacy in popular mindfulness scales.* International Society for Contemplative Research Inaugural Annual Conference (San Diego, CA).

Brown, K.W. & **Beloborodova, P.** (2021, February). *How presence supports the basic human need for social connection.* Society for Personality and Social Psychology Annual Convention (online).

Beloborodova, P. (2019, October). *Discernment of career calling: A quest for meaning and authenticity.* Society of Southeastern Social Psychologists 42nd meeting (Johnson City, TN).

Beloborodova, P. (2019, July). *"I'm looking for a calling, not just a job": Testing a career calling discernment intervention for college students.* 16th European Congress of Psychology (Moscow, Russia).

Beloborodova, P. (2019, April). *Make your future job matter: Career calling discernment course for university students.* 20th April International Academic Conference on Economic and Social Development (Moscow, Russia).

Beloborodova, P. (2018, June). *How to find your calling? Testing of an intervention for college students.* International research seminar 'Quality of life in times of the global transformation of mankind' (Aktru, Russia).

Beloborodova, P. (2017, May). *Intervention for the discernment of calling: Pilot test and results.* XXII International symposium 'Psychological problems of life meaning and acme' (Moscow, Russia).

Beloborodova, P. (2016, May). *Life calling: Philosophical and psychological concepts.* XXI International symposium 'Psychological problems of life meaning and acme' (Moscow, Russia).

Posters

Beloborodova, P. (2024, March). *Effects of online mindfulness training on social well-being.* Society for Affective Science Meeting (New Orleans, LA).

*Pemmasani, S., *Washington, O., *McRae Cooper, A., *Lim, A., **Beloborodova, P.** (2023, October). What makes college students comply with a stress reduction intervention? Society of Southeastern Social Psychologists 44th meeting (Charlotte, NC).

Beloborodova, P. & Brown, K. W. (2023, October). *The mismeasurement of mindfulness: Evidence of a jangle fallacy in popular mindfulness scales.* Mindfulness Mechanisms and Methods Meeting (M^4) (St. Louis, MO).

*Pemmasani, S., *Floyd, J., *Kanuri, N., *Kumar, V., **Beloborodova, P.**, & Brown, K. W. (2023, April). *The effects of smartphone-based mindfulness intervention on social and emotional well-being among VCU undergraduate students.* Virginia Commonwealth University Poster Symposium for Undergraduate Research and Creativity (Richmond, VA).

Beloborodova, P. & Brown, K. W. (2023, April). *Effects and mechanisms of online mindfulness training on emotional experience.* Society for Affective Science Meeting (Long Beach, CA).

Beloborodova, P. & Brown, K. W. (2022, February). *Does Five Facet Mindfulness Questionnaire (FFMQ) actually measure mindfulness?* Society for Personality and Social Psychology Annual Convention (San-Francisco, CA).

Juberg, M. & **Beloborodova, P.** (2021, July). *Empathy: A critical link between self-compassion and social dominance orientation.* 7th International Positive Psychology Association (IPPA) World Congress (online).

Beloborodova, P. (2021, April). *Career calling and time perspective: Looking further into the future.* Western Psychological Association (WPA) Annual Conference (online).

Beloborodova, P., Villalba, D., Dey, A., Cohen, S., Creswell, K., Mankoff, J., Sutkus, J., Lovett, M., Dutcher, J., Tumminia, M., Doryab, A., Creswell, J. D., & Brown, K.W. (2020, June). *Mindful states: A promoter of social well-being and mental health.* Mind & Life Summer Research Institute (online).

Beloborodova, P., Villalba, D., Dey, A., Cohen, S., Creswell, K., Mankoff, J., Sutkus, J., Lovett, M.,

Dutcher, J., Tumminia, M., Doryab, A., Creswell, J. D., & Brown, K.W. (2020, June-September). *Mindfulness and social well-being in emerging adults: An ecological momentary assessment study.* Association for Psychological Science (APS) Virtual Poster Showcase (online).

Beloborodova, P., & Leontiev, D. (2018, June). *Russian students' conceptualization of life calling: A qualitative analysis.* 9th European Conference on Positive Psychology (Budapest, Hungary).

TEACHING & MENTORING

2019–2023	**Virginia Commonwealth University** (Richmond, Virginia)
	Multilevel Modeling (graduate, Fall 2023, 12 students), Primary instructor
	Statistics I (graduate, Fall 2022, 21 students), Primary instructor
	Statistics I & II (graduate, 2020–2022, 13-21 students), Lab instructor
	Application of Statistics in Psychology; Perception; Principles of Learning and Cognition; Physiological Psychology (undergraduate, 2019–2020, ~100 students), Teaching assistant
2015–2019	**Higher School of Economics** (Moscow, Russia)
	Career Calling and Professional Development (2016–2019, 15-90 students), Primary instructor
	Career Development (2015–2019, 10-100 students), Primary instructor
	Psychology of Personal Wellbeing (Fall 2018, 30 students), Primary instructor

RESEARCH EXPERIENCE

2023	**University of Wisconsin-Madison** (Madison, Wisconsin)
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2019–	**Virginia Commonwealth University** (Richmond, Virginia)
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2018	**Naropa University** (Boulder, Colorado), Research assistant
2015–2019	**HSE University** (Moscow, Russia)
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ADMIN & INDUSTRY EXPERIENCE

2015–2019	**HSE University** (Moscow, Russia)
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2012–2013	**Severstal**, Graduate recruitment and employer brand specialist (Moscow, Russia)
2011–2012	**Universum**, Employer branding consultant (Stockholm, Sweden & Moscow, Russia)

SERVICE

Peer review	Mindfulness, 2024– Personality and Social Psychology Review, 2022– (Emerging Editor Board member) Psychology in Russia: State of the Art, 2021– Cognition and Emotion, 2022 (as hoc with Advisor) Current Directions in Psychological Science, 2020 (ad hoc with Advisor)
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Mentoring	Peer advisor, Society for Personality and Social Psychology, 2022–2023

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Public scholarship	Presenter at Without Prejudice, a project helping Russian-speaking people in distress. Topic: *Here, now, and together: How mindfulness helps us to build bridges instead of walls*, 2022 (online)
	Discussant at 'Consciousness: The science, metaphysics, and poetics' panel at VCU Arts, 2022 (online)
	Presenter at 'Conscious, subconscious, (collective) unconscious' exhibition at VCU Arts. Topic: *Being present and feeling connected: How present moment awareness helps us to have more fulfilling social lives*, 2022 (Richmond, VA)
	Discussant at *When green lifestyle meets personal well-being* panel discussion at the 'Different Ever After' British culture festival organized by the British Embassy in Russia, 2020 (online)
Other service	Factotum, VCU Social Psychology program, 2020–2023
	Graduate Student Poster Award reviewer, Society of Personality and Social Psychology, 2022
	Graduate School Application Seminars presenter, VCU Wellbeing Lab, 2020–2021
	History of Psychology undergraduate poster presentations judge, VCU Department of Psychology, 2019
	Pro-bono coach at *Socially Oriented Non-profit Organizations' Leaders' Development Program* PRONKO_2.0, 2015

Introduction

Throughout last decade, researchers keep reporting alarming trends, such as decreasing happiness and increasing prevalence of depression and anxiety symptoms in the USA, that seem paradoxical in the light of improving standards of living (Twenge et al., 2019). Declining social support is one of the major factors contributing to those tendencies (Sachs, 2017). Indeed, lockdowns in the early months of the COVID-19 pandemic, followed by ubiquitous social distancing, showed how much we suffer without social connection. Mental health consequences of the pandemic are predicted to last for months or even years (Brooks et al., 2020). There is an urgent need to develop ways to buffer those trends. The cultivation of open, receptive awareness of the present moment experience is, we propose, one such way. In the following sections, we expound the concept of emotional well-being and its recent decline. Then we elucidate the connection between presence of mind and its putative opposite of mind wandering and emotional experience. We further suggest that this connection might be mediated by social well-being, including both overt social behaviors and subjective states of loneliness and connection to others. Then we present an intervention study aimed at testing those relations, expected results, theoretical and practical implications and limitations.

Emotional Well-Being

Mental well-being has traditionally been regarded as an opposite of mental ill-being. A person free of psychopathology was presumed to be mentally healthy. However, scholars have long suggested that health consists of not merely the absence of illness, but also the presence of something positive (Ryff & Singer, 1998; Sigerist, 1941), an approach referred to as complete or holistic model of health. This model received empirical support: rather than being mutually exclusive, mental illness and mental health are best represented as a gradient where the

prevalence of depression and anxiety decreases as the level of positive mental health increases (Keyes, 2005). Emotional well-being is key feature in a holistic approach to public health that has become a research priority within the National Institute of Health's National Center for Complementary and Integrative Health (2021). Prevalent daily mood is a key component of the metal health gradient. Recent studies showed that there is a substantial phenotypic and genotypic overlap between low positive affect and depressive symptoms, as well as neuroticism (Baselmans et al., 2019).

Positive emotional experience includes an abundance of positive over negative emotions (Tov, 2018). Abundance can be understood in terms of both frequency and intensity of emotions. Diener et al. (2009) showed that the proportion of time when the participants felt more positively than negatively was more predictive of long-term, global well-being than the intensity of positive emotions. Moreover, excessive and disruptive positive emotions that arise regardless of the stimulus valence are characteristic of mania, a core criterion of bipolar disorder (Gruber et al., 2008).

From an evolutionary perspective, emotions are considered adaptations to problems that help us to navigate our lives (Keltner & Gross, 1999). Emotions can be regarded as a feedback system that directs attention and incites analysis, learning, and adaptation (Baumeister, Vohs, DeWall, et al., 2007). Unlike global evaluation of one's life as a whole, as well as its specific areas, emotional experience changes in response to daily events (Tov, 2018). However, despite those fluctuations, there are stable individual differences in average levels of affect, as well as covariation with personality traits (e.g., positive emotional experience is positively correlated with extraversion and negatively with neuroticism; Schimmack, 2008). Furthermore, emotional experience is related to physical health. Pressman et al. (2019) showed that positive affect is

associated with better health across a wide range of health outcomes, including improved cardiovascular functioning, decreased disease severity, and decreased mortality. Higher levels of positive affect are beneficial for survival and recovery in physically ill patients (Lamers et al., 2012) and are associated with C-Reactive Protein, an inflammatory biomarker important for cardiovascular and other diseases (Ironson et al., 2018). Compromised emotional well-being (depression) has opposite relations with the above-mentioned health outcomes (Slavich & Irwin, 2014).

Emotional experience has been steadily worsening among adults residing in the USA. since at least 2000, an effect attributable to a time trend, rather than generational differences. A previously established positive correlation between age and happiness has been decreasing since the beginning of data collection in the 1970s, disappearing by the early 2010s (Twenge et al., 2016). At the same time, the prevalence of depression, stress, and suicide has increased substantially from 2008–2017, especially among young adults aged 18–25 (Twenge et al., 2019). COVID-19 pandemic exacerbated this trend, with USA adults being tree times more likely to develop a depression and/or anxiety disorder in April-May 2020 than in the first half of 2019 (Twenge & Joiner, 2020). Mental health consequences of the pandemic are predicted to extend far into the future. Studies of long-term psychological effects of disease pandemics and quarantine have reported harmful effects lasting from months up to years after the initial event (Brooks et al., 2020). Thus, there is an urgent need to investigate factors contributing to emotional experience and develop cost-efficient, scalable solutions to improve it. One possible solution is, we propose, a mindfulness-based smartphone-delivered intervention.

States of Mind and Emotional Well-Being

Mind wandering, defined as mental content that is current task-unrelated and stimulus-independent (Stawarczyk et al., 2011), and its purported opposite presence of mind (Mrazek et al., 2012) are known to be closely associated with emotional well-being and physical health. Mind wandering is a frequently occurring state that is estimated to take up from 30% (Kane et al., 2007) to 47% (Killingsworth & Gilbert, 2010) of waking time that often happens with little or no awareness of its occurrence (Schooler et al., 2011). Research has demonstrated that mind wandering can be both a precursor (Killingsworth & Gilbert, 2010) and an antecedent of negative mood (Smallwood et al., 2009; Poerio et al., 2013). The content of mind wandering qualifies its relation to emotional experience. Retrospective thoughts are more strongly associated with poorer experience than thoughts about the future (Smallwood & O'Connor, 2011) and present concerns (Poerio et al., 2013).

The opposite of mind wandering is presence of mind, a state characterized by attention to current tasks and experiences. Presence of mind has chiefly been studied as part of a larger, multidimensional construct of mindfulness, rooted in Buddhist teachings (e.g., Anālayo, 2004). Mindfulness is commonly defined as receptive, non-judgmental, sustained attention to and awareness of present-moment events and experiences (Bishop et al., 2004). There is an ongoing debate on the meaning and exact definition of mindfulness both among and between Western researchers and Buddhist scholars (Gethin, 2011; Grossman & Dam, 2011). For clarity, we will use the term "mindfulness" when referring to the above-mentioned multidimensional construct, usually measured at the trait level or used as a base for interventions. The term "presence" will be employed to refer to momentary experience, usually measured with experience sampling or ecological momentary assessment methods. Since the introduction of secular mindfulness

training programs to clinical practice (Kabat-Zinn, 1990), a considerable body of research accumulated that showed its role in mental and physical health and well-being (Brown et al., 2015). A meta-analysis revealed that at the trait level, mindfulness positively correlated with mental health ($\rho = .38$) and negatively correlated with negative emotions ($\rho = –.40$), anxiety ($\rho = –.34$), and depression ($\rho = –.38$; Mesmer-Magnus et al., 2017). A number of studies on mindfulness interventions, such as Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 1990) and Mindfulness-Based Cognitive Therapy (MBCT; Segal et al., 2002) has shown a broad, positive impact on cognitive, affective, and interpersonal outcomes. Emotional well-being-wise, mindfulness interventions appear to reduce depression and anxiety symptoms or risk of depression relapse in at-risk populations. They were also found to improve self-reported measures of positive affect and reduce negative affect in healthy individuals (Creswell, 2017). A recent systematic review of mindfulness intervention randomized controlled trials meta-analyses showed that their effects on a range of outcomes differed depending on study characteristics (Goldberg et al., 2022). Not surprisingly, studies with passive controls yielded greater effects than studies with active controls; studies with evidence-based treatments as controls produced mostly non-significant effects. Depression relapse prevention was a notable exception, with mindfulness interventions showing consistently greater effects across all control types. Overall, mindfulness intervention effects ranged from very small ($d = 0.10$ for children and adolescents) to large ($d = 0.89$ for anxiety disorders), with most in the moderate range.

Concerning momentary presence of mind experiences, evidence from four observational intensive longitudinal studies showed that presence was concurrently associated with increased positive affect and decreased negative affect (Enkema et al., 2020). Brown and Ryan (2003) noted that momentary measure of presence had better psychometric characteristics than the trait

measure. Evidence from five experimental studies showed that participants of mindfulness interventions experienced increased daily positive affect and decreased daily negative affect (Enkema et al., 2020).

Internet- and smartphone-delivered or digital mindfulness interventions are of particular interest because of their accessibility, convenience, and relatively low cost. Hundreds of online self-help programs and mobile applications provide mindfulness-related content to millions of users, usually with minimal or no access to trained mindfulness teachers or other mental health professionals (Taylor et al., 2021). Currently, there is no evidence-based agreement on the safety and efficacy of these programs (Creswell, 2017). Taylor et al. (2021) meta-analyzed randomized controlled trials reporting the effects of unguided mindfulness interventions delivered via books, audio CDs, online programs, and smartphone applications. They found that at post-intervention they resulted in significantly lower depression and anxiety, as well as significantly higher well-being. Those effects waned at follow-up for depression and anxiety but remained significant for well-being. In studies with active controls, the effect for depression was smaller than in studies with passive controls, and it was non-significant for anxiety. The effect for well-being was not significantly different in intervention and control groups. Studies using digital mindfulness interventions such as smartphone applications, reported lower effects for depression and well-being and similar effects on anxiety compared to those relying on non-digital materials such as books. Taylor et al. reported considerable heterogeneity in the intervention effects and called for further examination of unguided mindfulness interventions in well-designed studies.

In sum, there is considerable evidence that both mind-wandering and presence of mind affect emotional experience. The exact psychological and behavioral mechanisms of those effects are however largely unknown. We further examine one candidate mechanism, namely

social well-being, including both overt social behavior and subjective evaluations of one's social life.

