Be Aware: Biocueing as an Addition to Aggression Regulation Therapy in Forensic Psychiatric Outpatients

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Annemieke ter Harmsel

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The feelings volcano

The book cover is inspired by the feelings volcano, an often used metaphor in psycho-education. The visual represents five levels of anger intensity. In therapy, these levels are used to increase emotional awareness and to identify coping strategies which could help patients return to a calmer state. Thereby, this visual serves both as a reminder and aid to regulate emotions.

Iets vertellen

Soms volg ik tijdens het gesprek
zijn ogen en hoe hij lijkt
te zoeken in mijn hoofd.

Of daar is opgeruimd, of
alle rompslomp in
betreffende containers
is verdwenen en
gedachten weer als nieuw.

Hij wil dat alles hier boven
schoner, beter wordt – ik
denk aan emmers sop

die ik met elk verhaal
voor hem naar boven takel,
op zijn bureau mijn
mond uitstort.

Ester Naomi Perquin,
Celinspecties (2012)

COLOPHON

Be Aware: Biocueing as an Addition to Aggression Regulation Therapy in Forensic Psychiatric Outpatients

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BE AWARE

Biocueing as an Addition to Aggression Regulation Therapy in Forensic Psychiatric Outpatients

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door

Janna Frederiek ter Harmsel

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CHAPTER 1

General introduction

GENERAL INTRODUCTION

Anger and aggressive behavior have intrigued me since I was a fresh psychology student. Raised in an environment in which expressing anger was quite uncommon, my initial interest may have been sparked by curiosity and some need for excitement. During the years I have been working as a psychologist I gained more insight into the devastating effects of severe aggressive behavior on victims, offenders and society, and experienced the challenges of treating anger regulation difficulties in outpatient care. Amongst others, difficulties in attending to and recognizing physiological signals that precede aggressive incidents as well as limitations in out-of-session practice seemed to hamper the treatment process, thereby contributing to suboptimal treatment outcomes. This stressed the need for development and evaluation of additive interventions with a direct impact on clinical practice, which perfectly fitted my role as a scientist-practitioner. Furthermore, it seemed highly valuable to investigate whether it would be feasible and effective to integrate the neurobiological research results regarding aggressive behavior into new interventions which could complement current treatment. Although research using neurobiological markers to predict aggressive incidents was still in its infancy when this research project was established, we decided to move with the initiated trend toward personalized medicine and the fast developments in wearable and mHealth technology facilitating behavioral monitoring and support in everyday life. In the challenging process of developing and evaluating a new biocueing intervention among forensic outpatients with anger regulation difficulties, we cooperated with multiple stakeholders.

First of all, we were aware that for this research project to succeed, long-term embedding in clinical practice would be essential. Inforsa, the forensic department of mental healthcare institute Arkin, offered us the opportunity to conduct ecologically valid research in clinical practice, involving both forensic outpatients and therapists. Furthermore, close cooperation with a research group investigating aggressive behavior, the Child and Adolescent Psychiatry Department of Amsterdam UMC, affiliated with the Vrije Universiteit, was ensured. At the start of this project, we established a collaboration with developers and researchers of the Psychology, Health and Technology Department of the University of Twente. To enhance further development and maintenance of the Sense-IT app we closely cooperated with app developers and designers. During the project, several other clinicians, researchers, developers, and designers expressed interest, which resulted in the formation of the Sense-IT consortium aimed at facilitating research into and implementation of the Sense-IT app. Last but not least, this project would not have been possible without the financial support of the Dutch Ministry of Justice and Security.

In this innovative research project, we were guided by three main questions. First, what is already known about the feasibility and effectivity of interventions using physiological information to enhance emotion regulation? Second, will a biocueing intervention be feasible and usable for this complex group of forensic outpatients with anger regulation difficulties? Third, will the use of a biocueing intervention as an addition to aggression regulation therapy be associated with positive effects on interoceptive awareness, emotion regulation, and aggressive behavior in forensic outpatients?

Emotion regulation

The human ability to regulate emotions, by monitoring, evaluating, and modulating emotional responses, is essential for mental health (Gross & Jazaieri, 2014). Emotion regulation consists of the integrative functioning of psychological and physiological processes to adequately identify and respond to real and perceived threats (Taylor, 2006). The large variety of psychopathology and maladaptive behaviors associated with emotion regulation difficulties, ranging from anxiety and mood disorders to substance abuse and aggressive behavior, indicates that the multifaceted process of emotion regulation should be considered one of the core transdiagnostic factors in treatment of psychiatric disorders (Ten Ham, Hulsbergen, & Bohlmeyer, 2016) and stresses its clinical relevance (McRae & Gross, 2020; Sheppes, Suri, & Gross, 2015).

For adequate emotion regulation, emotional awareness is considered an important prerequisite (Füstös, Gramann, Herbert, & Pollatos, 2013; Gross & Jazaieri, 2014). This ability is often divided into two main components: the ability to attend to the own emotional experiences (attention to emotion) and the extent to which the own emotional experiences are understood (emotional clarity) (Boden & Thompson, 2015). Research results indicate that both internalizing problems (Berenbaum et al., 2012; Sendzik et al., 2017) and externalizing problems (Roberton et al., 2015; Velotti et al., 2017) are accompanied by limitations in emotional awareness.

In turn, interoceptive awareness has been identified as an important component of emotional awareness and, thereby, as another essential building block for adequate emotion regulation (Füstös et al., 2013). Interoceptive awareness refers to the conscious perception of sensations from inside the body, such as heartbeat, respiration, and other autonomic nervous system sensations related to emotions, which creates a physiological condition of the body (Calì, Ambrosini, Picconi, Mehling, & Committeri, 2015). Multiple psychiatric disorders, for example, depression, anxiety, post-traumatic stress disorder, and substance use disorder, have been associated with difficulties in detecting, appraising, and responding to interoceptive signals (Goodkind et al., 2015; Khoury, Lutz, & Schuman-Olivier, 2018). Adequate emotion regulation seems therefore closely related to attending

to, selecting, and recognizing physiological responses which are, in turn, regulated by the autonomic nervous system (Crockett, Gill, Cashwell, & Myers, 2017).

Anger regulation and aggressive behavior

One emotion that is particularly hard to regulate, which might result in aggressive behavior, is anger. Anger is associated with greater symptom severity and worse treatment response across disorders (Cassiello-Robbins & Barlow, 2016). In forensic psychiatry, anger is often expressed more outwardly, for example in physical or verbal aggression. A frequently used and clinically relevant way to differentiate between aggressive behaviors is based on the motivations to engage in those behaviors. According to this view reactive aggression is defined as an impulsive response to a provocation or threat, whereas proactive aggression is characterized by instrumental, premeditated behavior to achieve a secondary goal (Dodge & Coie, 1987). Adequate anger regulation requires awareness of social situations that may evoke anger, awareness and recognition of bodily signals indicating building anger, and adaptive coping strategies to control anger and prevent aggressive behavior (Bellemans et al., 2019).

Given the negative impact of aggressive behavior on victims and offenders as well as the high costs for healthcare and society (Bindler, Ketel, & Hjalmarsson, 2020; Cohen, 2020; Koegl & Farrington, 2021; Krug, Mercy, Dahlberg, & Zwi, 2002), reducing anger regulation difficulties and preventing violent recidivism is an important goal in forensic psychiatry. For this purpose, several treatment interventions have been developed over the last decades. Most of these interventions are based on the principles of cognitive behavioral therapy and could be considered derivates of Aggression Replacement Training (Goldstein, Glick, & Gibbs, 1998): a treatment program in which behavioral, affective, and cognitive components are combined to improve emotion regulation. However, although treatment-associated risk reductions in violent recidivism have been reported in several studies (Henwood, Chou, & Browne, 2015), results of another review demonstrated insufficient evidence for a positive impact of ART programs on recidivism, self-control, social skills or moral development (Brännström, Kaunitz, Andershed, South, & Smedslund, 2016). Since risk reductions are more pronounced among treatment completers, part of the limited effectiveness of the current programs is probably related to low treatment adherence (Henwood et al., 2015). Low adherence might not only result in dropout, but might also constrain the transfer of therapeutic skills into daily practice by impairing the completion of out-of-session assignments (Fletcher, Tam, Omojola, Redemske, & Kwan, 2011; Kazantzis et al., 2016). Furthermore, by focusing on achievement of cognitive control over aggressive responses, current treatment programs might spend insufficient time on awareness and recognition of fluctuations in physiological sensations associated with aggression and other

dysregulated behaviors (Bellemans et al., 2019; McDonnell et al., 2015; Price & Hooven, 2018).

The fictional vignette below is based on clinical experience and illustrates a typical forensic outpatient with anger regulation difficulties and common challenges faced in therapy.

Roy is a 25-year-old man who was referred to an outpatient forensic mental health care facility by his probation officer. Since the age of 15, he has been arrested many times, first mainly for thefts, but later also for violent crimes. He has served two longer prison sentences and performed several community service tasks. Now, the judge ordered a conditional sentence for repeatedly committing violence, both toward his partner, toward a colleague and in two nightclubs. As a part of this conditional sentence, Roy has to attend aggression regulation treatment. At the start of the treatment, his motivation is ambivalent. He tends to downplay the seriousness of the aggressive incidents and puts the blame mainly on others, who should not have provoked him. However, he also starts to realize that his actions are part of the problem. In the process of creating a prevention plan, the therapist discusses with Ray the signals that precede aggressive outbursts. This is difficult for Roy, who reports that he 'just got a blackout' and that his anger rises 'from 0 to 10 within a split second'. He is not aware of any physiological sensations associated with aggressive behavior, such as accelerating heartbeat or sweating. To increase awareness, his therapist gives him out-of-session registration assignments. However, Roy forgets to do these assignments and seems to get more and more annoyed by the 'scholarly' paper-and-pencil assignments. He reports he cannot visit the therapist every week, due to the distance to his work. He comes up with excuses, is increasingly absent, and difficult to reach by his therapist. In the end, the therapeutic process is terminated prematurely. Two years later, Roy is being referred again because of new violent offenses.