Social Well-Being as a Mechanism

Humans are, by nature, highly social species (Baumeister & Leary, 1995; Cacioppo & Patrick, 2008). Social connection is one of the main promoters of emotional well-being, mental and physical health, and increased resilience to stress (Helliwell & Aknin, 2018). According to the Harvard Study on Adult Development that followed 268 Harvard sophomores of 1938–44 cohorts for their entire lives, warm and intimate relationships were better predictors of flourishing in later life than social class, IQ, or bodily constitution (Vaillant, 2012). Continued loneliness, on the other hand, disrupts cognitive abilities and will power, damages immune systems (Cacioppo & Patrick, 2008), and can be as detrimental for heath as obesity or smoking (Holt-Lunstad et al., 2010). Loneliness was shown to be the main risk factor for depression and anxiety during the COVID-19 pandemic, more prominent than the risk for health complications (Palgi et al., 2020).

Social well-being has been studied both in terms of quantity of social contacts (frequency and diversity of interactions) and their quality (subjective evaluations, feelings during interaction). Research shows that both aspects are contributing to emotional well-being, however the evidence for quality is stronger. Menec et al. (2020) demonstrated that feelings of loneliness were a more robust predictor of psychological distress than objective social isolation. Hyland et al. (2019) found that the perceived quality rather than quantity of social interactions was associated with poor mental health. Baumeister and Leary (1995) argued that the sheer number of social contacts and time spent with others fail to predict the feelings of loneliness, rather it is predicted by negative affect and perceived lack of others' affectionate concern. This conclusion

is further supported by the results of Rook's (2001) daily diary study where negative social exchanges were associated with greater feelings of loneliness, and positive social exchanges were associated with lower feelings of loneliness. Bernstein et al. (2018) also showed that more pleasant interactions elicited higher momentary positive and lower negative emotions at both between and within-participant levels. Sun et al. (2020) revealed that both quantity and quality of interactions measured with experience sampling were linked with social well-being and positive emotional experience. Quantity of social interactions was robustly associated with greater well-being in the moment and on average, and both conversational (depth of conversation and degree of self-disclosure) and relational (affection towards interaction partners) aspects of social interaction quality predicted social connectedness and happiness.

Buddhist and other scholars have long proposed that present-centered attention helps to ameliorate social interactions and relationships (e.g., Amaro, 2015; Pétrement, 1976). Cross-sectional research indicates that trait mindfulness is positively related to higher relationship satisfaction (Barnes et al., 2007) and secure attachment in romantic relationships (Kimmes et al., 2018) and buffers the effect of insecure attachment on well-being (Davis et al., 2016). Evidence from intervention research suggests that mindfulness training predicts greater perceived social connection (Adair et al., 2018), improvements in romantic relationships functioning (Carson et al., 2004), greater supportive communication skills (Jones et al., 2019), higher prosocial behavior (Berry et al., 2018, 2020), and decreased loneliness (Creswell et al., 2012; Davis et al., 2016). There is however little research investigating whether those effects translate into day-to-day life. Lindsay et al. (2019) found that mindfulness training reduced daily loneliness and increased social contact both in terms of the number of interactions and the number of people with whom

participants communicated. Fredrickson et al. (2019) showed that more frequent informal meditation practice was linked to increased perceived social integration and positive emotions.

Taken together, this evidence points out to the potential mediating role of social well-being in the relationship between mindfulness and emotional experience. Testing these pathways is especially relevant considering the adverse impact of the COVID-19 pandemic on social ties and the resulting increase in loneliness and isolation that are associated with compromised emotional well-being (Killgore et al., 2020).

Daily States and Behavior Data Collection Challenges

Scholars have long called for more research examining daily behaviors and their connections with psychological outcomes (Baumeister, Vohs, & Funder, 2007). Ambulatory assessment has been widely used in medicine since 1980s and is gaining momentum in psychology (Fahrenberg et al., 2007). Obtaining a detailed trajectory of emotional experience as it unfolds over time is especially important, given the effects of frequency and intensity of emotions that are confounded in aggregated measures. However, data collection in intensive longitudinal studies can be quite burdensome for the participants and difficult to implement on an ongoing basis. Leveraging the data passively collected via smartphone sensors and logs provides a solution to this challenge (Harari et al., 2016; Stachl et al., 2020). This technology permits tracking of a variety of overt behaviors unobservable through other research means: actual social interactions (e.g., calls, text messages, in-person communication rates, size of social groups), daily health behaviors (e.g., sleep, physical activity), and mobility patterns (e.g., frequency of visiting various locations, movement between locations, distance travelled) (Harari et al., 2016). Recent research has found that patterns in these data can predict social behavior (Harari et al., 2020), loneliness (Doryab et al., 2019), and depressive symptoms (Wang et al.,

2017; Ware et al., 2020) with high accuracy. Passive sensing not only reduces participant burden, but also permits investigation of objective behavior associated with compromised emotional experience that in future may permit brief, just-in-time smartphone-delivered interventions to alter such behavior (e.g., social isolation).

The Present Research

In the present study, we test the effects and mechanisms of a smartphone-delivered mindfulness intervention on emotional experience, measured as happiness, depressive mood, and anxiety via ecological momentary assessment (EMA). College students were chosen as a population of interest, as they are a group particularly vulnerable to poor emotional well-being, as well as social isolation and disconnection. Over the last decade, the prevalence of depression, stress, and suicide has increased substantially in this population (Auerbach et al., 2016; Mortier et al., 2018). The COVID-19 pandemic has exacerbated this trend: for example, the prevalence of depression in this population increased from 21% before the pandemic to 54% since its onset (Li et al., 2021). Feelings of loneliness and isolation are also widespread: In a recent U.S.A. national survey of nearly 48,000 college students, 64% of respondents reported feeling “very lonely” in the last year (American College Health Association, 2018). Rates of social disconnection appear to be increasing in this population: In 1987, 38% of freshmen students reported socializing with friends more than 16 hours a week (Astin et al., 1988), whereas in 2019 this figure dropped to 18.6% (Stolzenberg et al., 2020).

The results of our preliminary observational study indicated that social well-being may indeed mediate the connection between presence of mind and emotional experience. Examining college students’ rates of depressive feelings and happiness via ecological momentary assessment, we found that rates of happiness decreased over an academic semester in three

independent samples (n = 209, n = 173, and n = 266) while depressive mood increased. However, in sample 3 day-to-day presence of mind predicted higher happiness and lower depressive mood; further, presence predicted reduced loneliness at the next time point and was associated with higher felt connection (Beloborodova et al., 2020). There is also preliminary evidence of digital mindfulness interventions positive effects on college students' emotional well-being (Flett et al., 2019; Linardon, 2020).

The specific aims of the study are:

1. Main aim: To evaluate the effect of a two-week smartphone-based mindfulness intervention, relative to a coping control intervention, on daily emotional experience measured through EMA as depressive feelings, anxiety, and happiness.
2. Exploratory aim: To examine the role of momentary felt connection and loneliness as mediators of the intervention effect on emotional experience.
3. Exploratory aim: To test the mindfulness intervention effect on social behaviors, measured with EMA and passive smartphone sensing.

Regarding the first aim, we hypothesize that there will be a significant improvement in emotional experience between the baseline and post-training assessment in the mindfulness group, relative to the control group. We do not make hypotheses regarding the training effect in the follow-up period as previous research found only short-term smartphone-based mindfulness programs effects (Goldberg et al., 2022). However, we include follow-up measures for exploratory purposes.

Regarding the exploratory aims, we do not set formal hypotheses. We examine whether EMA-assessed loneliness and felt connection mediate the relation between mindfulness training and emotional well-being and evaluate whether the mindfulness intervention has any effect on

social behaviors. Thus, this study builds on and extends previous research on the topic (Beloborodova et al., 2020; Lindsay et al., 2018; Lindsay et al., 2019) by examining mindfulness training effects on emotional well-being, as well as mediating effects of social well-being and training effects on social behaviors.

The study hypotheses, procedures, materials, measures, and planned data analysis were registered on the Open Science Framework (OSF; https://osf.io/wudqm). The study was also registered on the National Institute of Health Clinical Trials website (https://classic.clinicaltrials.gov/ct2/show/NCT05518656). The study was approved by the Virginia Commonwealth University Institutional Review Board and Information Security Office (approval number HM20024191).

Method

Participants

The data were collected in three waves in the Spring 2023, Fall 2023, and Spring 2024 semesters from a total of 121 Virginia Commonwealth University (VCU) undergraduate students. The inclusion criteria were:

- 18-25 years old;
- Enrollment as a full-time student;
- Studying in-person (to limit extraneous heterogeneity in social contact);
- Low positive affect and high negative affect (evaluated with the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988), with scores above 15 on the Negative Affect subscale and scores below 32 on the Positive Affect subscale; Crawford & Henry, 2004);

- Absence of current major depressive, generalized anxiety, and panic disorder diagnoses (to avoid the risk of adverse effects due to heightened awareness of one's emotional state and distressing thoughts);
- Ownership of a smartphone with an OS no older than iPhone 5 or Android 5 and an active data plan.

Demographic characteristics are presented in Table 1. Mindfulness and control training groups were demographically equivalent, as shown by the Mann Whitney U Test for age (p = .458), as well as Fisher's Exact Tests for gender (p = .079) and ethnicity proportions (p = .514). Only seven out of 121 participants reported a current meditation practice. This included three participants who tried it once or a few times and meditating less than once (one participant) or once to twice per week (two participants). One participant has meditated for less than six months, less than once per week. Two participants meditated three to four times per week, for six months to one year. Only one participant practiced meditation for over one year and meditated five to six time per week. None of the participants practiced meditation for over five years. Thus, the sample was largely meditation naïve.

Table 1
Demographic characteristics by sample and group

	Total	Fall 2023	Spring 2023	Spring 2024	CT	MT
Sample size	121	41	44	36	60	61
Age, M (SD)	19.82 (1.41)	19.71 (1.52)	19.65 (1.25)	20.17 (1.42)	19.71 (1.34)	19.93 (1.47)
Age range	18-24	18-24	18-23	18-24	18-24	18-24
Age not reported	1	0	1	0	1	0
Gender, N (%)						
Cisgender woman	93 (76.86)	35 (85.37)	29 (65.91)	29 (80.56)	49 (81.67)	44 (72.13)
Cisgender man	14 (11.57)	3 (7.32)	5 (11.36)	6 (16.67)	3 (5)	11 (18.03)
Transgender man	3 (2.48)	1 (2.44)	2 (4.55)	0	2 (3.33)	1 (1.64)
Genderqueer	2 (1.65)	0	1 (2.27)	1 (2.78)	0	2 (3.28)
Non-binary	8 (6.61)	2 (4.88)	6 (13.64)	0	5 (8.33)	3 (4.92)
Not listed	1 (0.83)	0	1 (2.27)	0	1 (1.67)	0
Race and ethnicity, N (%)						
White	38 (31.4)	18 (43.9)	11 (25.00)	9 (25.00)	22 (36.67)	16 (26.23)
Black or African American	19 (15.7)	7 (17.07)	7 (15.91)	5 (13.89)	12 (20)	7 (11.48)
Hispanic or Latino(a)	6 (4.96)	0	3 (6.82)	3 (8.33)	2 (3.33)	4 (6.56)
Middle Eastern	3 (2.48)	0	3 (6.82)	0	1 (1.67)	2 (3.28)
Asian Indian	14 (11.57)	5 (12.2)	5 (11.36)	4 (11.11)	8 (13.33)	6 (9.84)
Chinese	5 (4.13)	4 (9.76)	1 (2.27)	0	2 (3.33)	3 (4.92)
Filipino	2 (1.65)	0	0	2 (5.56)	0	2 (3.28)
Korean	2 (1.65)	0	2 (4.55)	0	0	2 (3.28)
Vietnamese	10 (8.26)	2 (4.88)	4 (9.09)	4 (11.11)	4 (6.67)	6 (9.84)
Other Asian	5 (4.13)	1 (2.44)	3 (6.82)	1 (2.78)	1 (1.67)	4 (6.56)
Two or more races	17 (14.05)	4 (9.76)	5 (11.36)	8 (22.22)	8 (13.33)	9 (14.75)

Note. SD = standard deviation, CT = control training, MT = mindfulness training.

Participants were compensated $20 for the pre-training survey, $15 for the post-training and follow-up surveys each, $20 for the post-training interview, as well as $1 for every completed EMA survey. In total, they could earn up to $175 for their study contribution.

Sample Size Justification

Sample size was determined according to available funding and Maas and Hox (2005) simulation-based recommendations of 100 Level 2 units (participants) needed for unbiased estimates of the regression coefficients and standard errors in multilevel models. We did not conduct a priori power analysis because it requires specification of multilevel model parameters, such as the magnitude of the fixed effects (intercepts and slopes), the variances for the random effects, and the covariance matrix of the random effects. Our study is the first to our knowledge to use piecewise multilevel zero-inflated regression models to test smartphone-delivered mindfulness intervention effects. Hence, we did not have grounds to hypothesize expected model parameters.

Interventions

The mindfulness intervention is a 14-lesson course designed to foster attentional monitoring and acceptance of present-moment experiences. The structurally equivalent coping intervention delivered by the same instructor aims to promote the use of reappraisal and other adaptive coping strategies. The participants will receive 15-20 minutes long daily audio lessons that include brief experiential homework assignments (3-10 minutes per day). Each audio lesson introduces participants to specific topics using didactic instruction, guided practice, and self-guided practice. The interventions will be delivered through REDCap, which permits tracking of participants' progress and adherence. A team of research assistants will track lesson completion daily and contact participants if they skip lessons. They will also contact each participant by phone on days 3 and 9 of the training program to inquire about the difficulties, address questions, and encourage participants to keep up with the training.

Mindfulness training is designed to teach participants three core skills introduced in the first lesson: concentration (ability to maintain attention to the present moment experience),

clarity (or monitoring; ability to distinguish between specific moment to moment experiences), and equanimity (or acceptance; open and nonjudgmental attitude to experiences). Subsequent lessons will teach various evidence-based practices that help to develop those skills. Coping training is structured similarly to the mindfulness training; however, it teaches a different set of skills: reflection (guided investigation of thoughts), analytic thinking (thinking in more detail about the thoughts and ideas that arise during reflection), and problem solving (tackling problems identified through analytic thinking). Both programs teach validated stress management techniques, but they differ in their approach to present moment experience. While mindfulness training encourages present focus and acceptance, coping training promotes focus of the past and future and active change. Lesson by lesson training program outlines are presented in Appendix A.

The interventions have been tested in previous studies on a group of stressed community adults. Both training programs reduced momentary negative affect; mindfulness training also increased momentary positive affect, while control training did not (Lindsay et al., 2018). Mindfulness training participants benefited from reduced daily loneliness and increased number of social interactions, as well as the number of people with whom they communicated (Lindsay et al., 2019).

Measures

Trait Measures & Demographics

The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) was used to assess positive and negative affect. The measure contains two subscales, 10 items each: Positive Affect (sample Cronbach's alpha = .85; examples: "Interested," "Enthusiastic") and Negative Affect (sample alpha = .86; examples: "Distressed," "Upset"). The participants were instructed

to mark how frequently they experienced those feelings over the last two weeks on a 5-point scale (from 1 = *very slightly or not at all* to 5 = *extremely*). Scores above 15 on the Negative Affect subscale and scores below 32 on the Positive Affect subscale indicate poor emotional experience (Crawford & Henry, 2004). The measure was used for screening of eligible participants, as well as baseline positive and negative affect assessment.

Depression was be evaluated with the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977; sample alpha = .86). The scale contains 20-items (example: "I thought my life had been a failure."). The participants were asked to indicate how often they have felt as described in the items during the past week on a 4-point scale (from 1 = *rarely or none of the time (less than 1 day)* to 4 = *most or all of the time (5-7 days)*).

Beck's Anxiety Inventory (BAI; Beck et al., 1988; sample alpha = .91) was used to measure anxiety. This is a 21-item scale that contains common anxiety symptoms (examples: "Fear of worst happening," "Hands trembling"). The participants were be instructed to evaluate how much they have been bothered by those symptoms during the past month on a 4-point Likert scale (from 1 = *not at all* to 4 = *severely – it bothered me a lot*).

Loneliness was measured with the UCLA Loneliness Scale (Russell, 1996; sample alpha = .92), an instrument assessing frequency of felt social disconnection. This measure contains 20 items (example: "How often do you feel that you are no longer close to anyone?") which the participants evaluated on a 4-point Likert scale (from 1 = *never* to 4 = *always*).

Social support was assessed with the Two-Way Social Support Scale (Shakespeare-Finch & Obst, 2011; sample alpha = .93) that consists of 21 items and represents emotional and instrumental dimensions of social support (example item: "There is someone I can talk to about the pressures in my life"). A 6-point Likert scale was used (from 1 = *not at all* to 6 = *always*).

Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003; sample alpha = .87) was used to measure trait mindfulness. The scale includes 15 items such as "I rush through activities without being really attentive to them" that the participants assessed on a 6-point Likert scale (1 = *almost always* to 6 = *almost never*). The scale is reverse scored to indicate paying attention to the present moment experience.