Psychophysiological correlates of aggressive behavior

Over the last years the number of studies investigating the neurobiological correlates of antisocial spectrum behavior, including aggression, has increased. Neurobiological assessment includes for example electrophysiological, psychophysiological and neuroendocrinological measures. In this research project, we focused on psychophysiological measures such as heart rate (HR), heart rate variability (HRV) and skin conductance level (SCL), indicating the activity of the autonomic nervous system (ANS) and its two branches: the sympathetic nervous system (SNS) and the parasympathetic system (PNS). Important to note is that optimal behavioral adaptation depends on the interplay of these two systems.

Whereas activation of the SNS increases arousal, thereby promoting fight or flight responses, activation of the PNS decreases arousal, promoting resting conditions.

To understand the underlying mechanisms of aggression, ANS patterns of patients with antisocial and aggressive behavior have been compared to those of healthy controls, both at rest as well as in response to arousal-inducing events (i.e. reactivity measures). Recent meta-analyses demonstrated that lower HR at rest has most consistently been found to be positively related to antisocial behavior in general and proactive aggression in particular, although the overall effect size is small (De Looff et al., 2021a; Portnoy & Farrington, 2015). The research findings for reactivity measures are more mixed. Regarding overall ANS reactivity, previous studies have shown increases in HR reactivity in response to emotional stimuli (Lorber, 2004; Ortiz & Raine, 2004) and provocation, associated with reactive aggression (Crozier et al., 2008). Other research results demonstrated blunted HR reactivity, suggesting diminished sensitivity to stressors such as threat or punishment (Van Goozen, Fairchild, Snoek, & Harold, 2007), associated with proactive aggression.

Over the last years, studies also focused on the functioning of the SNS and PNS independently. There is some evidence that reactive aggression is related to heightened SNS reactivity (Armstrong et al., 2019; Murray-Close, Holterman, Breslend, & Sullivan, 2017; Thomson et al., 2021) and proactive aggression to blunted SNS and PNS reactivity (Moore et al., 2018; Murray-Close et al., 2017; Patrick, 2014; Thomson et al., 2021), although null-findings for one or both associations have also been reported (Centifanti, Kimonis, Frick, & Aucoin, 2013; Wagner & Abaied, 2015; Zijlmans, Marhe, et al., 2021). Given these inconsistent findings, the evidence for models stating that proactive or callous-unemotional aggressive behavior is related to low arousal, while reactive or frustration-based aggression is related to high arousal, remains weak (Fanti et al., 2019). Since studying the interaction between SNS and PNS is stressed in recent research, instead of hypo- or hyperreactivity of these subsystems alone (Branje & Koot, 2018; Moore et al., 2018; Puhalla & McCloskey, 2020), the autonomic underpinnings of reactive and proactive aggression need further investigation. Moreover, as these lab findings on group level lack generalizability to treatment of individual patients, new psychophysiological studies should also be conducted in daily life, within individuals (Fisher, Medaglia, & Jeronimus, 2018).

Psychophysiological measures are not only used to understand aggressive behavior but can also be used to predict aggressive incidents in everyday life. Until recently, most studies aimed at identifying these physiological biomarkers were conducted in laboratory settings (Adams et al., 2017). Facilitated by the development of wearable devices, several studies have been conducted in clinical settings over the last years. These studies demonstrated increased PNS-activity in the last stage of extreme

tension in patients with intellectual disabilities and behavioral problems (Palix, Akselrod, Cungi, Giuliani, & Favrod, 2017) and increased HR approximately 1 min before occurrence of challenging or aggressive behaviors in young people with autism spectrum disorders (Goodwin, Mazefsky, Ioannidis, Erdogmus, & Siegel, 2019; Nuske et al., 2019). Furthermore, research results indicated that aggressive incidents in forensic inpatients are preceded by significant increases in HR and SCL up to 20 minutes before manifestation (De Looff et al., 2019). Given the focus of most neurobiological studies on HR, and the technological developments facilitating affordable and accessible assessment of cardiovascular measures in everyday life (McGarry & Portnoy, 2022), we decided to focus on HR in this research project.

New technological interventions

Implementation of the psychophysiological results using innovative technological interventions might help to address the beforementioned challenges in treatment of forensic outpatients with aggressive behavior, such as the difficulties in attending to and recognizing physiological signals as well as the limitations in out-of-session practice. These new interventions, such as serious gaming (Smeijers & Koole, 2019), virtual reality therapy (Klein Tuente et al., 2020), and mobile biofeedback apps (Mackintosh et al., 2017), create opportunities to increase treatment adherence, for example by enhancing motivation and lowering barriers for out-of-session practice (Bath, Tolou-Shams, & Farabee, 2018). Since only biofeedback provides the patient with real-time physiological feedback in everyday life, this intervention specifically caught our attention.

However, when this research project was initiated in 2015, most biofeedback interventions still used static devices to provide users with real-time physiological information, enabling them to train their physiological reactions by consciously alternating their responses to the given feedback. Most ambulatory biofeedback interventions, enabling at home training, also used devices that did not support real-time feedback in daily life situations. In only a few studies real-time physiological feedback and just-in-time behavioral support in everyday life were combined (Nahum-Shani et al., 2018; Riley, Serrano, Nilsen, & Atienza, 2015), for which we introduced the term 'biocueing'. In these studies, wearable and mobile devices were used to collect and display physiological biomarkers to the user during daily activities. In contrast with traditional biofeedback, these new interventions focus on enhancing interoceptive and emotional awareness, and restrict the training component to the moments when physiological tension elevates and the user is provided with a just-in-time message encouraging the use of adequate coping strategies (Nahum-Shani et al., 2018). Since both components of biocueing – increasing awareness and delivering just-in-time behavioral support – were suggested as potentially useful treatment additions to reduce and prevent

aggressive incidents in forensic psychiatry (Cornet, Mandersloot, Pool, & De Kogel, 2017), we felt support for our aim to develop and evaluate a biocueing intervention as an addition to aggression regulation therapy among forensic outpatients.

THE CURRENT DISSERTATION

In order to develop this new intervention, we started with a systematic review of the existing literature regarding the use of ambulatory biofeedback and biocueing interventions to enhance emotion regulation. After establishing a cooperation with the developers of a precursor version of the Sense-IT app, we briefly assessed therapists' and other forensic professionals' perspectives on the use of a biocueing intervention and piloted the precursor version of the app in 10 forensic outpatients with aggressive behavior. With their information, we cooperated with app developers, designers, and other researchers to develop a new version of the Sense-IT app. Subsequently, we explored the effects of this biocueing intervention as an addition to aggression regulation therapy in 25 forensic outpatients. To assess changes related to interoceptive awareness, emotion regulation, and aggressive behavior, we used a quasi-experimental pretest-posttest group design, multiple single case experimental designs, and qualitative information. Furthermore, we used the qualitative information of the forensic outpatients and the results of two focus groups with therapists to identify guideposts for future implementation of the Sense-IT biocueing app. Finally, we contributed to the field of research aimed at unraveling the neurobiological underpinnings of aggressive behavior by investigating neurobiological responses to aggressive interactions among delinquent young adults and controls.

OUTLINE OF THIS THESIS

In **chapter 2** we present an overview of biocueing and ambulatory biofeedback interventions applied to enhance emotion regulation in psychiatric and non-psychiatric populations, resulting from the systematic literature search. **Chapter 3** elaborates on the process of user-centered development of a wearable biocueing intervention, the Sense-IT app, among forensic outpatients with aggressive behavior. Furthermore, acceptability, usability, and clinical outcomes are presented. In **chapter 4** we present the results of a mixed-methods study exploring the effects of a biocueing intervention, using a new version of the Sense-IT app, as an addition to aggression regulation therapy on interoceptive awareness, emotion regulation, and aggressive behavior. **Chapter 5** sheds light on the perspectives of both forensic outpatients and therapists on use and implementation of the Sense-IT biocueing app in clinical practice. In **chapter 6** we describe whether the neurobiological

responses toward stimuli depicting aggressive interactions differed between delinquent young adults and controls. Among the delinquent young adults, we also explored whether these responses were associated with reactive and/or proactive aggression. Finally, in **chapter 7** we summarize and discuss the main findings of this dissertation, including their implications for future research and clinical practice.

CHAPTER 2

Biocueing and Ambulatory Biofeedback to Enhance Emotion Regulation: A Review of Studies Investigating Non-Psychiatric and Psychiatric Populations

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ABSTRACT

Over the last years, biofeedback applications are increasingly used to enhance interoceptive awareness and self-regulation, in psychiatry and beyond. These applications are used to strengthen emotion regulation skills by home training (ambulatory biofeedback) and real-time support in everyday life stressful situations (biocueing). Unfortunately, knowledge about the feasibility and effectivity of these applications is still scarce. Therefore, a systematic literature search was performed. In total, 30 studies (4 biocueing, 26 ambulatory biofeedback) were reviewed; 21 of these studies were conducted in non-psychiatric samples and 9 studies in psychiatric samples. Study characteristics, biofeedback characteristics, effectivity and feasibility outcomes were extracted. Despite the rapid advances in wearable technology, only a few biocueing studies were found. In the majority of the studies significant positive effects were found on self-reported (stress-related) psychological measures. Significant improvements on physiological measures were also reported, though these measures were used less frequently. Feasibility of the applications was often reported as sufficient, though not adequately assessed in most studies. Taken into account the small sample sizes and the limited quality of the majority of the studies in this recently emerging field, biocueing and ambulatory biofeedback interventions showed promising results. Future research is expected to be focusing on biocueing as a just-in-time adaptive intervention. To establish this research field, closer cooperation between research groups, use of more rigorous as well as individually tailored research designs and more valid feasibility and effectivity assessment are recommended.

INTRODUCTION

Emotion regulation and psychopathology

The human ability to regulate emotions, by monitoring, evaluating and modulating emotional responses, is essential in mental health (Gross & Jazaieri, 2014). Emotion regulation or self-regulation consists of the integrative functioning of psychological and physiological processes to adequately identify and respond to real and perceived threats (Taylor, 2006). Over the last years, the multifaceted process of emotion regulation gained attention as one of the core transdiagnostic concepts in treatment of psychiatric disorders (Hulsbergen, Bohlmeijer, & Berking, 2014). The large variety of psychopathology and maladaptive behaviors associated with emotion regulation difficulties, ranging from anxiety and mood disorders to substance abuse and aggressive behavior, stresses the clinical relevance of this concept (Gratz & Tull, 2010; Sheppes et al., 2015). Adequate assessment and treatment of problematic patterns of emotion regulation, is important in ameliorating psychiatric symptoms as well as general functioning (Gross & Jazaieri, 2014). Therefore, the development of technological applications aimed to enhance insight and to support self-regulation by real-time monitoring of physiological processes and delivering just-in-time-adaptive interventions (Riley et al., 2015) are of high relevance for therapy.

Emotional awareness is considered essential for adequate emotion regulation (Füstös et al., 2013; Gross & Jazaieri, 2014). This ability is often divided into two main components: the ability to attend to the own emotional experiences (attention to emotion) and the extent to which the own emotional experiences are understood (emotional clarity) (Boden & Thompson, 2015). Emotional awareness, or lack thereof, has been found to be important in understanding psychopathology, both in internalizing problems (Berenbaum, Bredemeier, Thompson, & Boden, 2012; Sendzik, Schäfer, Samson, Naumann, & Tuschen-Caffier, 2017) and externalizing problems (Roberton, Daffern, & Bucks, 2015; Velotti et al., 2017). For example, considering sadness, low emotional awareness has been identified as a significant predictor of anxiety and depression symptoms, especially in younger populations. Considering anger, a lack of emotional awareness can result in behavioral problems. For example, forensic psychiatric patients often have difficulty observe increased inner tension and timely detect rising arousal levels using physiological signals such as accelerating heartbeat or sweating, which have been shown to precede aggressive behavior (De Looff et al., 2019).

Emotional granularity, a more nascent concept in emotion theory, seems relevant for adequate emotion regulation as well. This term refers to the ability to differentiate between emotions based on a combination of the dimensions of valence (negative versus positive affectivity) and arousal (calming versus exciting) (Tugade,

Fredrickson, & Feldman Barrett, 2004). Lowered levels of emotional granularity are associated with psychopathology, such as schizophrenia, borderline personality disorder, depression and substance abuse (Smidt & Suvak, 2015).

Furthermore, adequate emotion regulation depends on the body's ability to achieve and maintain homeostatic regulation (Crockett et al., 2017). One of the human regulatory systems is the autonomic nervous system (ANS), which regulates respiration, heartbeat and sweat secretion. The ANS is divided into two branches: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). Typically, in case of emotional stress, SNS and PNS cooperate reciprocally: when the SNS is activated, creating a fight- or flight-response, the PNS is deactivated (Levenson, 2014). In case of coactivation of SNS and PNS, research results indicate that coping resources are overwhelmed by exaggerated arousal, leading to internal distress and anxious responses (Hastings et al., 2009) as well as reactive aggression (El-Sheikh et al., 2009; Raine, 2008). In case of coinhibition of both systems, studies report passive attention to threat or dangerous activities to induce arousal, contributing to covert forms of externalizing behavior, such as proactive aggression (Boyce et al., 2001; El-Sheikh et al., 2009). Altogether, dysregulated responses of the ANS have been shown to hinder homeostatic and adaptive functioning, to enhance stress vulnerability and to give rise to both physical and psychological dysfunctions (Mandel, 2003). Therefore, training methods aimed at enhancing emotional awareness, such as mindfulness based interventions for patients with internalizing problems (Kranzler et al., 2016) and treatment interventions focusing on recognition of arousal for patients with externalizing, aggressive behavior (Novaco, 2007) are often mentioned as potentially beneficial additions to current treatment protocols. Nevertheless, it should be noted that no consistent or specific patterns of ANS changes were found in association with specific emotion categories (Siegel et al., 2018). In summary, ANS information may support emotional awareness (particularly the facet of attention to emotion) and may aid the detection of emotional intensity based on the arousal dimension, though is not expected to enhance emotional granularity by strengthening the determination of valence.

Biofeedback to enhance emotion regulation

The addition of real-time biofeedback in- and outside the treatment setting, using new technological applications, is an innovative attempt to enhance emotion regulation skills. In the process of biofeedback, instruments monitor physiological parameters (e.g., heart rate, skin conductance, respiration), transform these measurements into auditory and/or visual signals and present these signals directly to the user (McKee, 2008). Providing psychiatric patients with this physiological information is considered to be a helpful means to signal arousal changes in response to emotional events, to recognize emotions adequately and to influence

emotional processes in a health-improving way (Cornet et al., 2017; Lisetti & Nasoz, 2004; Yucha & Montgomery, 2008).

In the past decades, several biofeedback approaches have been developed. During a standard biofeedback paradigm consisting of multiple sessions, patients are trained to influence a physiological parameter, for example Heart Rate Variability (HRV) (Lehrer, 2013) or a derivative thereof called coherence (McCraty & Zayas, 2014), by consciously alternating their (breathing) responses to the feedback provided. The ability to regulate their physiological reactions in response to emotional stimuli is trained during the sessions and is supposed to be transferred to emotionally challenging situations outside the sessions, when biofeedback is not available (Peira, Fredrikson, & Pourtois, 2013). To differentiate this biofeedback training paradigm from more modern approaches, this type is called traditional biofeedback. To support patients to train at home, new devices were developed and studied (Whited, Larkin, & Whited, 2014). These portable devices can be used at home, in combination with a personal computer, when the users wants, preferably several times a day. In this study, we will refer to this biofeedback type as ambulatory biofeedback. Over the last years, rapid developments in the field of non-invasive devices (such as breast bands, wrist sensors, smart fibers and interactive textiles) opened up opportunities for real-time measurement in everyday life. These developments have enabled a new type of personalized biofeedback, delivered in everyday life, which will be referred to as biocueing in this review. Biocueing can be defined as cueing users when physiological values are in a specific 'at risk'-range, and allowing just-in-time behavioral support (Paradiso, Faetti, & Werner, 2011; Riley et al., 2015). As such, whereas ambulatory biofeedback can mainly be seen as a method to encourage at home training, biocueing has an additional function to signal deviating arousal levels, real-time, in everyday life.

Based on multiple studies, mainly performed among patients with internalizing psychological problems, traditional biofeedback is considered efficacious in treatment of anxiety and chronic pain, and possibly efficacious in treatment of depression (Yucha & Montgomery, 2008). Considering cardiovascular feedback, the main focus of our study, two recent meta-analyses revealed significant reductions in (self)-reported stress and anxiety after HRV-biofeedback training (Goessl, Curtiss, & Hofmann, 2017) and an overall small to medium effect size for HRV-biofeedback, with largest effect sizes for anxiety, depression, anger and performance measures (Lehrer et al., 2020). It is hypothesized that HRV-biofeedback stimulates activity in the prefrontal regions that are sensitive to interoceptive information, thereby strengthening the neuronal pathways underlying emotion regulation (Mather & Thayer, 2018). In ambulatory biofeedback studies, this potential to enhance self-regulation skills is also found, both among psychiatric and non-psychiatric populations with emotional problems (Eddie, Kim, Lehrer, Deneke, & Bates, 2015;

Tolin, McGrath, Hale, Weiner, & Gueorguieva, 2017; Yu, Funk, Hu, Wang, & Feijs, 2018). Biocueing is relatively new, but may be particularly useful for patients who lack insight in the physiological signals that precede dysregulated behavior in everyday life such as binge eating episodes (Godfrey, 2018), self-injurious behavior (Koenig et al., 2017) and psychotic experiences (Schlier, Krkovic, Clamor, & Lincoln, 2019). Focusing on aggression, several studies showed that physiological information can be used as a predictor of aggressive behavior, for example among youth with autism spectrum disorder (Cumpanasoiu et al., 2018; Ferguson et al., 2019; Nuske et al., 2019), patients with intellectual disabilities (Palix et al., 2017), patients with schizophrenia (Wang, Yang, Chen, & Chueh, 2019) and forensic patients (De Looff et al., 2019; Kuijpers, Nijman, Bongers, Lubberding, & Ouwerkerk, 2012). Considering the emotion of anger – in forensic populations often manifested as externalizing, aggressive behavior – biocueing could strengthen awareness of high risk situations and support patients to use learned behavioral skills to prevent aggressive incidents (Cornet, Bootsman, Alberda, & Kogel, 2016).