Demographic variables included age, gender identity, and racial/ethnic identity. In the same block, we also inquired whether participants currently had a meditation practice, for how long they have been meditating (from 1 = *tried it once or a few times* to 5 = *over five years*), and how often (from 1 = *never* to 6 = every day). All measures are presented in Appendix B. For other study purposes (not reported here), the questionnaire contained eight other measures.

Ecological Momentary Assessment (EMA)

At each EMA prompt, participants reported their mood state, including how depressed, anxious, happy, lonely, and connected to others they felt at the moment, using a 5-point scale (from 1 = *not at all* to 5 = *extremely*). Lastly, the participants reported whether they were among others, whether it was a face-to-face, virtual, or blended environment, and whether they interacted with someone since the previous survey. For other study purposes not reported here, the EMA surveys additionally included questions on participants' current activities, autonomy, competence, and social experiences. A complete overview of the EMA items (including those not used in this dissertation) is presented in Appendix C. EMA surveys were administered through the REDCap survey software. The links to the surveys were sent via text messages three times per day on a quasi-random schedule in the morning (9 AM-1 PM), afternoon (1 PM-5 PM), and evening (5 PM-9 PM). If a participant did not complete a survey, they received two

reminders 15 and 30 minutes after the link was sent. If a participant failed to complete a survey within one hour, the survey became inactive, and data was set to missing.

Smartphone Passive Sensing

We collected smartphone logs and sensors data through AWARE, an open-source mobile application with supporting backend and network infrastructure (Ferreira et al., 2015). For this study, the app recorded the calls logs. The content of calls and phone numbers of interaction partners were not recorded. Instead, AWARE saved the direction (incoming, outgoing), duration (of calls), and a random identifier for interaction partners. For other study purposes not reported here, AWARE also recorded screen, battery, location, wi-fi, and activity data. Table 2 shows the sensors and plugins that were activated in AWARE, the data that we collected from them, and behaviors that can be inferred from that data.[1]

[1] In addition to the listed logs and sensors, we originally intended to record text message and app usage logs to infer smartphone-mediated social activity, Bluetooth logs to infer social proximity, and microphone audio samples to infer social interactions. However, access to text messages, app usage, and Bluetooth was restricted on iPhones, which were used by the majority of the study participants. Additionally, the AWARE audio sampling Conversations plugin provided low-quality data. Therefore, we relied solely on available call data and replaced social proximity and interaction data with self-reported data collected through Ecological Momentary Assessment (EMA) to fulfill Aim 3.

Table 2
AWARE Configuration

Sensor/plugin	Data	Sampling frequency	Behaviors derived from the data
Communication	Incoming/outgoing calls	Smartphone keeps the logs of every call	Smartphone-mediated communication
Screen*	Screen on/off	Smartphone keeps the logs of every screen status	Screen time (for how long the user engages with their device)
Battery*	Battery charging	Smartphone keeps the logs of every battery status	Sleep (the majority of users put their devices on charge when they go to sleep)
Location*	GPS coordinates	Every five minutes	Mobility (out-of-home departures, distance traveled, frequency and duration of visiting various locations on campus, etc.)
Wi-Fi*	Wi-fi networks	Smartphone keeps the logs of every wi-fi network that it connected to	Mobility (supplement GPS location data)
Activity Recognition*	Accelerometer data (phone horizontal and vertical orientation), processed on the device to infer activity	Every five minutes	Activity and movement (still, walking, running, biking, in vehicle)

Note. * Sensor that does not directly address this study's research question but will be activated for other study purposes; ESM = Experience Sampling Method; BT = Bluetooth; GPS = global positioning system; m = meters; SMS = short message service; app = application.

The data was transferred to a back-end server daily through wi-fi. To protect participant confidentiality, raw data was stored on a secure VCU Category I (sensitive identifiable data) database server.

Procedure

Data collection occurred in three waves: Spring 2023, Fall 2023, and Spring 2024 semesters. At the beginning of the semester, we advertised the study via TelegRAM (daily student mailing), flyers on both VCU campuses and surrounding cafes, and student social media groups. Each communication contained a link to the study website https://beloborodp.wixsite.com/stressreduction with more detailed information on the study purpose, the activities that the participants would engage in, the kinds of data that they would be requested to provide, as well as the link to the eligibility survey, hosted on REDCap. See eligibility survey in Appendix D and advertisement materials in Appendix E. Interested students

completed the survey, and it automatically determined their eligibility. Those who met the eligibility criteria were asked to provide their email address to get more detailed information about the study. If they agreed, they received an email invitation to the study and a link to request an online consent form. Once they signed it, they were randomly assigned to one of the training programs (mindfulness or control). For randomization, we used R to create a table containing a sequence of 4-digit random numbers (participant IDs) alongside a random sequence of 1's (mindfulness training) and 0's (control training). Each new participant was then assigned the next available ID and the corresponding group. Following randomization, participants received an invitation to an online study onboarding meeting where they installed the AWARE app, connected it to the study, and received training on completing the EMA surveys. Participants were invited to complete the baseline pre-training survey one week before the start of the EMA surveys. EMA and smartphone data collection spanned five weeks, including one week before the training, two weeks of the mindfulness or control training, one week after the training, and one week at end of the semester. In addition to that, after the training and at the end of the semester, the participants completed the same measures as at baseline. For other study purposes not reported here, they also participated in a phone interview after the training. Table 3 depicts the approximate data collection calendar. Actual data collection dates were adjusted to the VCU academic calendar.

Table 3
Data Collection Calendar

Semester week	Activity
Week 1-7	Participant recruitment
Week 8-9	Random assignment into mindfulness and control training groups Initial lab visits (AWARE installation, EMA training) Baseline (pre-training) measures
Week 9	Pre-intervention smartphone and EMA data collection

Weeks 10-11	Smartphone and EMA data collection Mindfulness and control training (according to participants' groups)
Week 12	Post-training passive sensing and EMA data collection Phone interviews
Week 13	Post-training measures Phone interviews
Week 16	Follow-up smartphone and EMA data collection Follow-up measures

A team of research assistants monitored study protocol adherence daily and contacted participants by phone, voice mail, or text messages if they missed one or more of the previous day's EMA surveys or did not complete previous day's training. Compensation structure was designed to incentivize the participants to keep up with the study as they were paid only for the parts that they completed. If participants missed lessons, they received an email with a schedule to compete two lessons per day until they caught up with the training program, as well as a warning that their participation would be stopped if they did not complete the training program. Participants who missed more than six out of 14 lessons or more than six EMA surveys in a row were withdrawn from the study to preserve data quality and optimize study funding allocation. The conditions of their participation were listed in the consent form. Participant attrition is depicted in Fig. 1.

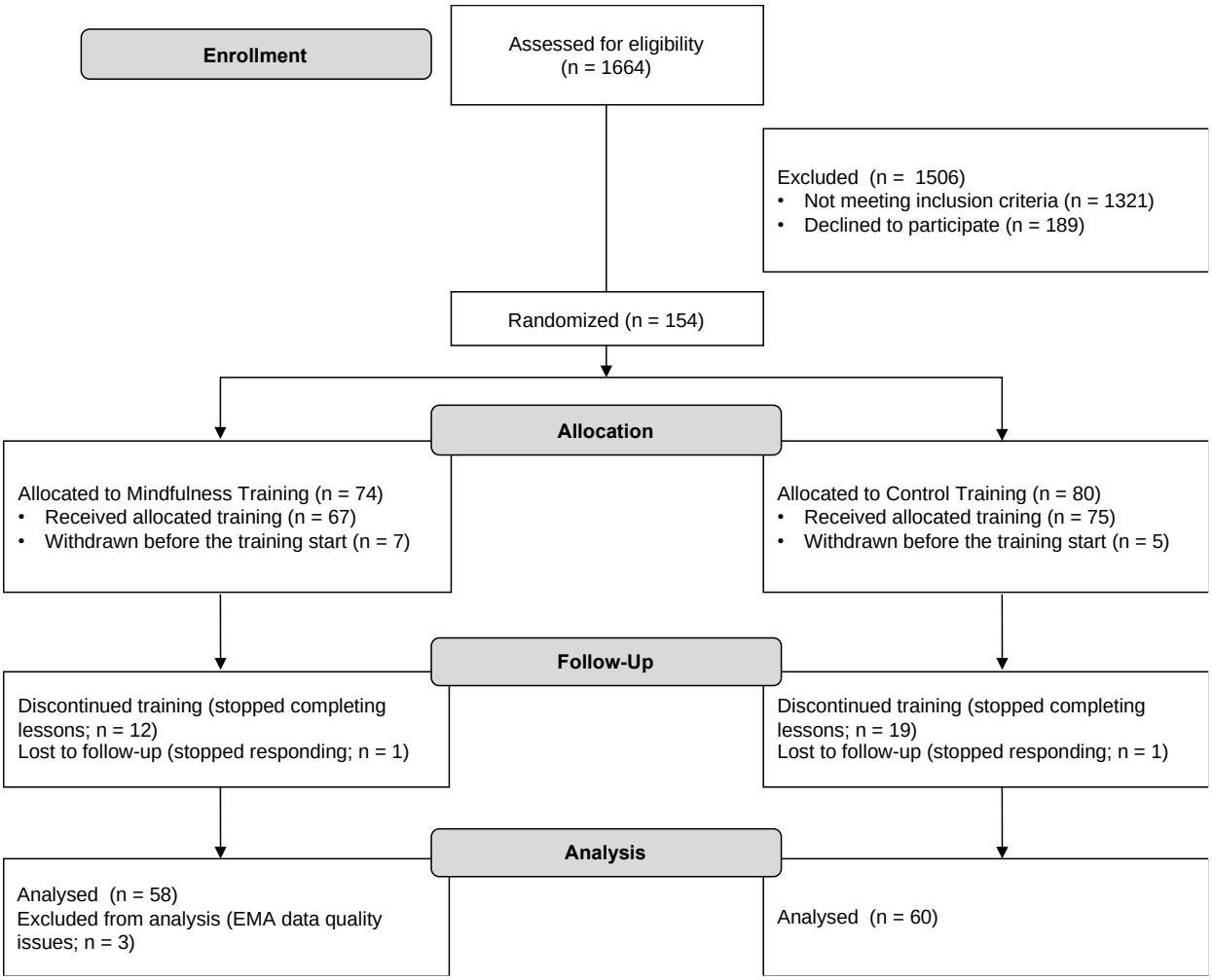

Figure 1. CONSORT flow diagram

As shown in Fig. 1, 21.8% of the participants who started the training did not complete it. The majority of participants who did not complete the study ceased responding to communications. Among those who provided reasons for withdrawal, most cited the intensity of the study, particularly the training, exceeding their expectations, or noted changes in their schedule that made it difficult to accommodate.

Data Analysis

Data Preparation

The baseline survey scales were averaged to obtain a single score for each variable. If a participant completed less than half of the scale items, their mean score was set to missing. State mindfulness scores were averaged in the same manner for each EMA survey. Additionally, time variables were added to the EMA dataset: EMA index, (an ordinal EMA identifier, starting with 1 as the first EMA survey of the study), time of day (1 = *morning*, 2 = *afternoon*, 3 = *evening*), study day (from 1 to 35), day of the week (from 1 = *Monday* to 7 = *Sunday*), and study period (pre-training, training, post-training, and follow-up).

Smartphone data was processed through the Reproducible Analysis Pipeline for Data Streams (RAPIDS; Vega et al., 2021) that permits extraction of behavioral features (aggregates of the raw data) in different time segments. In this study, we calculated the amount of various social behaviors in daily (24-hour) time periods. For the calling behaviors (the focus of this dissertation), this resulted in the following features: call in frequency, call in duration, call out frequency, call out duration, missed call frequency. The feature extraction procedure unveiled inconsistencies in data collection between iPhone and Android participants. To ensure uniformity, we relied on the data from iPhone participants (n = 93).

Statistical Models

Aim 1

Aim 1 hypothesis stated that there would be a significant improvement in emotional experience between the baseline and post-training assessment in the mindfulness training group, relative to the control group. Anxiety and depressive states had zero-inflated distributions, with a large share of the participants choosing the lowest values on these scales. Happiness had a close to Gaussian distribution. Estimating the preregistered Restricted Maximum Likelihood multilevel models on depressive feelings and anxiety resulted in a distribution of residuals that substantially

deviated from Gaussian (see residual plots in Appendix F, supplemental fig. 1). We attempted square root, log, and inverse data transformations to reduce skewness in these outcomes, however their distribution remained zero-inflated (see histograms of raw and transformed data in Appendix F, supplemental fig. 2). Model misspecification reflected in non-Gaussian residuals distribution may lead to incorrect estimation of model parameters and standard errors, resulting in incorrect calculation of *p*-values (Loy & Hofmann, 2013). Thus, we decided to deviate from the preregistered analysis in the modelling of intervention effects on depressive feelings and anxiety.

To account for the zero-inflated part in anxiety and depressive states, we tested the training effects on these outcomes with a zero-inflated Gaussian multilevel piecewise regression model[2] with random intercepts, estimated using the *NBZIMM* R package (Zhang & Yi, 2020). Zero-inflated models consist of two submodels: (1) a logistic multilevel model fitted using Penalized Quasi-Likelihood to estimate the probability of the outcome being zero or a positive value and (2) a linear multilevel model fitting the non-zero responses using Maximum Likelihood. To model mindfulness training effects on happiness, we estimated a single Restricted Maximum Likelihood multilevel model with random intercepts and slopes that did not contain a zero-inflated part, with the *nlme* R package (Pinheiro & Bates, 2022).

Multilevel models are well-suited for grouped data, in our case, EMA surveys (Level 1) nested within participants (Level 2). They can incorporate tests of the three primary characteristics that commonly appear in time-serial data: linear trend over time, regular cyclicity over intervals of time (e.g., daily and weekly), and serial autocorrelation (West & Hepworth, 1991). Piecewise

[2] Sometimes multilevel models are referred to as hierarchical models, random effects models, random coefficient models, or mixed models.

models allow comparison of scores in different time periods. Our study contains four time periods: pre-training (baseline), training, post-training, and end of semester (follow up). They were coded as dummy variables, with the pre-training period as a base. We determined an optimal residuals covariance structure (unstructured, variance components, or autoregressive) for the happiness model with a chi-square test comparing the –2 restricted log likelihood model fit indices. Autoregressive (AR-1) structure was supported. The *NBZIMM* R package does not support model comparison. We chose the autoregressive (AR-1) covariance structure for the depressive states and anxiety models, given the intensive longitudinal nature of the data.

Each outcome in both zero-inflated and Gaussian submodels was regressed on the following variables: study cohort (with Spring 2023 as a baseline category), time (EMA index), weekly cyclicity (calculated by applying a sine or cosine transformation to a day-of-week variable), and time of day. To test the effects of the mindfulness-based vs. control training, we included cross-level interactions between the study period (Level 1), and training program (Level 2; coded as 0 = *control training*, 1 = *mindfulness training*) variables. All time-related variables except weekly cyclicity were pre-treated so that they included zero as the lowest value. The Gaussian submodel, as well as the single model for happiness, were based on the equations presented below. The zero-inflated logistic submodel was based on the equations with the same predictors, modelling the probability of the outcome being non-zero.

Level one (EMA surveys):

$$Y_{ij} = \beta_{oj} + \beta_{1j} time_{ij} + \beta_{2j} weekcycle_{ij} + \beta_{3j} time\ of\ day_{ij} + \beta_{4j} training\ period_{ij} + \beta_{5j} post\ training\ period_{ij} + \beta_{6j} follow\ up\ period_{ij} + r_{ij} \quad (1.1)$$

where Y_{ij} is the score on the outcome variable (depressive states, anxiety, or happiness) for an individual observation at Level 1 (subscript *i* refers to EMA survey, subscript *j* refers to participant);

β_{0j} is the intercept of the outcome variable in participant *j* (Level 2);

β_{1j}, β_{2j}, …, β_{6j} are the slopes for the relationship in participant *j* (Level 2) between the Level 1 predictors and the outcome variable;

r_{ij} is the random error of prediction for the Level 1 equation.

Level two (participants):

$$\beta_{oj} = \gamma_{00} + \gamma_{01} cohort + \gamma_{02} mindfulness\ training + u_{0j} \quad (1.2)$$

where γ_{00} is the intercept (the grand mean of the emotional well-being scores) of a Fall wave participant, enrolled in the control training;

γ_{01} and γ_{01} are the slopes between the intercept of a participant and Level 2 predictors;

u_{0j} is the random error component for the deviation of the intercept of a participant from the overall intercept.

$$\beta_{1j} = \gamma_{10} + \gamma_{11} cohort + \gamma_{12} mindfulness\ training + u_{1j} \quad (1.3)$$

where γ_{10} is the average slope between time variable and emotional well-being of a Fall wave participant, enrolled in the control training;

γ_{11} and γ_{12} are the average slopes between the Level 1 predictors and outcome, as moderated by Level 2 predictors (cohort and training program);

u_{1j} is the error component for the slope (the deviation of the individual participant slopes from the overall sample slope).