Study objective

Given the potential of biocueing and ambulatory biofeedback, the main aim of this systematic review is to provide an overview of the current state of research concerning these new applications in treatment of emotion regulation difficulties, in psychiatry and beyond. Furthermore, we will focus on the feasibility of these interventions and their (preliminary) effects on psychological and and/or psychophysiological functioning. Finally, suggestions for future research and implementation of biocueing and ambulatory biofeedback as adjuncts to treatment will be considered.

METHODS AND MATERIALS

This review is conducted and reported in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses for Protocols 2015 (PRISMA-P 2015) guidelines (Moher et al., 2015). The review has been registered in PROSPERO International Prospective Register of Systematic Reviews (crd.york.ac.uk/prospero, registration number: 112586).

Information sources

A systematic literature search was performed using the databases Web of Science, PubMed, EMBASE, PsychINFO and ACM Digital Library. The search was conducted in March 2020. Given the focus of this review on recent advances in biocueing and ambulatory biofeedback research, the start of the search period was set to 2007. The search was limited to papers that could be accessed in English or Dutch.

Search strategy

First, we checked for ongoing reviews considering real-time monitoring, biocueing and/or ambulatory biofeedback and emotion regulation in the WHO international clinical trial registry platform (WHO ICTRP) and the Clinical.gov databases. No ongoing reviews with the same scope were found. The key concepts "biofeedback" or "wearable" or "biosensor" or "real-time monitoring", were searched in combination with physiological parameters "heart rate" or "skin conductance" or "respiration" and terms considering (inadequate) emotion regulation such as "emotion regulation", "self-regulation" or "aggression". These key concepts were adjusted in order to fit the different bibliographic databases, applying appropriate (controlled) terms, database specific search fields and syntaxes. In addition, the authors reviewed the reference lists of relevant articles and review papers. See supplementary appendix A for the detailed search strategy.

Selection criteria

We decided to include published experimental and pilot-studies in which new biofeedback interventions, using ambulatory technology, were used for a wide range of emotion regulation difficulties in psychiatric populations (according to DSM-IV-TR or DSM-5 criteria) and non-psychiatric populations. Exclusion criteria for the studies were: 1) use of a non-human sample; 2) use of a sample with physical conditions; 3) background articles and reviews; 4) articles only accessible in a language other than English or Dutch; 5) conference, poster or presentation abstracts and 6) use of another intervention instead of biocueing or ambulatory biofeedback (e.g., pharmacotherapy, yoga, mindfulness training). Neurofeedback studies were excluded as well, since neurofeedback devices do not allow ambulatory measurement in everyday life.

Selection procedure

First, duplicate publications were excluded. Titles and abstracts of studies resulting from the search were independently screened for eligibility by authors JtH and MN. Discrepancies in judgement for eligibility were discussed until agreement between reviewers was achieved. The reviewers used the web application Rayyan (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016) for the selection process. Subsequently all selected papers were read in full to check for all in- and exclusion criteria. Only two articles met the most strict criteria for inclusion. Therefore, the remaining papers were read to include studies using biocueing among non-psychiatric populations and studies investigating ambulatory biofeedback in psychiatric and non-psychiatric populations as well. Among the ambulatory biofeedback studies, we found eight studies in which the same samples were used. In these cases, the most recent (3) or complete (1) studies were included.

Data collection

JtH extracted the following data from the included studies: the study characteristics (sample size, research design), participant characteristics (age, gender and psychopathology), used device or application, modality and duration of biofeedback, outcome measures, feasibility information and effectivity outcomes. Regarding the feasibility and effectivity outcomes, we extracted both qualitative and quantitative information (psychological and physiological measures, statistical significance). Data extraction was checked by the second author (MN). Disagreements were resolved by consensus.

Risk of bias in individual studies

Three master students, EN, NvE and LS, independently assessed and rated methodological rigor, selection and reporting bias of the included studies using the PEDro checklist (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). Based on this checklist, the quality of a paper was considered 'high' in case of 8–11 points, 'medium' in case of 4–7 points and 'low' in case of 1–3 points. In case of discrepancy between the raters, the final score was based on the mean.

RESULTS

Identified studies

The literature search yielded a total of 4149 unique study records. After title and abstract screening, 119 studies remained. The most common reason for exclusion after preliminary screening was the population: a non-human sample or a human population with physical problems (e.g., heart failure, asthma). The full text of the remaining 119 papers were examined in detail. Based on the in- and exclusion criteria described above, only two biocueing studies using a psychiatric sample were found. Two more biocueing studies were added, performed among non-psychiatric populations. Expansion of our search strategy made us include 26 ambulatory biofeedback studies; seven studies performed among psychiatric populations and 19 studies among non-psychiatric populations. After final selection, information from 30 studies was extracted and summarized. An overview of the selection process is visualized in Figure 1.

Study quality

Of the 30 studies we selected for inclusion in this review, two studies were rated as high quality, 19 were rated as medium quality and 9 were rated as low quality. Based on recent guidelines (Koo and Li, 2016), interrater reliability between the three raters was excellent, ICC(3,k) = 0.91–0.97.

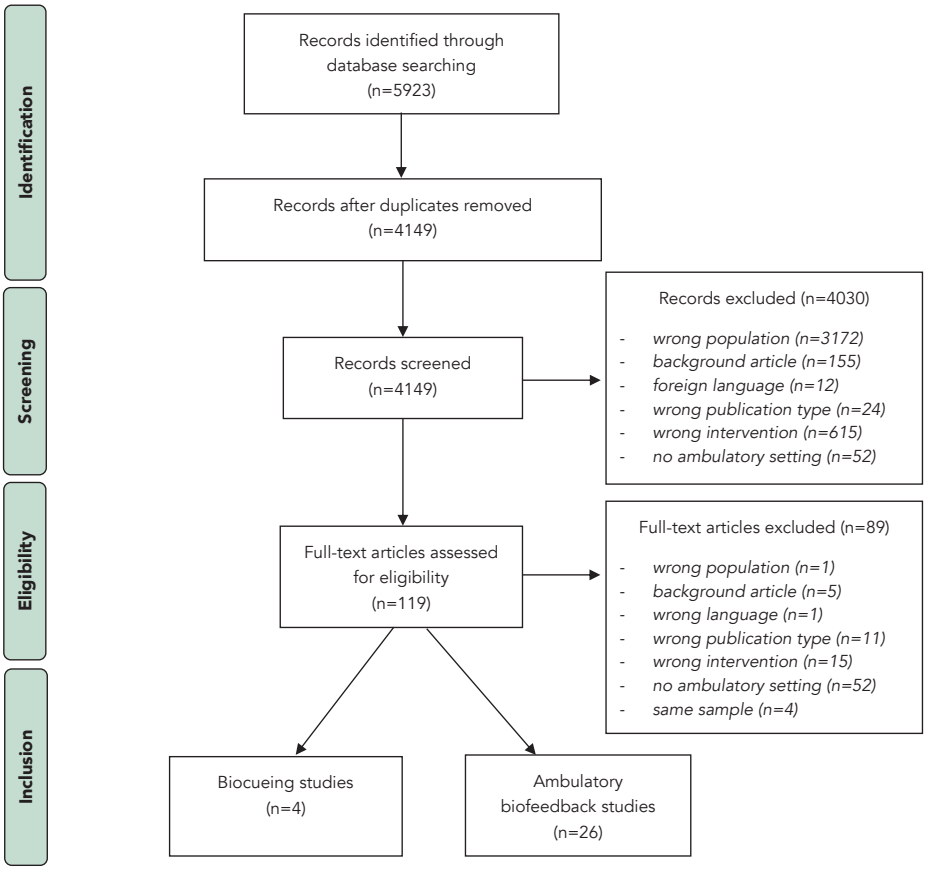

Figure 1. Flowchart of the study selection process.

Study characteristics

In total, we included four biocueing and 26 ambulatory biofeedback studies. Of all studies, 21 used a non-psychiatric sample and 9 studies were performed among psychiatric populations. Targeted psychological problems varied widely: aggressive behavior, post-traumatic stress, depression, anxiety and pregnancy-, work- and performance-related stress. Participants were predominantly adults (24 studies); young adults (5) and children (1) formed a minority. Different study designs were used: randomized controlled trials (6 studies), quasi-experimental studies (12), case studies (5) and pilot studies (8). A summary of the study characteristics is presented in Table 1.

Biofeedback characteristics

Different devices and applications were used in the selected studies. Considering the ambulatory biofeedback studies, most studies used the emWave device (12

studies), followed by the StressEraser (6). Other applications were the Positive Technology app (2), the RELAX app (1), the BART app (1), the Freespira (1), the EliteHRV app (1), the Breath Pacer (1), the STRS app (1), the Ripple shirt (1), the MioFuse heart rate monitor (1), a not specified heart rate monitor (1) and a multi-biosensor platform (1). In most studies, Heart Rate Variability (HRV) was chosen as biofeedback modality (23). Other studies used Heart Rate (HR; 3), respiration measures (2), Skin Conductance Level (SCL; 1) or a combination of measures (1). The duration of training and actual use of the biofeedback devices varied widely. In the majority of the biocueing studies, a brief instruction was given or a user manual was provided. Actual frequency of use depended on the user; except for one, more structured study. In the ambulatory biofeedback studies, training varied from a single and brief instruction up to 10 training sessions. Participants in these studies were encouraged to train once to three times a day, with a total duration ranging from one week to eight weeks. A summary of the biofeedback characteristics can be found in Table 1.

Table 1. Description of main characteristics of the selected studies

Study characteristics				**Biofeedback characteristics**				**Outcomes**		
Author(s)	Sample	Participants (number; age range; gender)	Design	Application	Modality	Implemented protocol	Duration (training; practice; intervention length)	Psychological measure(s)	Physiological measure(s)	Feasibility measure(s)
Biocueing among non-psychiatric populations										
Howell (2018)	Society members interested in biosensing	N=17 Age: 19-41 FIM: 53I47	Pilot; app evaluation study	Ripple	SCL	No traditional protocol used	T: brief instruction, one meeting P: daily L: 8-20 hours	No measures used; diaries, interviews and observation	No measures used	Qualitative feedback only; mainly critical
McHugh et al. (2010)	Children with violent behavior	N=3 Age: 10-15 FIM: 33I67	Case studies; evaluation study	Heart rate monitor	HR	No traditional protocol used	T: brief instruction P: user dependent L: user dependent	No measures used, only qualitative information	No measures used	Qualitative feedback only; positive
Biocueing among psychiatric populations										
Mackintosh et al. (2017)	Veterans with PTSD	N=58 Age: 24-71 FIM: 0I100	RCT; TAU + BF vs. TAU	RELAX app	HR	No traditional protocol used	T: introduction and user manual P: user dependent L: 6 weeks	STAXI, DAR-5, B-IPF, PHQ-9, PCL-5; *pp, TAU+ = TAU	No measures used	TFQ, qualitative feedback; positive
Savard (2017)	Adolescents with anger-related diagnosis or behavior	N=5 Age: 15-18 FIM: 20I80	Case studies: mixed methods, ABABAB-design	Mio Fuse heart rate monitor	HR	No traditional protocol used	T: daily during intervention phase P: 5 days a week L: 6 weeks	DOF, YSR, TRF, CBCL, STAXI, qualitative information; *pp (3I5)	No measures used	Qualitative feedback only; positive yet critical

Table 1. Continued.

Study characteristics				Biofeedback characteristics				Outcomes		
Ambulatory biofeedback among non-psychiatric populations										
De Bruin et al. (2016)	Stressed young adults	N=75 Age: 18-40 F|M: 73|27	RCT; MM vs. BF vs. PE	StressEraser	HRV	HRV-BF protocol not further specified	T: instruction and assisted practice P: daily L: 5 weeks	ACS, BRIEF-A, FFMQ, SCS, PSWQ; *pp, MM = BF = PE	No measures used	No measures used
Gaggioli et al. (2014)	Society members interested in stress therapy	N=32 (7) Age: n.r. F|M: n.r.	Pilot; app evaluation study	Positive Technology app	HRV	No traditional protocol used	T: guided training P: user dependent, 5-15min/ session L: user dependent	SAM/PSS; *pp	HR before and after exercise; n.s.	Author report only; positive yet critical
Hasuo et al. (2019)	Family caregivers of cancer patients	N=54 Age: n.r.; m=63 F|M: 68|32	Open-label RCT; BF vs. control group	Breath Pacer	HRV	No traditional protocol used, based on HRV-BF protocol	T: 1 session and self-training P: 5-20min a day L: 4 weeks	SF-12; *pp, BF = control	HRV-indices; *pp, BF > control	Impl. rate and author report; positive
Keeney (2009)	Pregnant woman with stress and anxiety	N=7 Age: 18-45 F|M: 100|0	Pilot; pre-test vs. post-test	emWave	HRV	Coherence protocol	T: 5-6 sessions P: 20min a day L: +/- 5 weeks	STAI-Y, PES; n.s.	HRV-indices; *pp	Qualitative feedback only; positive
Kizakevich (2019)	Military personnel, veterans and civilians	N= 328 (49) Age: 20-60 F|M: 47|53	Pilot; app-evaluation study	BART app	HRV	No traditional protocol used, based on HRV-BF principles	T: 1 session and self-training P: 3 times a week L: 6 weeks (up to 12 months)	CD-RISC, BCS, PSS, PGI, SDS(2); outcomes not reported	HRV-indices; *pp in subset	Adherence rate and author report; mainly critical

Table 1. Continued.

Study characteristics				Biofeedback characteristics				Outcomes		
Kudo et al. (2014)	Mothers in early post-partum period with stress	N=55 Age: n.r.; m=33.4 vs. m=30.5 FIM: 100l0	Quasi-experiment; TAU + BF vs. TAU	StressEraser	HRV	HRV-BF protocol not further specified	T: brief instruction P: daily L: +/- 4 weeks	EPDS; *pp, TAU+ > TAU	HRV-indices; *pp, BF > control	Author report only; positive
Lemaire et al. (2011)	Physicians with work-related stress	N=40 Age: n.r.; m=44.8 vs. m=47.8 FIM: 42l58	RCT; TAU + BF vs. TAU	emWave	HRV	Coherence protocol	T: 1 session and support visits P: 5min, 3 times a day L: 4 weeks	PSS, POQA-R; *pp, TAU+ > TAU .	HR, BP, salivary and cortisol levels, n.s., BF = control	Adherence scores and author report; positive
May et al. (2018)	Students	N=90 Age: n.r.; m=18.55 FIM: 82l18	RCT; BF vs. HIIT vs. wait-list control	emWave	HRV	Coherence protocol	T: 3 sessions a week P: 20min sessions, and frequent self-practice L: 4 weeks	SBI, CES-D, STAI, serial subtraction task; *pp, BF > HIIT + control	HRV-indices, BP; *pp; BF > HIIT + control	No measures used
McCraty et al. (2009)	Correctional officers with work-related stress	N=75 Age: n.r.; m=39.5 vs. m=40.7 FIM: 22l68	Quasi-experiment; BF vs. wait-list control	emWave	HRV	Coherence protocol	T: 5 sessions P: several times a week; ≥ once a day L: 3 months	PWP, JAS, BSI, POQA-R; *pp, BF > control	HRV-indices, BP, cortisol; *pp, BF > control	No measures used
McCraty et al. (2012)	Police officers with work-related stress	N=65 Age: 24-55 FIM: 15l85	Quasi-experiment; BF vs. wait-list control	emWave	HRV	Coherence protocol	T: 3 sessions P: several times a week; ≥ once a day L: +/- 7 weeks	POQA-R, qualitative information; *pp; BF > control	No measures used to evaluate	No measures used

Table 1. Continued.

Study characteristics				**Biofeedback characteristics**				**Outcomes**		
Narita et al. (2018)	Pregnant woman with anxiety about labor	N=97 (38) Age: 24-45 FIM: 10010	Quasi-experiment; BF vs. no intervention	StressEraser	HRV	HRV-BF protocol not further specified	T: brief instruction P: daily L: 3-4 weeks	W-DEQ, PSQI, Fatigue-VAS, qualitative information; *pp, BF > no intervention	HRV-indices; n.s.	Qualitative feedback only; positive
Poston (2017)	Pregnant women with depressive symptoms	N=41 Age: 18-40 FIM: 10010	Quasi-experiment; self-selected BF vs. no intervention	emWave	HRV	Coherence protocol, not further specified	T: video training and self-training P: daily L: 4 weeks	EPDS, PDSS(2), qualitative information; *pp, BF > no intervention	No outcomes reported	Author report only; positive yet critical
Ramey et al. (2016)	Police officers with work-related stress	N=38 Age: 22-54 FIM: 24176	Quasi-experiment; baseline vs. post-tests	emWave	HRV	Coherence protocol, not further specified	T: educational class P: before and after stressful events L: 3 weeks	PSS, MQ, IES, POQA-R, RSES; n.s.	HRV-indices, BP, cortisol; *pp	Qualitative feedback only; positive
Serino et al. (2014)	Society members interested in stress therapy	N=68 Age: n.r. FIM: n.r.	Pilot; app evaluation study	Positive Technology app	HRV	No traditional protocol used	T: brief instruction P: user dependent, 5-15min/ session L: user dependent	SAM/PSS; *pp	HR before and after exercise; n.s.	Author report only; positive yet critical

Table 1. Continued.

Study characteristics				Biofeedback characteristics				Outcomes		
Schumann et al. (2019)	Society members interested in biofeedback	N=24 Age: 18-55 F|M: 50|50	Quasi-experiment; BF vs. control	EliteHRV app	HRV	No traditional protocol used, based on HRV-BF protocol	T: self-training after one session P: 5 times a week L: 8 weeks	SST; n.s.	HRV, SCL, BP, BR, BRS, DIA; *pp, BF > control	No measures used
Tanis (2012)	Female athletes with sports related mental stress	N=13 Age: 18-23 F|M: 100|0	Quasi-experiment; pre-test vs. post-test	emWave	HRV	Coherence protocol, not further specified	T: 6 sessions P: daily L: 6 weeks	Performance score, qualitative information; n.s.	No measures used	Qualitative feedback only; positive yet critical
Thurber et al. (2007)	Student musicians with performance anxiety	N=14 Age: 19-32 F|M: 36|64	RCT; BF vs. no intervention	emWave	HRV	Coherence protocol	T: 4-5 sessions, self-practice after 3 sessions P: daily L: 6 weeks	STAI-Y, PAI, FSS, qualitative information; *pp; BF > no intervention	HRV-indices; *pp; BF > control	Author report only; positive yet critical
Weltman et al. (2014)	Police office personnel with work-related stress	N=14 Age: early 20 – late 40 F|M: 29|71	Case-study; app evaluation study	SRTS app	HRV	No traditional protocol used, based on coherence principles	T: 1 training session, 4 telemonitoring sessions P: user dependent L: 6 weeks	POQA-R, qualitative mentor and participant reports; *pp	No measures used	Qualitative feedback only; positive
Wu et al. (2012)	Society members, half of them unemployed	N=67 (33) Age: 20-45 F|M: 22|78	Quasi-experiment; pre-test vs. post-test evaluation	Multi-Biosensor Platform	Respiration, HRV	No traditional protocol used	T: lab-experiment, 3 training sessions P: 20min a day L: +/- 1 week	No measures used	HRV-indices, respiratory pattern; *pp	No measures used

Table 1. Continued.