Equations for β_{2j}, …, β_{6j} coefficients are similar to β_{1j}.

After substituting the Level 2 equations into the Level 1 equation, we obtain the full regression model (not presented here for the sake of brevity). The full model includes the following cross-level interactions: γ_{42}mindfulnes training × training period$_{ij}$; γ_{52} mindfulnes training × post-training period$_{ij}$; and γ_{62} mindfulnes training × follow up period$_{ij}$ where regression coefficients γ_{42}, γ_{52}, and γ_{62} show the change in the outcome in different periods in the mindfulness training group, relative to the control group. Based on the previous study that used the same intervention (Lindsay et al., 2019), as well as other studies on the effects of smartphone-delivered mindfulness-based interventions (Taylor et al., 2021), we expect that the participants in the mindfulness training group will enjoy a higher positive training effect on their emotional experience in the training and post-training periods than participants in the control group. Research on longer-term smartphone mindfulness training effects is mixed, hence we examine training effects in the follow-up (end of semester) period exploratorily, without setting formal hypotheses.

Aim 2

First, we provide an overview of single-level parallel mediation analysis and conditions for establishing causality. Then, we introduce multilevel mediation analysis and present our model equations. In mediation analysis, the effect of one variable is transmitted to another through an intervening variable (mediator), as shown in Figure 2. The effect of a predictor variable on an outcome through a mediator is known as the *indirect effect*, whereas the effect of a predictor on an outcome independent of a mediator is labeled the *direct effect*.

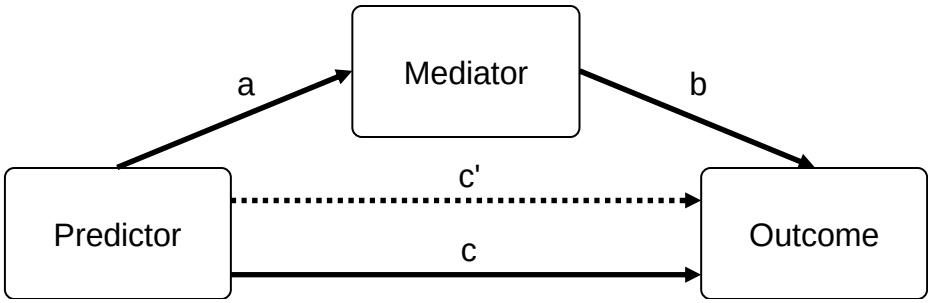

Figure 2. Mediation Diagram

Those effects are often estimated using the following equations:

$$M_1 = \beta_0 + \beta_a X_i + r_i \quad (2.1)$$

$$Y_i = \beta_0 + \beta_c X_i + r_i \quad (2.2)$$

$$Y_i = \beta_0 + \beta_{c'} X_i + \beta_b M_i + r_i \quad (2.3)$$

where *Y* is the outcome variable, *X* is the predictor variable, *M* is the mediator. The slope β_c (the expected change in *Y*, resulting from a one unit change in *X*) is the total effect, and $\beta_{c'}$ (the expected change in *Y*, resulting from a one unit change in *X* while holding *M* constant) is the direct effect. The indirect effect (the expected change in Y through M resulting from a one unit change on X) is the product of β_a and β_b slopes. Total effect is equal to the sum of direct and indirect effects: $\beta_c = \beta_{c'} + \beta_a\beta_b$.

A fundamental requirement for establishing causality is that cause must precede the effect in time (Shadish et al., 2002). To fulfill this requirement, we used only the post-intervention EMA data in this analysis. We also used lagged EMA mediator measurements, such that afternoon emotional experience is predicted by morning social well-being, and evening emotional experience is predicted by afternoon social well-being. We excluded cross-day predictions (evening → next morning) as previous research showed within-day relations to be

more robust than cross-day relations (Brown & Ryan, 2003). Another causal inference requirement termed sequential ignorability, postulates that all relationships in the causal chain ($X \rightarrow M$, $M \rightarrow Y$, $X \rightarrow Y$) should not be confounded by variables measured prior to X (Emsley et al., 2010, Imai et al., 2010). In our study, X (training program) is randomly assigned, hence this condition automatically holds for $X \rightarrow M$ and $X \rightarrow Y$ relationships. Although M (subjective social well-being) is not randomly assigned, we relied on groups' equivalence to rule out the effects of the variables measured prior to X on the $M \rightarrow Y$ relationship.

In nested data, predictors, mediators, and outcomes can be collected at different levels of the hierarchy (within and between participants). To account for this, we used the multilevel modeling framework to test the hypothesized mediation effects. We estimated 2-1-1 multilevel mediation models where 2 denotes the initial variable in the mediation chain (training program, a between participant Level 2 variable), the first 1 denotes the mediator (EMA-measured loneliness or felt connection to others, within participants Level 1 variables), and the second 1 denotes the outcome (EMA-measured depressive feelings, anxiety, or happiness, also within participant Level 1 variables). We estimated separate multilevel mediation models for each combination of mediator and outcome variables, six models in total. In a 2-1-1 multilevel mediation model, equations 2.1-2.3 are modified to reflect the hierarchical data structure and measurement levels of Y, M, and X (Krull & MacKinnon, 2001), such that

$M_1 = \beta_0 + \beta_a X_i + r_i$ becomes

Level 1: $M_{ij} = \beta_{0j} + r_{ij}$ (2.4)

Level 2: $\beta_{0j} = \gamma_{00} + \gamma_a X_i + u_{0i}$ (2.5)

$Y_i = \beta_0 + \beta_c X_i + r_i$ becomes

Level 1: $Y_{ij} = \beta_{0j} + r_{ij}$ (2.6)

$$\text{Level 2: } \beta_{0j} = \gamma_{00} + \gamma_c X_i + u_{0i} \quad (2.7)$$

$Y_i = \beta_0 + \beta_{c'} X_i + \beta_b M_i + r_i$ becomes

$$\text{Level 1: } Y_{ij} = \beta_{0j} + \beta_b \mathrm{M}_{ij} + r_{ij} \quad (2.8)$$

$$\text{Level 2: } \beta_{0j} = \gamma_{00} + \gamma_{c'} X_j + u_{0j} \quad (2.9)$$

Mediator *M* is included in Level 1 equations, while *X* is included as a predictor of individual participant intercepts in Level 2 equations. While the $\beta_c - \beta_{c'}$ and $\beta_a\beta_b$ indirect effect estimates in single level models are algebraically equivalent, their multilevel analogues $\gamma_c - \gamma_{c'}$ and $\gamma_a\beta_b$ are not exactly equivalent due to the fixed effects estimation procedure. The discrepancy however becomes negligible at larger sample sizes (for more details, see Krull and MacKinnon, 1999).

The indirect effect is calculated as $\gamma_c - \gamma_{c'}$ or $\gamma_a\beta_b + \sigma_{\gamma a \beta b}$, the product of a-path and b-path regression coefficients, adjusted for their covariance. To account for temporal trends, we added Level 1 time, weekly cyclicity, and time of day variables similarly to Aim 1. We also controlled for cohort effects. We used a stacking method proposed by Bauer et al. (2006) to account for covariance between model parameters and estimate all paths simultaneously in a single equation (not presented here for the sake of brevity) using the *nlme* R package (Pinheiro et al., 2020). A significant γ_c regression coefficient indicates that there is a direct mindfulness training effect on emotional experience. Most importantly, if it significantly drops after accounting for social well-being, this means that social well-being mediates the training effect.

Aim 3

Prior to examining the relationships stated in exploratory Aim 3 (evaluate the effects of mindfulness training on overt social behaviors), we conducted exploratory analysis of the

smartphone-sensed sociability indicators and their trajectories in the two training groups. Harari et al. (2020) showed that there is substantial variability in smartphone-sensed social behavior features, so exploratory analysis is a necessary first step. Following Harari et al.'s (2020) example, we created line plots depicting smartphone-sensed behavioral features, aggregated across participants in each training program for each day of the study. This allowed us to visually examine the changes in the various sociability indicators during the study period and compare them between the programs. We calculated Spearman[3] correlation coefficients between the smartphone-measured call features and EMA-measured social behaviors aggregated at the day level and loneliness and felt connection, also aggregated at the day level. Those correlations show the strength of the relationship between behavioral sociability measures and subjective social well-being in our sample. After this preliminary step, we proceeded to statistical modeling.

To reduce the number of outcomes, we applied principal components analysis (PCA) with oblique (oblimin) rotation to the call features and chose the number of components to retain based on the share of explained variance, scree plot, and the interpretability of the resulting solutions. Similarly to Harari et al.'s (2020) study, we expect that PCA yields a one-component solution that will include all call features. Then we estimated the same multilevel models as for Hypothesis 1, but using the PCA-derived components as outcomes.

Results

Data Quality

We used the following procedures to check data quality. First, we calculated each participant’s training adherence rate as the number of completed lessons. The majority of the

[3] We use Spearman (instead of Pearson) correlation coefficients because based on the Harari et al. (2020) study, we expect that smartphone-sensed social behaviors will show high kurtosis values.

participants (70%) completed all lessons. The Mann Whitney U Test showed that adherence rates did not differ between the mindfulness and control groups (p = .604). To ensure high EMA data quality, we excluded the data of three participants who completed less than 70% of the EMA surveys. Apart from these cases, compliance with the EMA protocol was good: participants completed from 70.5% to 100% of the surveys (M = 90.8%, SD = 7.01%). The percentage of participants who responded to a given EMA survey prompt ranged from 74.3% to 97.1% (M = 87.8%, SD = 5.22%). Next, we assessed the quality of the daily call features data. For analyses that involved these variables, we retained only cases with data available for more than 70% of the study days (n = 68), removing the data of 25 participants. Finally, we ran a series of t-tests with Bonferroni-Holm correction to compare the baseline levels of positive and negative emotions, depression and anxiety symptoms, loneliness, social support, and trait mindfulness in the mindfulness and control training groups to ensure that they were equivalent. We did not observe any significant baseline differences across the variables (p's > .336). Thus, randomization was successful.

Aim 1: Mindfulness Training Effects on Emotional Experience

First, we review mindfulness training effects on depressive feelings and anxiety, evaluated with zero-inflated Gaussian multilevel piecewise regression models. The upper part of Table 4 presents the Gaussian submodel (modelling only the non-zero part of the distribution), and the lower part presents the zero-inflated submodel (modelling the probability of the outcome being above zero).

Table 4
Mindfulness training effects on depressive states and anxiety (all samples)

	Depressive State			Anxiety		
Gaussian Submodel						
Predictors	*B*	*95% CI*	*p*	*B*	*95% CI*	*p*
(Intercept)	1.26	1.04 – 1.47	<.001	1.76	1.54 – 1.98	<.001
Cohort (Fall 2023)	–0.19	–0.46 – 0.09	.185	–0.08	–0.35 – 0.19	.574
Cohort (Spring 2024)	0.04	–0.26 – 0.35	.779	–0.06	–0.36 – 0.24	.684
Weekcycle (sine)	–0.02	–0.05 – 0.01	.157	0.05	0.02 – 0.07	.001
Time of day	0.01	–0.01 – 0.03	.208	–0.02	–0.0406 – –0.0004	.055
EMA index	0.001	–0.001 – 0.003	.354	–0.001	–0.003 – 0.002	.593
Group (MT)	0.05	–0.21 – 0.29	.719	–0.11	–0.35 – 0.13	.369
Training period	0.07	–0.02 – 0.16	.133	0.02	–0.07 – 0.11	.679
Post-training period	–0.09	–0.24 – 0.06	.241	–0.04	–0.19 – 0.11	.590
Follow-up period	–0.05	–0.24 – 0.14	.637	0.08	–0.11 – 0.27	.412
Group × Training period	–0.01	–0.10 – 0.08	.875	0.06	–0.03 – 0.15	.168
Group × Post-training period	–0.01	–0.12 – 0.10	.848	0.04	–0.07 – 0.14	.485
Group × Follow-up period	–0.17	–0.28 – –0.07	.002	0.05	–0.06 – 0.16	.354
Random Effects						
σ^2		0.30			0.46	
τ_{00}		0.39			0.37	
ICC		0.565			0.445	
Marginal R^2 / Conditional R^2		.021 / .574			.007 / .449	
Zero-Inflated Submodel						
Predictors	*OR*	*95% CI*	*p*	*OR*	*95% CI*	*p*
(Intercept)	1.58	0.81 – 3.10	.183	0.38	0.19 – 0.78	.008
Cohort (Fall 2023)	1.41	0.61 – 3.25	.412	1.30	0.54 – 3.12	.550
Cohort (Spring 2024)	0.41	0.16 – 1.03	.059	1.00	0.38 – 2.64	1.000
Week cycle (sine)	0.91	0.85 – 0.97	.004	1.12	1.07 – 1.18	<.001
Time of day	0.99	0.94 – 1.04	.755	0.99	0.99 – 1.00	.029

EMA index	1.01	1.00 – 1.01	.026	0.82	0.76 – 0.87	<.001
Group (MT)	0.85	0.41 – 1.78	.668	0.88	0.41 – 1.90	.741
Training period	0.67	0.54 – 0.84	<.001	0.87	0.69 – 1.09	.217
Post-training period	0.76	0.53 – 1.11	.153	1.19	0.82 – 1.74	.367
Follow-up period	0.52	0.33 – 0.84	.007	1.40	0.87 – 2.26	.168
Group × Training period	1.13	0.90 – 1.40	.291	1.16	0.93 – 1.44	.199
Group × Post-training period	0.88	0.68 – 1.14	.325	1.00	0.77 – 1.29	.982
Group × Follow-up period	0.96	0.74 – 1.24	.740	0.88	0.68 – 1.14	.335
Random Effects						
σ^2		3.29			3.29	
τ_{00}		3.60			3.93	
ICC		.522			.544	
Marginal R^2 / Conditional R^2		.035 / .539			.007 / .548	
N_{ID}		112			112	
Observations		10169			10191	

Note. B = unstandardized regression coefficient; CI = confidence interval; EMA = ecological momentary assessment; MT = mindfulness training; σ^2 = level-1 residual variance; τ_{00} = variance in individual intercepts; ICC = intraclass correlation coefficient; N_{ID} = number of participants; marginal R^2 = proportion of variance in the outcome explained by fixed effects only; conditional R^2 = proportion of variance explained by fixed and random effects together.

As shown in Table 4, the non-zero Gaussian part of the depressive feelings scores did not display any temporal trends. The probability of reporting above-zero depression scores was lower during the middle of the week and higher towards the weekend, as evidenced by odds ratio < 1. It also increased throughout the study, as shown by odds ratio > 1 for the EMA index variable. Moreover, the probability of experiencing above-zero depressive states decreased during the training and follow-up periods for both the mindfulness and control groups, compared to the pre-training period, indicated by a significant main effect for the “post-training period” and “follow-up period” terms. However, due to the absence of a passive control group, we cannot conclusively attribute this effect to the training. Participants in the mindfulness training

group were not more likely to report zero depressive feelings than the control group participants in either training, post-training, or follow-up period (p's > .291). Importantly, when they reported above-zero depression, mindfulness group scores were significantly lower than control group scores in the follow-up period. However, there was no effect on above-zero depression scores in the training and post-training period (p > .848). The effects of mindfulness training on depressive states are illustrated in Fig. 3. The upper part of the figure displays the average non-zero depressive feelings, and the lower part shows the share of zero depressive feeling reports in the MT and CT groups in each study period.