Study characteristics				Biofeedback characteristics				Outcomes		
Ambulatory biofeedback among psychiatric populations										
Eddie et al. (2015)	Young adults with substance use disorder	N=41 Age: 20-25 F|M: 0|100	Quasi-experiment; TAU + BF vs. TAU	emWave	HRV	Abbreviated HRV-BF protocol	T: 3 sessions P: daily L: 3 weeks	PACS, PSS; *pp, TAU+ = TAU	HRV-indices; n.s.; TAU+ = TAU	Qualitative feedback only; positive
Kim and Zemon (2013)	Patients with severe brain injury	N=13 Age: 23-63 F|M: 54|46	Quasi-experiment; pre-test 1 vs. pre-test 2 vs. post-test	emWave	HRV	Coherence protocol	T: 10 sessions, self-practice after 4 sessions P: daily L: +/- 6 weeks	Impairment index, HCT, IVA-CPT, BRIEF-A; n.s.	HRV-indices; *pp	Author report only; positive
McLay and Spira (2009)	Military officer with adjustment disorder	N=1 Age: 39 F|M: 0|100	Case-study	StressEraser	HRV	No traditional protocol used, based on HRV-BF principles	T: evaluation after 1 week of self-practice P: user dependent L: 6 weeks.	PSQI, GSQS, ESS; *pp	No measures used	Author report only; positive
O'Neill and Findlay (2014)	Patients with traumatic brain injury and aggressive behavior	N=2 Age: 18, 33 F|M: 0|100	Case studies, within subjects AB-design	emWave	HRV	Coherence protocol	T: 10-20min a day, on weekdays P: user dependent L: 24 days (1); 22 weeks (2)	OASMNR; *pp (1|2)	No measures used	Author report only; positive
Reiner (2008)	Patients with anxiety disorders and depression	N=20 Age: 18-65 F|M: 50|50	Pilot; RSA-BF device evaluation study	StressEraser	HRV	HRV-BF protocol not further specified	T: 15min instruction P: 20min a day L: 3-4 weeks	STAI-Y, PSQI, STAXI, and qualitative information; *pp	No measures used	Qualitative feedback only; positive yet critical

Table 1. Continued.

Study characteristics				Biofeedback characteristics				Outcomes		
Tolin et al. (2017)	Patients with panic disorder	N=48 Age: 18-65 F|M: 59|41	Quasi-experiment; pre-test vs. post-test vs. follow-up	Freespira	Respiration	No traditional protocol used	T: brief instruction P: 17min, twice a day L: 4 weeks	PDSS(1), SDS (1) and CGI-S; *pp	RR, PETCO2; *pp	Adherence and patient satisfaction scores; positive
Zucker et al. (2009)	Patients with substance use disorder and PTSD	N=38 Age: 18-60 F|M: 45|55	Pilot; RSA-BF vs. PMR as adjunctive interventions	StressEraser	HRV	HRV-BF protocol not further specified	T: brief instruction P: 20min a day L: 4 weeks	DAPS, PCL-C, BDI-II, ISI; *pp, BF > PMR	HRV-indices; *pp, BF > PMR	No measures used

Note. *pp, significant pre-post intervention change ($p < .05$) on at least one of the outcome measures; X > Y, significant difference ($p < .05$) between intervention and control group, favoring the intervention, on at least one of the outcome measures; X = Y, no significant difference ($p < .05$) between intervention and control group.
Abbreviations. ACS, Attention Control Scale; BART, Biofeedback-Assisted Resilience Training; BCS, Brief Coping Scale; BF, Biofeedback; BDI-II; Beck Depression Inventory; B-IPF, Brief Inventory Psychosocial Functioning; BR, Breathing Rate; BRIEF-A, Behavior Rating Inventory of Executive Function-Adult Version; BRS, Baroreflex Sensitivity; BSI, Brief Symptom Inventory; CBCL, Child Behavior Checklist; CD-RISC, Connor-Davidson Resilience Scale; CES-D, Center for Epidemiologic Studies Depression Scale; CGI-S, Clinician Global Impression-Severity Scale; DAPS, Detailed Assessment of Posttraumatic States; DAR-5, Dimensions of Anger Reactions; DIA, Pupil Diameter; DOF; Direct Observation Form; EPDS, Edinburgh Postnatal Depression Scale; ESS, Epworth Sleepiness Scale; F/M: female-male ratio; FFMQ, Five Facet Mindfulness Questionnaire; FSS, Flow State Scale; GSQS, Groningen Sleep Quality Scale; HCT, Halstead Category Test; HITT, High Intensity Interval Training; HR, Heart Rate; HRV, Heart Rate Variability; IES, Impact Events Scale; ISI, Insomnia Severity Index; IVA-CPT, Integrated Visual and Auditory Continuous Performance Test; JAS, Jenkins Activity Survey; m, mean; MQ, Maastricht Questionnaire; N, number; n.r., not reported; n.s., not significant; OASMNR, Overt Aggression Scale Modified for Neurorehabilitation; PACS, Parental Account of Children's Symptoms; PAI, Performance Anxiety Inventory; PCL-5, PTSD Checklist for DSM-5; PCL-C, PTSD Checklist-Civilian Version; PDSS(1), Panic Disorder Severity Scale; PDSS(2), Postpartum Depression Screening Scale; PE, Physical Exercise; PES, Pregnancy Experience Scale; PETCO2, End-tidal CO2; PGI, Posttraumatic Growth Inventory; PHQ-9, Patient Health Questionnaire; PMR, Progressive Muscle Relaxation; POQA-R: Personal and Organizational Quality Assessment–Revised; PSQI, Pittsburgh Sleep Quality Index; PSS, Perceived Stress Scale; PSWQ, Penn State Worry Questionnaire; PWP, Personal Wellness Profile; RELAX, Remote Exercises for Learning Anger and Excitation Management; RCT, Randomized Clinical Trial; RR, Respiration Rate; RSES, Response to Stressful Experiences Scale; SBI, School Burnout Inventory; SCS, Self-Compassion Scale; SCL, Skin Conductance Level; SDS(1), Sheehan Disability Scale; SDS(2); Sleep Disturbance Scale; SF-12, Short Form Health Survey; STAI(-Y), State Trait Anxiety Inventory (Y-version); STAXI, State Trait Anger Expression Inventory; SUS, System Usability Scale; TAU, Treatment As Usual; TFQ, Teaching Feedback Questionnaire; TRF, Teacher's Report Form; VAS, Visual Analog Scale; W-DEQ, Wijma Delivery Expectancy/Experience Questionnaire; YSR, Youth Self-Report.

Effectivity outcomes

In most studies, effectivity of the intervention was evaluated using psychological or physiological measures (37%) or a combination of both (57%). In two studies (7%), no quantitative measures were administered. An overview of significant ($p < .05$) pre-post intervention changes (and group differences, if applicable) on at least one of the psychological or physiological outcome measures is presented in Fig. 2. The results of the biocueing studies – our primary focus – will be reviewed first and in more detail, followed by the ambulatory biofeedback studies; both categories subdivided into non-psychiatric and psychiatric populations.

Biocueing

Non-psychiatric populations

In general population samples, two studies were found in which devices enabled prompting of regulation strategies by physiological information. In one study, a systemic approach to biocueing was piloted among three children with violent or disruptive behavior (though without a formal diagnosis) and their parents in a multi-family group setting (McHugh, Dawson, Scrafton, & Asen, 2010). All children used heart rate breast band monitors, wirelessly connected with watch-like wrist bands. The monitor emitted an auditory signal when a specific threshold (compared to a personal baseline) was reached. In the first case, the use of the biofeedback system helped to show the child's difficulty to verbalize emotions. In the second case, the system was used for breathing control and focused relaxation to facilitate a faster return to resting heart rate levels after a stressful event. In the last case, the alarm function of the monitor supported the child to take time to 'cool down'. Teachers and parents reported increased self-control and anger management among pupils. Overall, the authors deemed the intervention helpful to reflect on triggers and to initiate (self-)calming strategies. They state that feedback from children and parents was consistently positive. In another study, the Ripple, a biosensing shirt measuring and displaying skin conductance levels, was piloted (Howell, Devendorf, Vega Gálvez, Tian, & Ryokai, 2018). Participants were observed, interviewed and encouraged to critically review the design. The Ripple system increased emotional awareness and reflection, but also yielded new questions. Whereas some participants related the displayed data to their own feelings in a natural way, others seemed to adjust their emotional experiences to the biosensing information. Furthermore, the system seemed to value some emotions over others; the absence or presence of display changes fostered insecurities in some participants. Authors emphasize that ethical issues should be considered in the future given the perceived authority of biosensing interventions.

Psychiatric populations

Two more biocueing studies were found among psychiatric populations. In one high-quality RCT, conducted among veterans with post-traumatic stress disorder,

a mobile application system was added to regular anger management therapy (Mackintosh et al., 2017). This system consisted of an app, a wearable heart rate monitor, a remote server and a web-based therapist interface. The app could be used to increase awareness, to prompt and practice skills in daily life, to monitor symptoms and to record physiological data. Post-treatment, participants in both conditions demonstrated significant reductions in anger severity and reductions in PTSD-symptomatology; the experimental condition did not outperform treatment as usual. Participants who used the RELAX-app reported increased ease of use, increased helpfulness and decreased frustration over time. In another study, a multi-method AB-design was used to evaluate the therapeutic use of a personal heart rate monitor among adolescents with anger-related diagnosis and disruptive behavior (Savard, 2017). Adolescents were instructed repetitively in the use of the monitoring device and deployment of their personalized relaxation strategy when their heart rate elevated. In three out of five cases, a significant decline in anger and aggressive behavior was shown; the other cases showed a non-significant decline or mixed results. Linear regression showed that aggressive behaviors declined in self-report as well as in all parents' and teachers' reports, except for one teacher. Overall, participants were satisfied with the simplicity of the method. Some reported mechanical or tactile issues with the device or difficulty following the directions. The majority of the adolescents, parents and teachers reported that the intervention contributed to (small) behavioral changes.

Ambulatory biofeedback

Non-psychiatric populations

Our search yielded 21 ambulatory biofeedback studies conducted in general population samples that are known to be prone to stress, due to work- or performance related pressure or pregnancy. Four studies were conducted among police personnel and correctional officers. In a quasi-experimental study among correctional officers significant improvements in HRV and blood pressure and significant reductions in psychological stress measures were found in the biofeedback condition compared to the wait-list control condition (McCraty, Atkinson, Lipsenthal, & Arguelles, 2009). A case-study among police staff, evaluating the STRSS biofeedback application, showed significant improvement on personal and organizational quality, including stress, post-intervention (Weltman, Lamon, & Freedy, 2014). In a study among police officers significantly greater reductions in distress, negative emotions and depression were found for the experimental condition compared to wait-list control (McCraty & Atkinson, 2012). In another study among police officers, the addition of ambulatory biofeedback was associated with significant improvement in HRV and positive, although non-significant, changes on other physiological and psychological outcomes (Ramey et al., 2016).

Ambulatory biofeedback was also tested among other groups in which high (work- and performance related) stress levels are often reported. In a subset of a study among (former) military personnel and civilians HRV-values significantly decreased in a stressor task and significantly increased during biofeedback-assisted slow paced breathing (Kizakevich et al., 2019). In a RCT among physicians the perceived stress score in the biofeedback condition decreased significantly compared to support visits only (Lemaire, Wallace, Lewin, de Grood, & Schaefer, 2011). In an usability study evaluating a portable resonant breathing device among family caregivers of cancer patients, quality of life scores significantly improved post-intervention, though not better compared to the control condition (Hasuo et al., 2019). Low-frequency HRV-values improved significantly better in the biofeedback condition. Furthermore, a quasi-experimental study among athletes with sports-related mental stress showed no significant changes on individual (athletic) performance (Tanis, 2012). Qualitatively, reductions in mental and physical stress and enhancement of mental and physical state were reported. In a study among student musicians performance anxiety and HRV improved with large effect sizes in the biofeedback condition compared to the control group (Thurber, 2007). Furthermore, a RCT among stressed young adults revealed that three stress regulation methods (mindfulness meditations, ambulatory biofeedback and physical exercises) were all effective in improving stress-related outcomes and did not differ significantly from each other (De Bruin, Van der Zwan, & Bogels, 2016). In a similar study, two interventions to reduce school burnout (ambulatory biofeedback and physical workout) were compared to a wait-list control condition (May, Seibert, Sanchez-Gonzalez, & Fincham, 2019). Significant reductions in burnout symptomatology and blood pressure improvements were found in the biofeedback condition only. HR decreased significantly from pre- to post-intervention in both experimental conditions; not in the control condition.

Several other studies were conducted among women at different stages of pregnancy. In a study piloting ambulatory biofeedback among pregnant woman with stress and anxiety, no significant reductions on anxiety or pregnancy specific stress measures were found (Keeney, 2009). However, HRV-results indicated improved autonomic function post-intervention. In a quasi-experimental study among women with labor anxiety, self-reported fear of childbirth scores were significantly reduced in the experimental condition, whereas no significant changes were reported for the control group (Narita, Shinohara, & Kodama, 2018). In another quasi-experimental study, in which women with elevated prenatal depression scores self-selected their condition, a significant drop in depression scores was found in the experimental condition only (Poston, 2018). Lastly, in a quasi-experimental study among mothers in the early post-partum period, significant decreases in depression scores were found post-intervention for the biofeedback group compared to the control condition, as well as significant decreases in heart rate and increases in the standard deviation of the normal heartbeat interval (Kudo, Shinohara, & Kodama, 2014).

Furthermore, four studies were conducted in convenience samples of society members interested in stress research. In one study, HRV and baroflex function significantly increased in the biofeedback condition; whereas performance on an impulsivity task did not improve (Schumann, Köhler, Brotte, & Bär, 2019). Furthermore, the authors of a quasi-experimental study state that their multi-biosensor platform is appropriate for decreasing sympathetic arousal, increasing parasympathetic activity and enhancing overall capability of ANS modulation, although the quantitative results of the ambulatory part of the intervention remained unclear (Wu, Gil, & Lee, 2012). At last, two pilot-studies investigating a mobile biofeedback application were found, both part of the INTERSTRESS project (Wiederhold & Riva, 2012). In one study, 196 sessions (out of which 63 sessions with biofeedback, not separately analyzed) from 38 participants were used for analysis (Serino et al., 2014). In the other study 182 relaxation sessions from 7 participants were analyzed (Gaggioli et al., 2014); potential overlap in these samples remained unclear. Results of both studies indicated significant decreases in stress level and arousal, and an increase in valence after a stress management exercise. In both studies a non-significant pre-post decrease in mean heart rate values was found.

Psychiatric populations

Finally, nine ambulatory biofeedback studies were found among psychiatric populations. Two quasi-experimental studies were performed among young adults with substance use disorder. In one study the biofeedback condition demonstrated a greater, though not significantly different, reduction in substance craving compared to treatment as usual (Eddie et al., 2015). Although significant pre-post session increases in HRV levels were found in the experimental group, no chronic HRV changes were found for both groups after the entire intervention. In a similar study comparing Progressive Muscle Relaxation (PMR) and ambulatory biofeedback, both interventions showed significant reductions in comorbid symptoms of insomnia and PTSD (Zucker, Samuelson, Muench, Greenberg, & Gevirtz, 2009). Compared to PMR, significantly greater reductions in depressive symptoms, increased HRV-indexes and a trend for reduced substance craving were found in the biofeedback condition.

Concerning depressed mood, anxiety and depression, one case-study evaluated the addition of ambulatory biofeedback to regular treatment of a military officer with adjustment disorder (McLay & Spira, 2009). Sleep improved significantly, though the intervention did not prevent the patient from developing more serious (PTSD-) symptoms later. Furthermore, a quasi-experimental study investigated a brief respiratory biofeedback program among patients with panic disorder. Significant decreases in panic severity, global illness severity and functional impairment, as well as a normalized amount of carbon dioxide in the exhaled air, were found post-intervention (Tolin et al., 2017). In another pilot-study among outpatients

with anxiety disorder and comorbid depression, significant reductions in state anxiety, trait anxiety and trait anger were found post-intervention (Reiner, 2008). Qualitatively, reduction of stress and increased relaxation were often reported. Overall, higher compliance was associated with greater stress reductions.

Finally, two studies were conducted among patients with severe traumatic brain injury. In a quasi-experimental study, HRV indexes increased significantly compared to baseline after an ambulatory biofeedback intervention (Kim et al., 2012). Although no significant improvements were found on psychological measures, self-rating scores of the participants became more closely aligned to the perception of their family members, probably indicating enhanced emotional insight. Enlarged ability to recognize emotions was also found in two case-studies evaluating ambulatory biofeedback (O'Neill & Findlay, 2014). An increased ability to recognize frustration and to use relaxation strategies to prevent self-harm was reported in case 1; significantly enlarged self-efficacy and control to maintain a calm state in case 2.

Feasibility outcomes

Feasibility assessment varied widely, ranging from a combination of quantitative measures and extensive qualitative reports (7%), to qualitative information only (33%) or a brief report of the author's opinion (37%). In seven studies (23%) no information regarding feasibility of the used devices was reported. In studies that (to a greater or lesser extent) assessed feasibility, the outcomes were predominantly positive (61%), positive yet critical, needing further improvement (30%) or mainly critical (9%). Most reports were positive, describing participants' enthusiasm, perceived helpfulness and continued use of the devices. Insufficient adherence to the device, side-effects or disadvantages (e.g., sleepiness, frustration) and ethical questions were mentioned as requiring further attention.