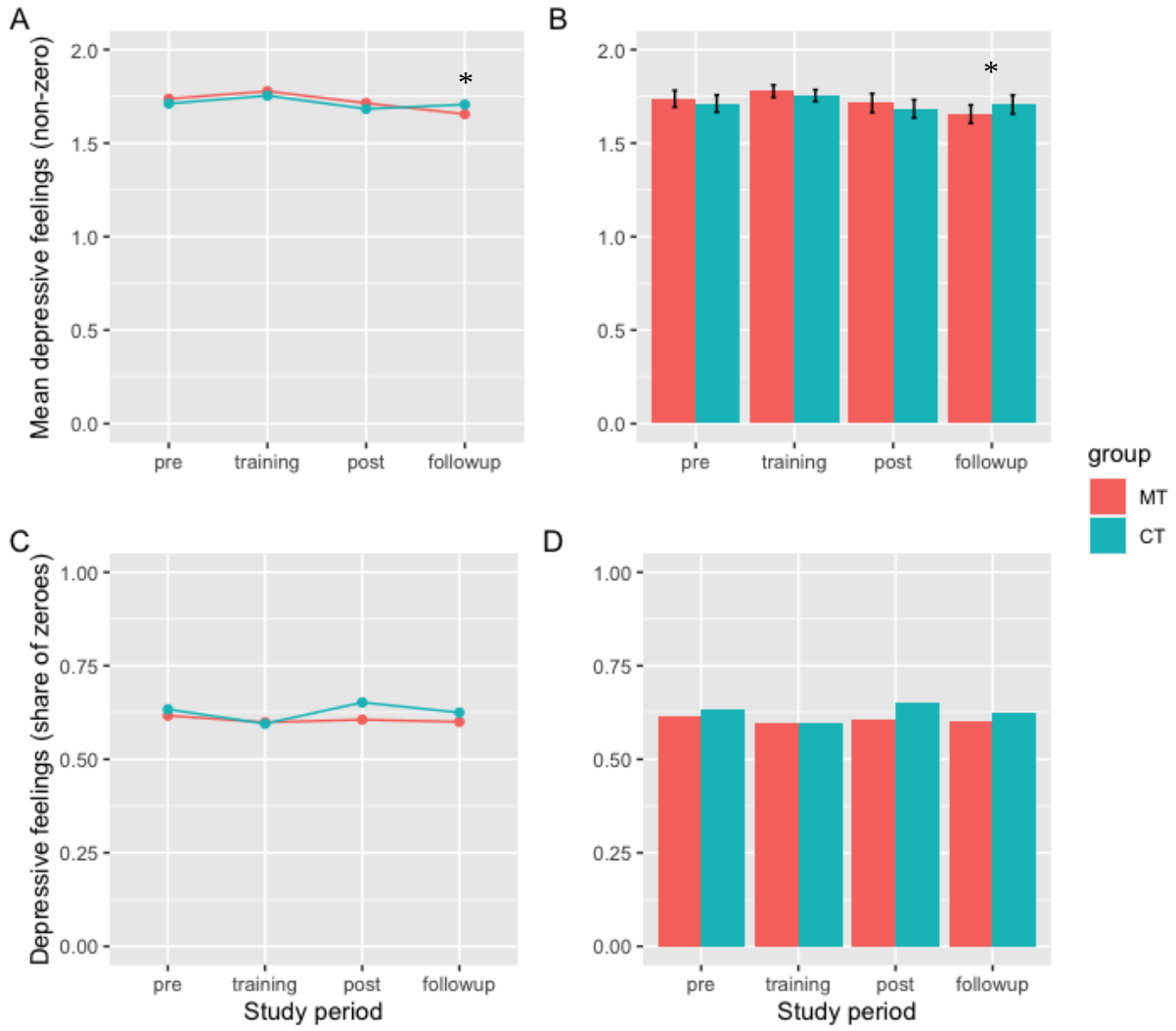

Figure 3. Average non-zero (A, B) and the share of zero depressive feelings scores (C, D) across the study; MT = mindfulness training; CT = control training; * significant group × study period interaction

Both the probability of above-zero anxiety, as well as actual above-zero anxiety scores grew toward the middle of the week and decreased closer to the weekend, as indicated by the significant week cycle trends. A odds ratio < 1 for time of the day indicated that the probability of reporting above-zero anxiety decreased throughout the day. The probability of reporting above-zero anxiety decreased throughout the study, as demonstrated by a significant odds ratio <

1 of EMA index. Participants in the mindfulness training group were not more likely to report zero anxiety than the control group participants in either training, post-training, or follow-up period (*p*'s > .199). The above-zero anxiety scores did not differ between mindfulness and control gtoups in any period (*p* > .168). These results are depicted in Fig. 4.

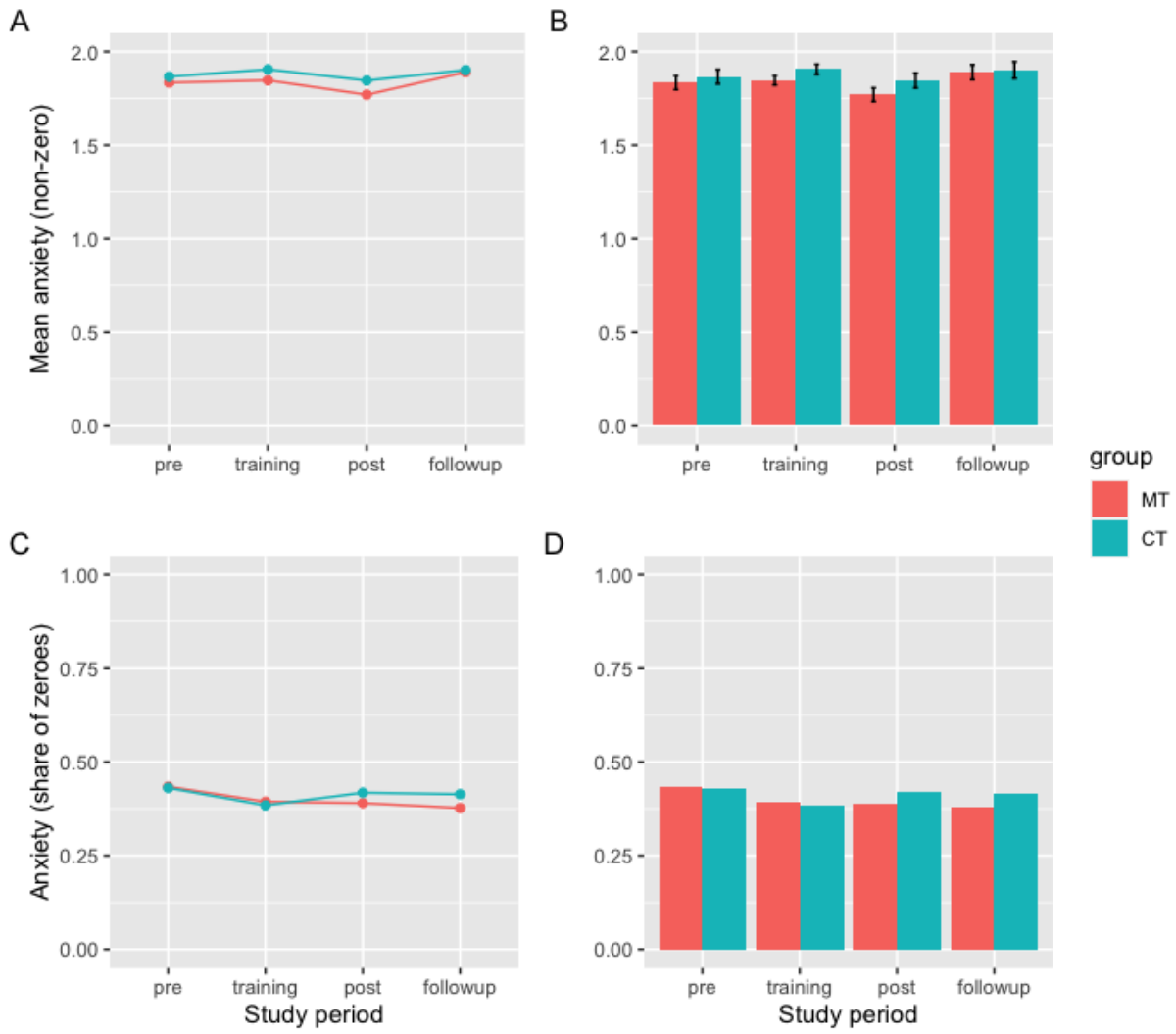

Figure 4. Average non-zero (A, B) and the share of zero anxiety scores (C, D) across the study; MT = mindfulness training; CT = control training

Mindfulness training effects on happiness estimated with a single Restricted Maximum Likelihood multilevel model are presented in Table 5.

Table 5
Mindfulness training effects on happiness (all samples)

Predictors	*B*	*95% CI*	*p*
(Intercept)	1.85	1.62 – 2.08	<.001
Cohort (Fall 2023)	–0.30	–0.57 – –0.02	.035
Cohort (Spring 2024)	–0.28	–0.58 – 0.03	.072
Week cycle (sine)	–0.10	–0.14 – –0.06	<.001
Time of day	0.11	0.08 – 0.14	<.001
EMA index	0.0002	–0.003 – 0.003	.918
Group (MT)	–0.24	–0.50 – 0.02	.074
Training period	–0.09	–0.22 – 0.04	.183
Post-training period	0.15	0.07 – 0.37	.173
Follow-up period	–0.07	–0.35 – 0.20	.598
Group × Training period	–0.05	–0.19 – 0.10	.545
Group × Post-training period	–0.15	–0.37 – 0.07	.191
Group × Follow-up period	–0.005	–0.27 – 0.28	.973
Random Effects			
σ^2		0.88	
τ_{00}		0.43	
τ_{11} ID / Week cycle (sine)		0.01	
τ_{11} ID / Time of day		0.02	
τ_{11} ID / EMA index		0.0001	
ρ_{01} ID / Week cycle (sine)		–0.18	
ρ_{01} ID / Time of day		0.07	
ρ_{01} ID / EMA index		–0.37	
N_{ID}		112	
Observations		10179	
ICC		0.36	
Marginal R^2 / Conditional R^2		0.042 / 0.386	

Note. B = unstandardized regression coefficient; CI = confidence interval; EMA = ecological momentary assessment; MT = mindfulness training; σ^2 = level-1 residual variance; τ_{00} = variance in individual intercepts; τ_{11} = variance in individual slopes; ρ_{01} = correlation between intercepts and slopes; ICC = intraclass correlation coefficient; N_{ID} = number of participants; marginal R^2 = proportion of variance in the outcome explained by fixed effects only; conditional R^2 = proportion of variance explained by fixed and random effects together.

Happiness exhibited temporal trends opposite to anxiety, decreasing towards the middle of the week and then increasing towards the weekend. Additionally, happiness tended to increase from the morning to the evening. Notably, participants undergoing mindfulness training did not show greater happiness during either the training, post-training, or follow-up periods (*p*'s > 191), as shown in Fig. 5.

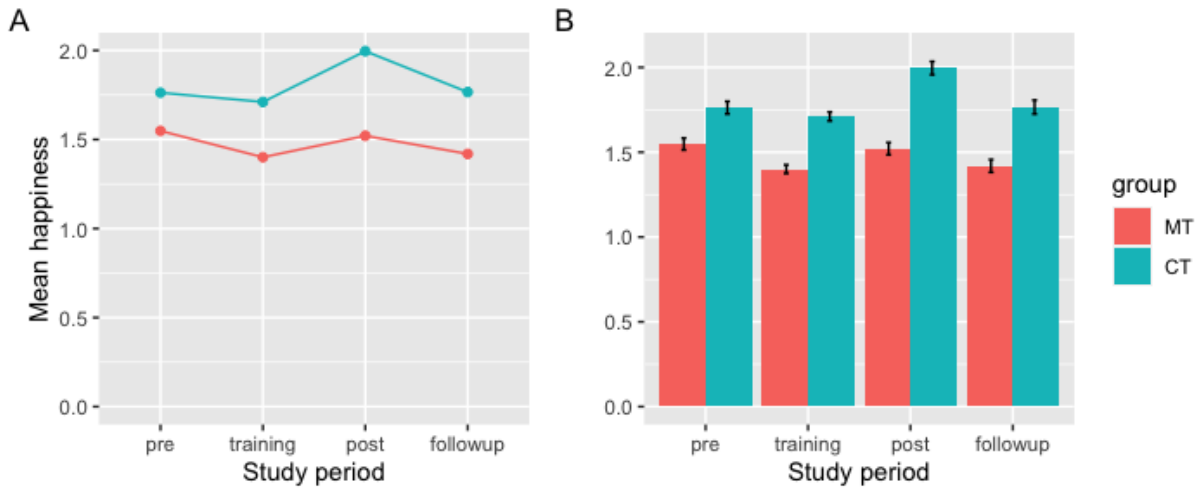

Figure 5. Average happiness scores across the study; MT = mindfulness training; CT = control training

In summary, mindfulness training did not lead to improved emotional experience compared to the control training during the program or in the post-training period. However, during the follow-up period, it resulted in lower above-zero depressive feelings scores.

Aim 2: Subjective Social Well-Being as Mediator

Before estimating the models, both mediator and outcome variables were mean-centered within participants, meaning that participant-specific averages were subtracted from each score. This adjustment enabled us to isolate and emphasize the within-subject connections among the variables. Additionally, it resulted in a more symmetric distribution of the mediators and outcomes, which facilitated model estimation. Next, we restructured the data using a stacking

method developed by Bauer et al. (2006). An excerpt of the resulting dataset is presented in Figure 3.

ID	Group	EMA Index	Week cycle (sine)	Time of day	Loneliness / depression	Loneliness	DM	DO
1177	0	3	0.975	1	0.706	0.706	1	0
1177	0	3	0.975	1	NA	0.706	0	1
1177	0	4	0.975	2	0.706	-0.294	1	0
1177	0	4	0.975	2	0	-0.294	0	1
1177	0	5	0.975	3	-0.294	0.706	1	0
1177	0	5	0.975	3	0	0.706	0	1

Figure 6. Stacked dataset excerpt. EMA = ecological momentary assessment; DM = dummy mediator; DO = dummy outcome

Structuring the dataset in this manner allowed estimating all mediation model paths in a single equation. The function of the DM and DO dummy variables is to select certain portions of the data matrix. The "× DM" interaction term selects the rows pertaining to the mediator (loneliness or felt connection to others) thereby allowing a submodel with mediator-specific intercepts and slopes. Similarly, the "× DO" interaction term selects the outcome (depressive state, anxiety, or happiness) rows only, allowing for an outcome-specific submodel. Intercepts were removed from the models to avoid singularity from including both DM and DO dummy variables. The results are presented in Tables 6 and 7

Table 6

Multilevel analyses of mindfulness training effects on emotional experience, mediated by loneliness (all samples)

	Depression			Anxiety			Happiness		
Predictors	*B*	*95% CI*	*p*	*B*	*95% CI*	*p*	*B*	*95% CI*	*p*
Group (MT) × DM (a-path)	–0.01	–0.06 – 0.03	.562	–0.01	–0.06 – 0.03	.561	–0.01	–0.06 – 0.03	.575
Cohort (Fall 2023) × DM	0.02	–0.03 – 0.08	.463	0.02	0.03 – 0.08	.459	0.02	–0.03 – 0.08	.458
Cohort (Spring 2024) × DM	–0.01	–0.06 – 0.05	.805	–0.01	–0.06 – 0.05	.806	–0.01	–0.07 – 0.05	.789
EMA index × DM	–0.001	–0.001 – 0.003	.135	–0.001	–0.001 – 0.003	.135	0.001	–0.001 – 0.003	.135
Week cycle (sine) × DM	0.04	0.01 – 0.08	.023	0.04	0.01 – 0.08	.023	0.04	0.01 – 0.08	.024
Time of day × DM	–0.01	–0.04 – 0.01	.194	–0.01	–0.04 – 0.01	.194	–0.01	–0.04 – 0.01	.195
Loneliness × DO (b-path)	0.39	0.32 – 0.46	<.001	0.26	0.19 – 0.34	<.001	–0.28	–0.35 – –0.20	<.001
Group (MT) × DO (c'-path)	–0.01	–0.05 – 0.04	.811	0.03	–0.04 – 0.09	.440	0.003	–0.06 – 0.07	.922
Cohort (Fall 2023) × DO	0.01	–0.05 – 0.06	.781	–0.02	–0.10 – 0.06	.618	0.02	–0.05 – 0.10	.524
Cohort (Spring 2024) × DO	0.003	–0.05 – 0.06	.921	0.02	–0.06 – 0.10	.658	0.01	–0.07 – 0.09	.783
EMA index × DO	–0.0004	–0.002 – 0.002	.723	0.003	0.0004 – 0.0061	.027	–0.01	–0.008 – 0.003	<.001
Week cycle (sine) × DO	–0.003	–0.04 – 0.03	.851	0.12	0.07 – 0.17	<.001	–0.17	–0.22 – –0.12	<.001
Time of day × DO	0.003	–0.02 – 0.03	.764	–0.04	–0.07 – –0.01	.016	0.07	–0.04 – 0.10	<.001
Random Effects									
σ^2		0.49			0.49			0.49	
$\tau_{11\ ID\ /\ Loneliness \times DO}$		0.07			0.05			0.07	
$\tau_{11\ ID\ /\ Group \times DO}$		<0.001			<0.001			<0.001	
$\rho_{01\ a\text{-}path\ \&\ b\text{-}path}$		.24			–0.32			–0.92	
$\rho_{01\ a\text{-}path\ \&\ c'\text{-}path}$		–.002			0.001			0.001	
ICC		0.03			0.04			0.03	
N_{ID}		112			112			112	
Observations		5823			5828			5822	
Marginal R^2 / Conditional R^2		.062 / .091			.037 / .056			.047 / .074	

Note: B = unstandardized regression coefficient; CI = confidence interval; MT = mindfulness training; EMA = ecological momentary assessment; DM = mediator dummy variable; DO = outcome dummy variable; σ^2 = level-1 variance after adjusting for predictors; τ_{11} = variance in individual slopes; ρ_{01} = correlation between individual a- and b-path slopes; ICC = intraclass correlation coefficient; N_{ID} = number of participants; marginal R^2 = proportion of variance in the outcome explained by fixed effects only; conditional R^2 = proportion of variance explained by fixed and random effects together.

Table 7
Multilevel analyses of mindfulness training effects on emotional experience, mediated by felt connection to others (all samples)

	Depression			Anxiety			Happiness		
Predictors	*B*	*95% CI*	*p*	*B*	*95% CI*	*p*	*B*	*95% CI*	*p*
Group (MT) × DM (a-path)	0.001	–0.06 – 0.06	.972	0.001	–0.06 – 0.06	.972	0.001	–0.06 – 0.06	.966
Cohort (Fall 2023) × DM	–0.02	–0.10 – 0.05	.533	–0.02	–0.10 – 0.05	.532	–0.02	–0.10 – 0.05	.517
Cohort (Spring 2024) × DM	0.01	–0.07 – 0.08	.882	0.01	–0.07 – 0.08	.881	0.01	–0.07 – 0.08	.895
EMA index × DM	0.002	–0.0001 – 0.0049	.058	0.002	–0.0001 – 0.0049	058	0.002	–0.0001 – 0.0049	.058
Week cycle (sine) × DM	–0.10	–0.14 – –0.05	<.001	–0.10	–0.14 – 0.05	<.001	–0.10	–0.14 – –0.05	<.001
Time of day × DM	–0.02	–0.05 – –0.01	.171	–0.02	–0.05 – 0.01	.171	–0.02	–0.05 – 0.01	.175
Connection × DO (b-path)	–0.13	–0.18 – –0.09	<.001	–0.10	–0.15 – –0.05	<.001	0.43	0.38 – 0.48	<.001
Group (MT) × DO (c'-path)	–0.01	–0.05 – 0.06	.845	0.03	–0.04 – 0.10	.407	0.004	–0.05 – 0.06	.886
Cohort (Fall 2023) × DO	–0.003	–0.06 – 0.06	.929	–0.03	–0.10 – 0.05	.510	0.002	–0.07 – 0.07	.961
Cohort (Spring 2024) × DO	–0.001	–0.06 – 0.06	.969	0.02	–0.06 – 0.11	.609	0.01	–0.06 – 0.08	.805
EMA index × DO	0.0001	–0.002 – 0.002	.961	0.003	0.001 – 0.006	.022	–0.01	–0.008 – 0.003	<.001
Week cycle (sine) × DO	0.01	–0.03 – 0.05	.509	0.13	0.07 – 0.18	<.001	–0.13	–0.18 – –0.09	<.001
Time of day × DO	0.003	–0.02 – 0.03	.798	–0.04	–0.069 – –0.005	.025	0.05	0.03 – 0.08	<.001
Random Effects									
σ^2		0.86			0.86			0.86	
$\tau_{11\ ID\ /\ Connection\ \times\ DO}$		0.04			0.02			0.03	
$\tau_{11\ ID\ /\ Group\ \times\ DO}$		<0.001			<0.001			<0.001	
$\rho_{01\ a\text{-}path\ \&\ b\text{-}path}$		–0.27			–0.06			0.86	
$\rho_{01\ a\text{-}path\ \&\ c'\text{-}path}$		0.003			<0.001			<0.001	
ICC		0.02			0.01			0.02	
N_{ID}		112			112			112	
Observations		5818			5823			5817	
Marginal R^2 / Conditional R^2		.013 / .028			.014 / .024			.086 / .100	

Note: B = unstandardized regression coefficient; CI = confidence interval; MT = mindfulness training; EMA = ecological momentary assessment; DM = mediator dummy variable; DO = outcome dummy variable; σ^2 = level-1 variance after adjusting for predictors; τ_{11} = variance in individual slopes; ρ_{01} = correlation between individual a- and b-path slopes; ICC = intraclass correlation coefficient; N_{ID} = number of participants; marginal R^2 = proportion of variance in the outcome explained by fixed effects only; conditional R^2 = proportion of variance explained by fixed and random effects together.

As demonstrated in Tables 6 and 7, there was no mindfulness training effect on any of the mediators (loneliness and felt connection to others; a-path) or outcomes (depressive state, anxiety, and happiness; c'-path) in the post-training and follow-up periods. However, loneliness and connection did predict emotional experience at the next time point (b-path). For an average participant, each additional loneliness scale point resulted in 0.39 added depression and 0.26 anxiety scale points, as well as 0.28 less happiness scale points a few hours later. The model predicts that based on the variance in slopes (square root of $\tau_{11\ \mathrm{ID\ /\ Loneliness \times DO}}$), approximately 95% of the individuals similar to our sample experience loneliness effects on depression in the range $0.39 \pm 1.96 * 0.27$, that is, –0.14 to 0.92, a remarkable variability. The range of loneliness effects on anxiety and happiness is estimated as [–0.18, 0.70] and [–0.80, 0.24] respectively. On the other hand, feeling one scale point more connected to others led to a 0.13 [–0.52, 0.26] points depressive state and 0.10 [–0.38, 0.18] points anxiety decrease, as well as 0.43 [0.09, 0.77] points greater happiness.

To summarize, we did not observe neither direct effect of the mindfulness training on emotional states, nor an indirect effect through social well-being. However, on average greater social well-being consistently predicted improved emotional experience at the next time point, with substantial variability in individual effects.

Aim 3: Mindfulness Training Effects on Social Behavior

As of the current writing, data processing for the Spring 2024 sample end-of-semester period is still underway. Here, we present the results encompassing the pre-training, training, and post-training study periods. Before conducting statistical modeling to assess the effects of mindfulness training, we review line plots illustrating aggregated social behaviors for each day of the study, for mindfulness and control training participants (Fig. 4). Daily interactions were

computed by summing the instances when a participant reported having interacted with another person since the last EMA survey. Similarly, daily social proximity was determined by summing the instances when a participant reported being in the presence of other people in an offline setting. Both daily call features and social behaviors exhibited significant skewness, with a considerable portion of participants not making, receiving, or missing any calls. Similarly, participants often did not report being in the presence of others or engaging in social interactions. Therefore, we opted to aggregate the data using the median instead of the mean.

Figure 7. Social behaviors in the mindfulness and control group (n = 68)

Upon visual inspection of the line plots presented in Fig. 4, no consistent differences were observed between the social behaviors of the mindfulness and control group participants. Some days exhibited greater sociability among mindfulness training participants, while on other days, control training participants were more social. Next, we calculated Spearman correlations of loneliness and felt connection with call features (Table 10) and social behaviors (Table 11).

Table 8
Spearman correlations of subjective social well-being and call features (n = 68)

Variable	1	2	3	4	5	6	7
1. Median daily loneliness	1	–0.078***	–0.028	–0.015	0.0099	–0.0068	–0.019
2. Median daily felt connection to others		1	0.047	–0.034	0.03	0.0019	–0.068**
3. Daily incoming call frequency			1	0.41***	0.34***	0.75***	0.23***
4. Daily outgoing call frequency				1	0.35***	0.28***	0.73***
5. Daily missed call frequency					1	0.27***	0.23***
6. Daily incoming call duration						1	0.21***
7. Daily outgoing call duration							1

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < .001$

As depicted in Table 10, median daily loneliness was not significantly correlated with any of the call features. Median daily connection to others was weakly, but significantly correlated with daily outgoing call duration. Surprisingly, the correlation coefficient was negative, indicating that making longer calls was associated with lower felt connection. As expected, all call features, were significantly positively correlated.

Table 9
Spearman correlations of subjective social well-being and social behavior (n = 121)

	1	2	3	4
1. Median daily loneliness	1	–0.058**	–0.14***	0.035
2. Median daily felt connection to others		1	0.25***	–0.17***
3. Daily instances of social proximity			1	–0.024
4. Daily number of social interactions				1

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < .001$

Both daily loneliness and feelings of connection were significantly correlated with social proximity. Individuals who reported lower levels of loneliness and greater feelings of social connection tended to be in the presence of others more frequently. Unexpectedly, feelings of connection were negatively associated with daily social interactions.

To reduce the dimensionality of calling behavior for further modeling, we used Principal Components Analysis (PCA) with oblique (oblimin) rotation. Principal component loadings and shares of explained variance are presented in Table 12.

Table 10
Call features Principal Components Analysis results (n = 68)

	PC 1	PC 2	PC 3	PC 4	PC 5
Daily incoming call frequency	0.59	–0.15	0.13	–0.34	–0.71
Daily outgoing call frequency	0.57	0.19	0.09	–0.44	0.66
Daily missed call frequency	0.46	–0.10	0.39	0.78	0.10
Daily incoming call duration	0.22	–0.68	–0.67	0.10	0.16
Daily outgoing call duration	0.26	0.68	–0.61	0.26	-0.17
Variance explained (%)	40.08	19.67	18.96	13.42	7.87

Note. PC = principal component.

Upon examination of the scree plot (Fig. 5), we retained a solution with one component explaining 40.08% of the variance in the call features. This principal component was then used as an outcome variable in the analysis of mindfulness training effects on calling behaviors.

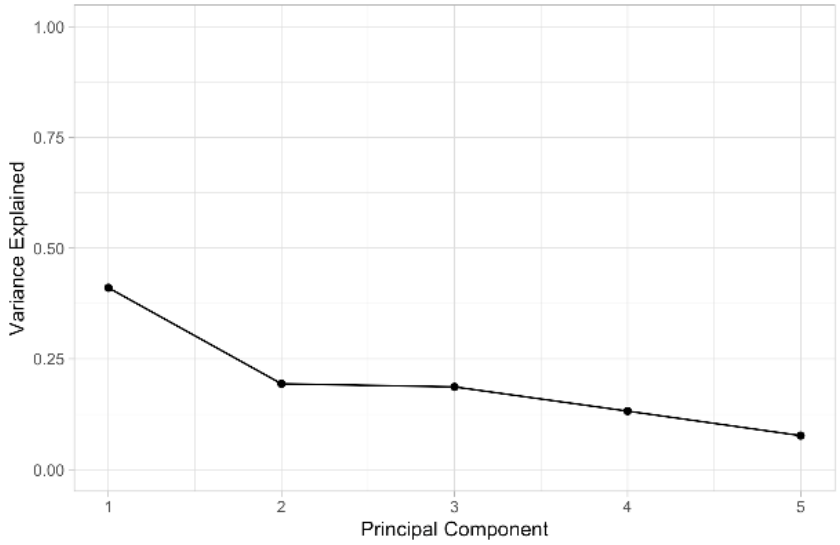

Figure 8. Scree plot of principal components

To estimate mindfulness training effects on social behaviors, we ran separate multilevel models for each outcome: Gaussian models for calling behaviors and social proximity (Table 13) and a zero-inflated model for social interactions (Table 14). We did not detect mindfulness training effects on calling behaviors, social proximity, or above-zero part of social interactions. However, the zero-inflated submodel for social interactions showed that in the training period, participants in the mindfulness group were more likely to report a greater than zero number of social interactions.

Table 11

Multilevel analyses of mindfulness training effects calling behavior and social proximity (all samples)

	Calling Behavior			Social Proximity		
Predictors	*B*	*95% CI*	*p*	*B*	*95% CI*	*p*
(Intercept)	–0.14	–0.47 – 0.18	.387	1.31	1.16 – 1.47	<.001
Week cycle (sine)	–0.02	–0.11 – 0.07	.657	0.02	–0.02 – 0.07	.292
Study day	0.02	–0.004 – 0.035	.127	–0.01	–0.011 – –0.002	.004
Group (MT)	0.02	–0.47 – 0.50	.947	–0.19	–0.39 – 0.01	.058
Training period	–0.10	–0.38 – 0.17	.463	–0.04	–0.13 – 0.05	.421
Post-training period	–0.31	–0.77 – 0.15	.181	0.11	–0.00 – 0.23	.057
Group × Training period	0.07	–0.22 – 0.37	.624	–0.05	–0.18 – 0.07	.422
Group × Post-training period	–0.11	–0.48 – 0.25	.543	–0.08	–0.24 – 0.07	.299
Random Effects						
σ^2		1.14			0.67	
$\tau_{00\ ID}$		0.75			0.27	
$\tau_{11\ ID\ /\ Week\ cycle\ (sine)}$		0.01			0.01	
$\tau_{11\ ID\ /\ Study\ day}$		0.0003			0.00	
$\rho_{01\ ID\ /\ Week\ cycle\ (sine)}$		0.04			-0.04	
$\rho_{01\ ID\ /\ Time\ of\ day}$		0.05			-0.45	
ICC		0.42			0.27	
N_{ID}		68			115	
Observations		1696			3808	
Marginal R^2 / Conditional R^2		0.004 / 0.427			0.019 / 0.281	

Note. B = unstandardized regression coefficient; CI = confidence interval; EMA = ecological momentary assessment; MT = mindfulness training; σ^2 = level-1 residual variance; τ_{00} = variance in individual intercepts; τ_{11} = variance in individual slopes; ρ_{01} = correlation between intercepts and slopes; ICC = intraclass correlation coefficient; N_{ID} = number of participants; marginal R^2 = proportion of variance in the outcome explained by fixed effects only; conditional R^2 = proportion of variance explained by fixed and random effects together.

Table 12
Multilevel analyses of mindfulness training effects on social interactions (all samples)

Gaussian Submodel *Predictors*	*B*	*95% CI*	*p*
(Intercept)	2.09	1.93 – 2.25	<.001
Week cycle (sine)	–0.01	–0.04 – 0.02	.546
Study day	–0.02	–0.02 – –0.01	<.001
Group (MT)	–0.09	–0.31 – 0.13	.423
Training period	–0.14	–0.21 – –0.06	<.001
Post-training period	0.01	–0.08 – 0.11	.770
Group × Training period	0.03	–0.07 – 0.13	.591
Group × Post-training period	0.001	–0.12 – 0.13	.983
Random Effects			
σ^2		0.41	
τ_{00}		0.30	
ICC		0.424	
Marginal R^2 / Conditional R^2		.032 / .443	

Zero-Inflated Submodel *Predictors*	*OR*	*95% CI*	*p*
(Intercept)	0.06	0.04 – 0.10	<.001
Week cycle (sine)	0.75	0.67 – 0.84	<.001
Study day	1.04	1.03 – 1.05	<.001
Group (MT)	1.01	0.49 – 2.06	.982
Training period	0.48	0.36 – 0.62	<.001
Post-training period	0.63	0.46 – 0.85	.003
Group × Training period	2.34	1.63 – 3.35	<.001
Group × Post-training period	1.19	0.78 – 1.79	.419
σ^2		3.29	
τ_{00}		3.04	
ICC		.481	
Marginal R^2 / Conditional R^2		.049 / .506	
N_{ID}		115	
Observations		3808	

Note. B = unstandardized regression coefficient; CI = confidence interval; EMA = ecological momentary assessment; MT = mindfulness training; σ^2 = level-1 residual variance; τ_{00} = variance in individual intercepts; ICC = intraclass correlation coefficient; N_{ID} = number of participants; marginal R^2 = proportion of variance in the outcome explained by fixed effects only; conditional R^2 = proportion of variance explained by fixed and random effects together.

In summary, this part of the analysis demonstrated connections between subjective social well-being and self-reported social behaviors, including social proximity and interactions. Participants in the mindfulness group were less likely to not communicate with anyone throughout the day than participants in the control group in the training period. However, we did not find mindfulness training effects on calling behaviors, social proximity, or above-zero number of social interactions.

Discussion

In the last decade, we have been witnessing alarming emotional well-being trends in the United States and around the world (Twenge et al., 2019). At least in part these trends are propelled by increasing society atomization and declining social support (Sachs, 2017). Mindfulness-based interventions (MBIs) hold promise as a possible path to improve both social and emotional well-being (Adair et al., 2018; Creswell, 2017; Lindsay et al., 2019). Digital MBIs are particularly promising because of their scalability, relatively low cost, and accessibility to populations who may face barriers to participating in in-person mindfulness training (Flett et al., 2019; Linardon, 2020). In this study, we tested the effects and mechanisms of a smartphone-delivered mindfulness intervention on college students' emotional experience, measured as day to day depressive feelings, anxiety, and happiness.

Mindfulness Training Effects on Emotional Experience

Previous research found only short-term smartphone-based mindfulness programs effects (Goldberg et al., 2022). Therefore, we anticipated that participants in the mindfulness group would exhibit improved emotional experiences during the post-training period compared to the pre-training period, in contrast to participants in the control group. Contrary to our expectations, during the post-training period, participants in the mindfulness training group did not score higher on the emotional experience measures. However, we found mindfulness training effects

on the depressive feelings in the follow-up period, two to three weeks after the training. This finding may have several explanations. First, the effects of digital MBIs show remarkable variability and depend on the intervention content, as well as the study design (Taylor et al., 2021). Participants in our study were strongly motivated to adhere to the training protocol. While they did not receive direct payment for completing the lessons, they were eligible to continue their participation and receive full compensation only if they completed more than half of the lessons. In the event that participants began to deviate from the training schedule, they were promptly contacted by the study team. Those who were not able to complete the lessons were withdrawn from the study. As a result of this approach, the participants who finished the study completed most of the lessons. Such level of engagement is atypical for most digital MBIs, which typically follow a self-paced structure and offer few external incentives (Taylor et al., 2021). In absence of face-to-face contact, factors such as program intensity and actual program use become pivotal in developing mindfulness skills (Strohmaier, 2020). We argue that as a result of a high level of engagement during the training, our participants continued using the techniques that they learned and building their mindfulness skills, which eventually had an effect on their depressive states. This suggestion is further supported by previous in-person mindfulness training research with a comparable age group that found little deterioration in self-report psychological outcomes such as coping and well-being, even after six years (Vibe et al., 2018).

Mediation by Social Well-Being

Our second objective was to investigate whether mindfulness training effects were mediated by subjective social well-being, specifically feelings of loneliness and connection to others. However, we did not observe any training effects on either subjective social well-being or emotional experience. Nevertheless, the association between subjective social well-being and

emotional experience at the subsequent time point remained consistent across all variables. It is important to note that only data from the post-training period was used for this analysis. Previous research strongly supports the connection between naturally occurring states of presence and improved momentary social well-being (Beloborodova et al., 2020), as well as mindfulness training effects on social well-being (Adair et al., 2018; Creswell et al., 2012; Davis et al., 2016; Lindsay et al., 2019). Given our ability to detect mindfulness training effects during the follow-up period, it is possible that mediation effects were too weak to be detected with the current sample size.

Mindfulness Training Effect on Social Behavior

Our study is the first to our knowledge to test mindfulness training effects on social behavior measured using smartphone call logs data. Exploratory analyses showed that behavioral features extracted from the logs (call in and out frequency and duration, missed calls frequency) were not significantly related to daily loneliness and felt connection. This finding runs counter to Harari et al.'s (2020) study that found consistent associations between smartphone-measured social behaviors and psychological factors such as extraversion. However, Harari et al. (2020) evaluated these associations at the level of psychological traits and smartphone-measured behavioral tendencies. In our study, we examined the relationships between psychological states and call features aggregated at the daily level. Although trait questionnaires and aggregated momentary assessments of personality are closely linked, they are not equivalent and may show differential associations with other variables (Augustine & Larsen, 2012). Further exploratory analysis did not show consistent differences in median levels of calling features across mindfulness and control groups. Statistical models did not detect mindfulness training effects on calling behavior either. Admittedly, calling is one of the many smartphone-mediated social behaviors. Other behaviors such as texting and social media app use that were not measured in

the current study due to software limitations may show different patterns of relationships with daily subjective social well-being and may respond differently to mindfulness training. For example, Meynadier et al. (2024) found a meta-analytic association between greater trait mindfulness and reduced problematic social media use. Throuvala et al. (2020) demonstrated that mindfulness training reduced smartphone and social media use-related distraction. However, these studies are limited by their reliance on self-report measures to assess smartphone and social media usage, which often differ from objective measures (Parry et al., 2021). Future studies using smartphone passive sensing technology would be able to overcome this limitation.

To assess the impact of mindfulness training on social proximity and interactions, we relied on participant EMA reports indicating their current presence among others and whether they had interacted with another person since the last survey. These measures correlated with subjective social well-being. As expected, social proximity correlated negatively with loneliness and positively with felt connection. Surprisingly, daily social interaction frequency was negatively associated with felt connection. Previous research found evidence for both quantity and quality of social interactions to be related to subjective social well-being, both in the moment and on average (Sun et al., 2020). Hence, the negative correlation between social interaction frequency and felt connection warrants further investigation, using interaction characteristics collected as part of this study, including interaction partner, perceived closeness, and others.

Mindfulness training did not exert an effect on social proximity, however it made the participants less likely to not interact with anyone on a given day during the training period. This finding is in line with the Lindsay et al. (2019) study that showed mindfulness training effect on the number of daily social interactions.

Limitations

The findings of this study should be interpreted within the context of several limitations. Firstly, participants who were unable to adhere to the training protocol were excluded from the study. While this may have heightened motivation among participants to complete lessons, thereby potentially maximizing effect size, analyzing data solely from participants who completed the training precludes Intent-to-Treat analysis and does not replicate real-world scenarios where a higher degree of non-compliance is anticipated, particularly in digital interventions. Second, the study design did not allow for a more flexible approach to mindfulness and control training programs, such as stretching them over a longer period of time for those participants who need it. A preliminary analysis of the Spring 2023 wave participants qualitative interviews revealed that some of them found the training too fast-paced and would have appreciated an option to receive lessons less frequently or take breaks (Pemmasani et al., 2023). In addition to the compensation structure, the participants were frequently contacted by the study team, which likely further increased their motivation to adhere to the training program. Thus, the results of this study may not generalize to self-paced digital mindfulness programs that do not feature strong external incentives.

One more limitation is rooted in the state of smartphone data collection technology. AWARE has to run in the background at all times to record the data. If a participant closed the app or turned off their device, data collection stopped. AWARE shows a warning message when a user attempts to close it, but some data loss is inevitable as participants may ignore this message or their devices may run out of battery. The majority of the participants had iPhones whose operating system is more restrictive than Android. App foreground and Bluetooth logs were available only for Android devices that were too few to run any exploratory analyses or statistical tests.

Finally, while our sample was ethically and racially diverse, similarly to other studies on mindfulness, cisgender female participants were overrepresented in our sample. Thus, the results of this study might not generalize to other demographics. Future research may test the hypothesized relations in populations with greater representations of individuals that do not identify as cisgender female.

Conclusion

Our study underscores the complexity of evaluating the effects of digital mindfulness interventions on emotional experience, social well-being, and overt social behavior. While we did not observe immediate effects on emotional experience or subjective social well-being, sustained engagement with mindfulness practice influenced emotional experiences during the follow-up period of the study. However, further research is warranted to clarify the mechanisms underlying these effects, particularly concerning social well-being and behavior. Overall, our findings contribute to a nuanced understanding of the potential of digital MBIs to enhance emotional well-being and social functioning in today's technologically advanced world.

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Appendixes

Appendix A

Supplemental Table 1
Lesson by Lesson Outline of Training Programs

	Mindfulness	Coping control
Lesson 1	Introduction: Intro to the course and three core skills: *Concentration:* ability to maintain focus on present-moment experiences *Clarity (Monitoring):* ability to pinpoint exactly what you're experiencing in each moment *Equanimity (Acceptance):* openness to experience	Introduction: Intro to the course (MyTime) and three core skills: *Reflection:* guided exploration of thoughts; mind can wander where it wants *Analytic Thinking:* analyze and think deeply about thoughts and ideas that occur during reflection *Problem-Solving:* techniques for tackling problems that are apparent through analytic thinking
Lesson 2	Concentration I: developing a deeper understanding of concentration	Reflection I: choosing to control thought content or get lost in mind wandering
Lesson 3	Concentration II: concentrating continuously on body experience	Reflection II: letting the mind wander toward pleasant thoughts or toward or away from unpleasant thoughts
Lesson 4	Concentration III: maintaining focus on body experience while listening to someone speak (with topic options)	Reflection III: pleasant guided imagery with option to let the mind drift
Lesson 5	Concentration IV: labeling body experiences to maintain focus	Reflection IV: reflecting on Shakespeare monologues
Lesson 6	Concentration V: labeling different types of body experiences	Analytic Thinking I: remembering a positive experience and considering how to make future experiences more positive
Lesson 7	Equanimity I: maintaining global body relaxation to promote equanimity	Analytic Thinking II: imagining a positive experience in the future (e.g., goal achievement)
Lesson 8	Equanimity II: promoting equanimity by intentionally using a matter-of-fact tone of voice when labeling	Analytic Thinking III: reframing a past negative experience
Lesson 9	Clarity I: discriminating different types and patterns of body sensations	Analytic Thinking IV: reframing an anticipated future negative experience
Lesson 10	Clarity II: detecting subtle or faint body sensations, and increasing sensual fulfillment by detecting subtle pleasure	Problem-Solving I: time management and planning out your day
Lesson 11	Equanimity III: developing equanimity by applying a welcoming attitude toward all experiences	Problem-Solving II: time management and reflecting on yesterday's plans and accomplishments

Lesson 12	Clarity III: recognizing four basic categories of body experience (physical, emotional, restful, “energy flow”)	Problem-Solving III: identifying a problem and the causes of stress
Lesson 13	Equanimity IV: integrating the three equanimity strategies: body relaxation, tone of voice, welcoming attitude	Problem-Solving IV: considering barriers and solutions to a problem
Lesson 14	Course Review: guided practice through the major strategies learned in the preceding 13 lessons	Course Review: guided practice through the major strategies learned in the preceding 13 lessons

Appendix B

Positive and Negative Affect Schedule

Select the box that best describes how frequently you have experienced each of the feelings listed below during the past two weeks.

		Very slightly or not at all	A little	Moderately	Quite a bit	Extremely
1	INTERESTED	□	□	□	□	□
2	DISTRESSED	□	□	□	□	□
3	EXCITED	□	□	□	□	□
4	UPSET	□	□	□	□	□
5	STRONG	□	□	□	□	□
6	GUILTY	□	□	□	□	□
7	SCARED	□	□	□	□	□
8	HOSTILE	□	□	□	□	□
9	ENTHUSIASTIC	□	□	□	□	□
10	PROUD	□	□	□	□	□
11	IRRITABLE	□	□	□	□	□
12	ALERT	□	□	□	□	□
13	ASHAMED	□	□	□	□	□
14	INSPIRED	□	□	□	□	□
15	NERVOUS	□	□	□	□	□
16	DETERMINED	□	□	□	□	□
17	ATTENTIVE	□	□	□	□	□
18	JITTERY	□	□	□	□	□
19	ACTIVE	□	□	□	□	□
20	AFRAID	□	□	□	□	□

Scoring:

Positive Affect Score: Add the scores on items 1, 3, 5, 9, 10, 12, 14, 16, 17, and 19.
Negative Affect Score: Add the scores on items 2, 4, 6, 7, 8, 11, 13, 15, 18, and 20.

Center for Epidemiologic Studies Depression Scale (CES-D)

Below is a list of the ways you might have felt or behaved. Please indicate how often you have felt this way during the past week.

		During the Past Week			
		Rarely or none of the time (less than 1 day)	Some or a little of the time (1-2 days)	Occasionally or a moderate amount of time (3-4 days)	Most or all of the time (5-7 days)
1	I was bothered by things that usually don't bother me.	□	□	□	□
2	I did not feel like eating; my appetite was poor.	□	□	□	□
3	I felt that I could not shake off the blues even with help from my family or friends.	□	□	□	□
4	I felt I was just as good as other people.	□	□	□	□
5	I had trouble keeping my mind on what I was doing.	□	□	□	□
6	I felt depressed.	□	□	□	□
7	I felt that everything I did was an effort.	□	□	□	□
8	I felt hopeful about the future.	□	□	□	□
9	I thought my life had been a failure.	□	□	□	□
10	I felt fearful.	□	□	□	□
11	My sleep was restless.	□	□	□	□
12	I was happy.	□	□	□	□
13	I talked less than usual.	□	□	□	□
14	I felt lonely.	□	□	□	□
15	People were unfriendly.	□	□	□	□
16	I enjoyed life.	□	□	□	□
17	I had crying spells.	□	□	□	□
18	I felt sad.	□	□	□	□
19	I felt that people dislike me.	□	□	□	□
20	I could not get "going."	□	□	□	□

Items 4, 8, 12, and 16 should be reverse-scored.

Beck Anxiety Inventory

Below is a list of common symptoms of anxiety. Please carefully read each item in the list. Indicate how much you have been bothered by that symptom during the past month, including today.

	Not At All	Mildly but it didn't bother me much	Moderately - it wasn't pleasant at times	Severely – it bothered me a lot
Numbness or tingling	•	•	•	•
Feeling hot	•	•	•	•
Wobbliness in legs	•	•	•	•
Unable to relax	•	•	•	•
Fear of worst happening	•	•	•	•
Dizzy or lightheaded	•	•	•	•
Heart pounding/racing	•	•	•	•
Unsteady	•	•	•	•
Terrified or afraid	•	•	•	•
Nervous	•	•	•	•
Feeling of choking	•	•	•	•
Hands trembling	•	•	•	•
Shaky / unsteady	•	•	•	•
Fear of losing control	•	•	•	•
Difficulty in breathing	•	•	•	•
Fear of dying	•	•	•	•
Scared	•	•	•	•
Indigestion	•	•	•	•
Faint / lightheaded	•	•	•	•
Face flushed	•	•	•	•
Hot/cold sweats	•	•	•	•

UCLA Loneliness Scale: Version 3

Instructions: The following statements describe how people sometimes feel. For each statement, please indicate how often you feel by responding with the following numbers:

4= ALWAYS
3= SOMETIMES
2= RARELY
1= NEVER

R1. How often do you feel that you are "in tune" with the people around you? _____

2. How often do you feel that you lack companionship? _____

3. How often do you feel that there is no one you can turn to? _____

4 How often do you feel alone? _____

R5. How often do you feel part of a group of friends? _____

R6. How often do you feel that you have a lot in common with the people around you? _____

7. How often do you feel that you are no longer close to anyone? _____

8. How often do you feel that your interests and ideas are not shared by those around you? _____

R9. How often do you feel outgoing and friendly? _____

R10. How often do you feel close to people? _____

11. How often do you feel left out? _____

12. How often do you feel that your relationships with others are not meaningful? _____

13. How often do you feel that no one really knows you well? _____

14. How often do you feel isolated from others? _____

R15. How often do you feel you can find companionship when you want it? _____

R16. How often do you feel that there are people who really understand you? _____

17. How often do you feel shy? _____

18. How often do you feel that people are around you but not with you? _____

R19. How often do you feel that there are people you can talk to? _____

R20. How often do you feel that there are people you can turn to? _____

Two-Way Social Support Scale

	Not at All					Always
1. There is someone I can talk to about the pressures in my life.	0	1	2	3	4	5
2. I help others when they are too busy to get everything done.	0	1	2	3	4	5
3. I look for ways to cheer people up when they are feeling down.	0	1	2	3	4	5
4. There is at least one person that I can share most things with.	0	1	2	3	4	5
5. If stranded somewhere there is someone who would get me.	0	1	2	3	4	5
6. When I am feeling down there is someone I can lean on.	0	1	2	3	4	5
7. I give others a sense of comfort in times of need.	0	1	2	3	4	5
8. I have someone to help me if I am physically unwell.	0	1	2	3	4	5
9. When someone I lived with was sick I helped them.	0	1	2	3	4	5
10. There is someone in my life I can get emotional support from.	0	1	2	3	4	5
11. There is someone who can help me fulfill my responsibilities when I am unable.	0	1	2	3	4	5
12. I have helped someone with their responsibilities when they were unable to fulfill them.	0	1	2	3	4	5
13. There is at least one person that I feel I can trust.	0	1	2	3	4	5
14. People confide in me when they have problems.	0	1	2	3	4	5
15. There is someone who would give me financial assistance.	0	1	2	3	4	5
16. There is someone in my life that makes me feel worthwhile.	0	1	2	3	4	5
17. I am a person others turn to for help with tasks.	0	1	2	3	4	5
18. I feel that I have a circle of people who value me.	0	1	2	3	4	5
19. I am there to listen to other's problems.	0	1	2	3	4	5
20. I give financial assistance to people in my life.	0	1	2	3	4	5
21. People close to me tell me their fears and worries.	0	1	2	3	4	5

Mindful Attention Awareness Scale

Below is a collection of statements about your everyday experience. Using the 1-6 scale below, please indicate how frequently or infrequently you currently have each experience. Please answer according to what really reflects your experience rather than what you think your experience should be. Please treat each item separately from every other item.

1	2	3	4	5	6
Almost always	Very frequently	Somewhat frequently	Somewhat infrequently	Very infrequently	Almost never

1.	I could be experiencing some emotion and not be conscious of it until some time later.	1 2 3 4 5 6
2.	I break or spill things because of carelessness, not paying attention, or thinking of something else.	1 2 3 4 5 6
3.	I find it difficult to stay focused on what's happening in the present.	1 2 3 4 5 6
4.	I tend to walk quickly to get where I'm going without paying attention to what I experience along the way.	1 2 3 4 5 6
5.	I tend not to notice feelings of physical tension or discomfort until they really grab my attention.	1 2 3 4 5 6
6.	I forget a person's name almost as soon as I've been told it for the first time.	1 2 3 4 5 6
7.	It seems I am "running on automatic," without much awareness of what I'm doing.	1 2 3 4 5 6
8.	I rush through activities without being really attentive to them.	1 2 3 4 5 6
9.	I get so focused on the goal I want to achieve that I lose touch with what I'm doing right now to get there.	1 2 3 4 5 6
10.	I do jobs or tasks automatically, without being aware of what I'm doing.	1 2 3 4 5 6
11.	I find myself listening to someone with one ear, doing something else at the same time.	1 2 3 4 5 6
12.	I drive places on 'automatic pilot' and then wonder why I went there.	1 2 3 4 5 6
13.	I find myself preoccupied with the future or the past.	1 2 3 4 5 6
14.	I find myself doing things without paying attention.	1 2 3 4 5 6
15.	I snack without being aware that I'm eating.	1 2 3 4 5 6

Demographic Questionnaire

The following information is requested to help us characterize the whole group of people in this study. As with the other measures, *none of this information will be used to identify you personally.*

1. What is your age in years?

2. What is your current gender identity? (check one)
   - Man
   - Woman
   - Genderqueer
   - Non-binary
   - Not listed (please specify)
     _____

3. Do you identify as transgender?
   - Yes
   - No

4. What is your racial/ethnic origin? (check one)
   - American Indian/Alaskan
   - Asian Indian
   - Black or African American
   - Chinese
   - Filipino
   - Hawaiian or other Pacific Islander
   - Hispanic or Latino(a)
   - Japanese
   - Korean
   - Middle Eastern
   - Vietnamese
   - White
   - Other Asian
   - Two or more races
   - Not listed (please specify)
     _____

4. Do you currently have a meditation practice?
   - Yes
   - No

5. For how long have you been practicing meditation?
   - Tried it once or a few times
   - Less than 6 months
   - 6 months-1 year
   - 1-5 years
   - Over 5 years

6. How often are you practicing meditation?
    - Never
    - Less than once per week
    - Once to twice a week
    - Three to four times a week
    - Five to six times a week
    - Every day

Appendix C

Ecological Momentary Assessment Survey

Morning: Random time between 9:00am and 1:00pm
Afternoon: Random time between 1:00pm and 5:00pm
Evening: Random time between 5:00pm and 9:00pm

Activity (adapted from CMU study)	
Which of the following characterizes what you were doing just before you began this survey (select all that apply)	**Drop down box with scrolling through:** Studying, working on class project, homework, etc. research or lab related extra-curricular (e.g., social and/or academic clubs) in class going to class chores/errands daily self-care eating/drinking consuming alcohol job-related physical activity/exercise/sports socializing using social media sleeping leisure activity/hobby (e.g. watching TV, reading, playing video games, etc.) volunteering/helping other
Autonomy (from Brown & Ryan, 2003)	
Why were you engaged in this activity?	
Because other(s) wanted me to, or pressured me to	0- not at all, 3- somewhat, 6- completely
To help me look good to other(s)	0- not at all, 3- somewhat, 6- completely
To help me feel better about myself	0- not at all, 3- somewhat, 6- completely
Because I truly valued it	0- not at all, 3- somewhat, 6- completely
Because it was fun or interesting to do	0- not at all, 3- somewhat, 6- completely
Social Environment	
Are you among other people (including virtually, e.g., on Zoom)?	Yes/No If yes, show next 2 questions If no, jump to Affect
Is this a face-to-face or virtual setting?	Face-to-face Virtual
How many people are around you?	**Drop down box with scrolling through:** 1 2 3-5 5-10 Over 10
Affect	

(adapted from CMU study)	
How are you feeling right now?	
Anxious	0- not at all, 1- a little, 2- moderately, 3- quite a bit, 4- extremely
Depressed	0- not at all, 1- a little, 2- moderately, 3- quite a bit, 4- extremely
Happy	0- not at all, 1- a little, 2- moderately, 3- quite a bit, 4- extremely
Overwhelmed	0- not at all, 1- a little, 2- moderately, 3- quite a bit, 4- extremely
Lonely	0- not at all, 1- a little, 2- moderately, 3- quite a bit, 4- extremely
Connected to Others	0- not at all, 1- a little, 2- moderately, 3- quite a bit, 4- extremely
State Mindfulness (from Brown & Ryan, 2003)	
To what degree were you having these experiences *just before you were signaled*?	
I was doing something without paying attention.	0-not at all, 3- somewhat, 6- very much
I was doing something automatically, without being aware of what I was doing.	0-not at all, 3- somewhat, 6- very much
I was rushing through something without being really attentive to it.	0-not at all, 3- somewhat, 6- very much
I was finding it difficult to stay focused on what was happening	0-not at all, 3- somewhat, 6- very much
I was thinking about something other than what I was currently doing	Yes/No
Which of the following would best characterize these thoughts?	Past-focused Present-focused Future-focused No time focus
Social Interaction Questions (adapted from CMU study, unless stated otherwise)	
Did you interact with anyone since the last survey?	Yes/No If yes, show next 6 questions If no, finish survey **(for morning and afternoon surveys)** or jump to School Belonging **(for evening surveys)**
Think about your *most recent* interaction	
Who was this interaction with?	family member romantic partner friend roommate classmate instructor/supervisor acquaintance other (e.g., cashier)

How close to this person did you feel?	Not at all Very little Slightly Neutral Moderately Very much Extremely
Was this interaction face-to-face?	Yes/No
How pleasant was this interaction? (from Bernstein et al., 2018)	**Slider:** 0- Unpleasant, 6- Pleasant
Indicate how **the other person** was acting during this interaction. (Woods et al., 2022)	**Slider 1 (anchor at 0):** -50- Warm/Friendly/Caring, 50- Cold/Distant/Hostile **Slider 2 (anchor at 0):** -50- Assertive/Dominant/Controlling, 50- Accommodating/Submissive/Timid
Indicate how **you** were acting during this interaction. (Woods et al., 2022)	**Slider 1 (anchor at 0):** -50- Warm/Friendly/Caring, 50- Cold/Distant/Hostile **Slider 2 (anchor at 0):** -50- Assertive/Dominant/Controlling, 50- Accommodating/Submissive/Timid
School Belonging (evening survey only) (adapted from CMU study)	
Today, I feel like I belong at VCU	1-Strongly Disagree, 2- Disagree, 3- Moderately Disagree, 4- Neutral Moderately, 5- Agree, 6- Agree, 7- Strongly Agree
Competence (evening survey only) (from Brown & Ryan, 2003)	
How capable and effective did you feel today?	0-not at all, 3-somewhat, 6-extremely
Thank you for completing this survey! *Have a great day!*	

Appendix D

Participant sign up form

Thank you for your interest in joining our study! To find out if you are eligible, please fill this survey. Your answers will not be retained.

Button: Start survey

Are you a full-time VCU student?
- Yes
- No

What kind of educational program are you currently pursuing?
- Bachelor's
- Master's
- Professional
- Doctoral
- Certificate

Are you enrolled in any in-person courses in the Fall semester?
- Yes
- No

How did you first hear about the study?
- Flyer
- TeleRAM announcement
- Social media
- VCU Psychology Department website
- From a VCU professor
- From another student
- Other (please specify)

Button: Next page

What is your age? _____

What is your racial/ethnic origin? (check one)
- American Indian/Alaskan
- Asian
- Black or African American
- Hawaiian/Pacific Islander
- Hispanic/Latino
- Two or more races
- White
- Other (please specify)

Do you own a smartphone with Android or iOS operating system with an active data plan?

- Yes
- No

Button: Next page

Are you currently diagnosed with major depressive, generalized anxiety, or panic disorder?

- Yes
- No

Indicate the extent you have felt this way over the past two weeks.

		Very slightly or not at all	A little	Moderately	Quite a bit	Extremely
1	Interested	□	□	□	□	□
2	Distressed	□	□	□	□	□
3	Excited	□	□	□	□	□
4	Upset	□	□	□	□	□
5	Strong	□	□	□	□	□
6	Guilty	□	□	□	□	□
7	Scared	□	□	□	□	□
8	Hostile	□	□	□	□	□
9	Enthusiastic	□	□	□	□	□
10	Proud	□	□	□	□	□
11	Irritable	□	□	□	□	□
12	Alert	□	□	□	□	□
13	Ashamed	□	□	□	□	□
14	Inspired	□	□	□	□	□
15	Nervous	□	□	□	□	□
16	Determined	□	□	□	□	□
17	Attentive	□	□	□	□	□
18	Jittery	□	□	□	□	□
19	Active	□	□	□	□	□
20	Afraid	□	□	□	□	□

Button: Submit

If a participant meets the eligibility criteria, they see the following message:

Thank you for filling out the form! We are happy to invite you to the study. Please leave your email below, and we will send you more detailed information.

Email _____

If a participant does not meet the eligibility criteria, they see the following message:

Thank you for your interest in the study. Unfortunately, we cannot invite you to participate at this time. Please consider those alternative resources for developing your stress management skills, available to you at VCU:
Health Promotion and Well-Being Center (https://thewell.vcu.edu)
Counseling Services (https://counseling.vcu.edu)

Appendix E

TelegRAM Announcement Text

Invitation: Research study on Two Stress Reduction Programs

The VCU Wellbeing Lab invites you to participate in a research study on two stress reduction programs for undergraduate students. VCU investigators seek to understand how two online stress reduction programs affect students' mood and stress-related behavior. Compensation is available. Sing up before September 15! For more information, visit the study website https://beloborodp.wixsite.com/stressreduction or contact Polina Beloborodova at vcu.stress.reduction@gmail.com or (804) 215-6196.

Study Advertisement Flyer

ARE YOU STRESSED?

VCU Wellbeing Lab invites you to participate in a stress reduction study

- Learn stress management techniques
- Help us to understand what factors affect students' emotional well-being
- Compensation is available

Qualtrics survey QR code will be here

Take a survey to find out if you are eligible

Find out more: https://beloborodp.wixsite.com/stressreduction

Social Media Advertisement

ARE YOU STRESSED?

VCU Wellbeing Lab invites you to participate in a stress reduction study

- Learn stress management techniques
- Help us to understand what factors affect students' emotional well-being
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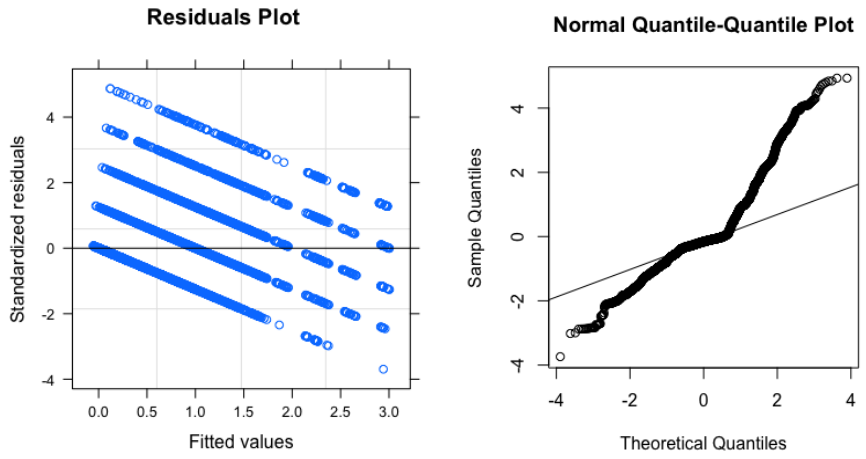
Qualtrics survey QR code will be here

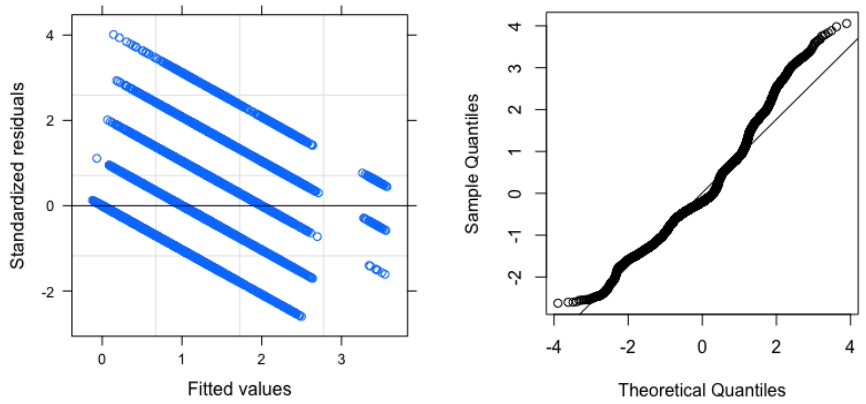
Find out more: https://beloborodp.wixsite.com/stressreduction

Appendix F

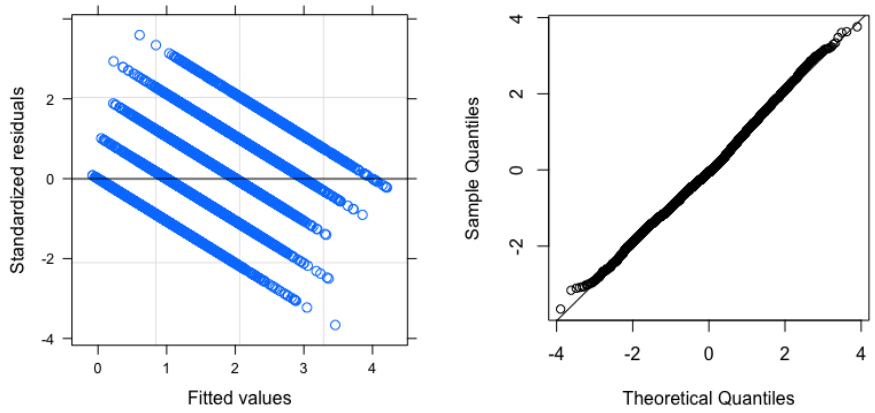
Depression



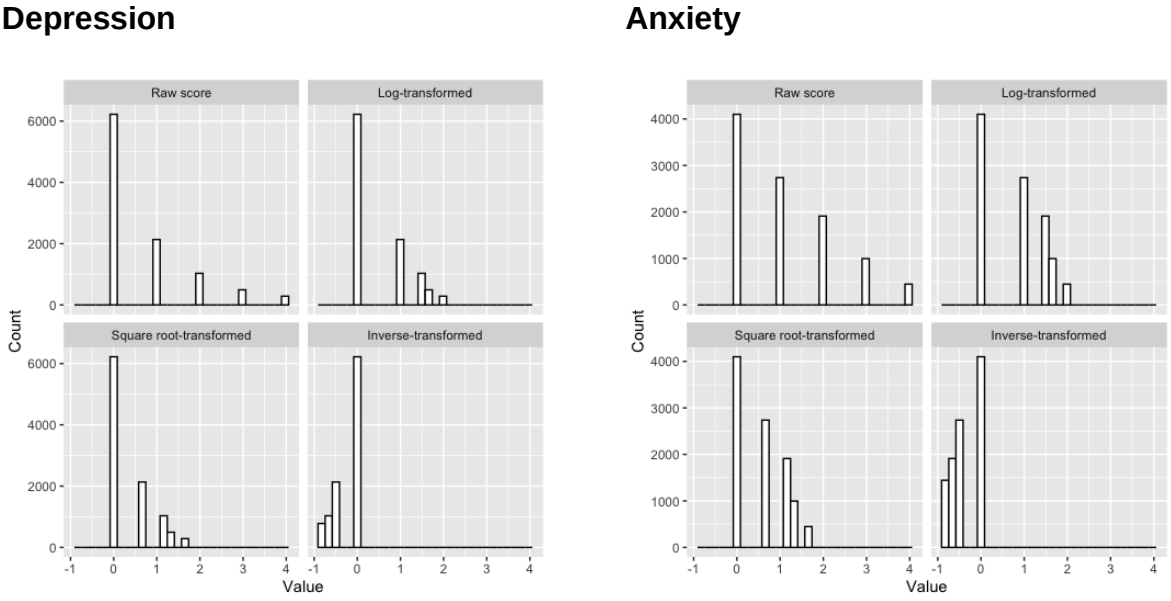
Anxiety



Happiness



Supplemental Figure 1. Residual plots of Aim 1 preregistered statistical models



Supplemental Figure 2. Histograms of raw and transformed Aim 1 outcomes