DISCUSSION

In this review, we aimed to provide an overview on effectivity and feasibility of biocueing and ambulatory biofeedback in (addition to) treatment of emotion regulation difficulties, in non-psychiatric and psychiatric populations. Therefore, we performed a systematic literature search, which yielded 30 relevant studies. In the majority of the studies, the addition of biocueing or ambulatory biofeedback yielded significant improvements on one or more self-reported (stress-related) psychological measures. In half of the studies using (less frequently assessed) physiological outcome measures, significant improvements were reported as well. Adherence to the biocueing and ambulatory biofeedback devices was assessed in only a few studies. Although the feasibility of the devices was often reported to be sufficient, most studies lacked adequate feasibility assessment. Before we

discuss these effectivity and feasibility results in more detail, we will focus on the differences between the two subsets of the included studies.

To create a broad overview of biofeedback interventions supporting daily practice aimed at enhancing emotion regulation skills, we included both biocueing and ambulatory biofeedback studies. Although both types of interventions use ambulatory devices, biocueing is the only intervention that can actually prompt users in everyday life stressful situations to practice regulation skills. Therefore, biocueing can be seen as a further developed extension of ambulatory biofeedback. Matching the relatively new status of this type of biofeedback, our review only identified four studies that could be categorized as biocueing. Two of these studies actually 'cued' participants in everyday life, when the physiological measures reached a specific range, possibly indicating emotional stress (McHugh et al., 2010; Savard, 2017). In another study, the possibility to prompt regulation skills was one of several options; actual use of this function was not reported (Mackintosh et al., 2017). In these studies, the biocueing system was used to initiate just-in-time (self-)calming strategies and practice emotion regulation skills to prevent disruptive or aggressive behavior in everyday life. In one study, the system was also used to reflect on triggers at a later time and to discuss the connection between physiological values and actual behavior (McHugh et al., 2010). Taken into account the limitations of the study designs, these pivotal studies provide preliminary evidence that interoceptive awareness, emotion regulation and self-control can be facilitated by monitoring physiological measures and biocueing in everyday life, in line with the results of previous studies (Füstös et al., 2013; Gross & Jazaieri, 2014; Novaco, 2007). In studies investigating ambulatory biofeedback, portable or wearable devices were provided to support out-of-session practice, often within a more traditional biofeedback training paradigm. In most studies, applications were used in combination with a personal computer, at home. In a few studies, applications enabled the participants to practice in everyday life, using their smartphone, though without the possibility to be cued in 'at risk'-situations. Although biocueing and ambulatory biofeedback differ in their applicability in everyday life stressful situations, both interventions showed significant results. Based on this review, biocueing seemed particularly useful for participants with low emotional awareness and externalizing behavior, whereas ambulatory biofeedback was mainly used among participants with internalizing, stress-related problems.

Concerning effectiveness, pre-post results demonstrate (predominantly) positive effects of biocueing and ambulatory biofeedback. The distribution of significant and non-significant results seemed not to differ between non-psychiatric and psychiatric populations. Significant improvements were mainly found on psychological measures, such as decreased perceived emotional, social or organizational stress and reduction of anxiety symptoms. In the smaller number of studies that included

physiological measures, a slightly smaller percentage of significantly improved physiological functions, known to be related to adequate emotion regulation (Crockett et al., 2017), was found. Whether this difference might be due to, for example, the duration of the intervention or social desirability, could not be derived from these studies. Furthermore, the majority of the (quasi-)experimental ambulatory biofeedback studies showed significantly better results compared to control conditions in non-psychiatric samples. Compared to other mind-body interventions, such as mindfulness meditation and physical exercise, ambulatory biofeedback was equally effective (De Bruin et al., 2016) or showed interchangeable results (May et al., 2019). In psychiatric samples, only three (quasi-)experimental studies included control conditions. In one study, ambulatory biofeedback was proven more effective than progressive muscle relaxation (Zucker et al., 2009); in two other studies, biofeedback interventions did show effective results, but did not outperform treatment as usual (Eddie et al., 2015; Mackintosh et al., 2017). Based on the results of this review, biocueing and ambulatory biofeedback are considered useful treatment supplements, especially in case of low emotional awareness or insufficient response to other interventions. Future studies should further evaluate their added value compared to other interventions, preferably using (randomized) controlled designs.

Looking at the practical features and feasibility of the used devices, the StressEraser and emWave, designed to improve HRV (Lehrer, 2013) and coherence (McCraty & Zayas, 2014) respectively, were applied most in the ambulatory biofeedback studies. In the biocueing studies, HR was used instead of HRV. This choice might have been made since HRV-measurement using unobtrusive wrist worn sensors is sensitive to motion artefacts and may therefore be less reliable for biocueing in everyday life (Van Lier et al., 2019), whereas HR-measurement can be corrected for movement using currently available wrist worn wearables and appropriately designed applications (Derks, Klaassen, Westerhof, Bohlmeijer, & Noordzij, 2019). Furthermore, among the studies that were categorized as biocueing, patients more often self-determined the time, frequency and place of practice. The method and duration of training was less structured and often shorter than in the ambulatory biofeedback studies. In most of these studies, training consisted of several hours or even multiple days and participants were encouraged to practice daily. These differences in duration of training and actual use complicate interpretation of the results. For example, if controlled for actual (frequency of) use, the effects of the interventions could have been larger. Furthermore, the usability of the devices was considered sufficient to good based on author reports and (concise) qualitative user feedback. However, only in a few studies feasibility and adherence were adequately measured, using usability measures and qualitative interviewing. This is a clear shortcoming of these studies, since it is known that many users stop using a health

application after two weeks, especially when their preferences and goals are not met (Torous et al., 2019).

The results of this systematic review should be viewed in the light of several limitations. First, our systematic search yielded only a small number of biocueing studies, in which we had a specific interest given the focus of this review on recent advances using new, wearable technology. Second, we did not limit the search strategy to specific study designs. Although this allowed us to provide a complete overview, the effectivity outcomes should be interpreted with caution due to the small sample sizes and low to medium quality of the majority of the papers. Third, due to the variation in designs, procedures and outcome measures of the selected studies, a reliable meta-analysis could not be performed. Therefore, studies were systematically and narratively reviewed. Fourth, some studies, especially those investigating new approaches and devices, lack a clear description of implementation procedures, complicating future replication. Furthermore, in several studies using more established devices, such as the StressEraser and emWave, protocols were not well specified; therefore, not all procedures might be implemented according to the corresponding theoretical principles. Fifth, some of the papers received commercial funding, which might have influenced selective reporting of (positive) study results. Sixth, it is important to note that outcomes of studies performed among non-psychiatric populations cannot be generalized to psychiatric populations. Given the small number of studies using a psychiatric sample, no firm conclusions can be drawn regarding psychiatric patients with (severe) emotion regulation difficulties.

Methodological considerations

To prevent an unwanted proliferation of biofeedback applications without evidence of their effectivity, more and better designed studies should be performed to validate future interventions (Bakker & Kazantzis, 2016; Leigh & Flatt, 2015). Among non-psychiatric samples independent, larger and (randomly) controlled designed studies should be performed. Meanwhile, case series and single case experimental designs should be considered to investigate effectivity in small psychiatric samples in which more robust research designs are not feasible (Smith, 2012). These individually tailored designs can also be used to evaluate (small) changes in applications or to detect the optimal duration of training and practice of interventions (Maric & van der Werff, 2020). Furthermore, to validate the effects of biofeedback interventions, self-reported psychological measures should preferably be combined with observed behavioral measures and physiological measures. Agreement between research groups on validated outcome measures and implementation procedures is also recommended. Regarding feasibility, adherence to and usability of the applications should be more thoroughly assessed by tracking actual use of the devices, administering system usability questionnaires

and qualitative interviewing. Finally, although beyond the scope of this article, ethical questions about surveillance and privacy, agency and autonomy should be carefully considered (Sharon, 2017; Torous et al., 2019).

Conclusions and future directions

Despite the rapid developments in mobile health technology and the increasing number of wearable, non-invasive devices that can be used for everyday stress regulation as an addition to psychotherapy, it seems that these applications have only sparsely found their way into clinical research and practice (Derks et al., 2019). Although modern biosensors showed their value in monitoring and predicting behavior (Goodwin et al., 2019; Kuijpers et al., 2012; Roushan et al., 2019) hardly any studies were found investigating biocueing in an everyday life context. Still, the limited but promising results of the included studies seem to suggest that biocueing and ambulatory biofeedback interventions can aid emotion or stress regulation, both on a psychological and physiological level. As such, the results support the potential of biocueing and ambulatory biofeedback to enhance emotion regulation by delivering individually tailored feedback. Fitting within the actual trend of personalized medicine, individual differences should be taken into account: whereas biocueing may help some patients to pay attention to physiological sensations in everyday life situations; others might get easily overwhelmed or irritated by this information (Cornet et al., 2017; Howell et al., 2018; Owens & Cribb, 2019). In the near future, we expect biofeedback research to be focusing more on biocueing as a just-in-time adaptive intervention (Riley et al., 2015; Wang & Miller, 2019) supporting users to practice regulation skills in everyday stressful situations.

CHAPTER 3

Development of a Wearable Biocueing App (Sense-IT) Among Forensic Psychiatric Outpatients With Aggressive Behavior: Design and Evaluation Study

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ABSTRACT

Background: The ability to regulate anger is often impaired in forensic psychiatric patients, frequently resulting in aggressive behavior. Although some treatment programs are partially successful in enhancing aggression regulation and reducing recidivism among specific subgroups, generalizable conclusions on the effectiveness of these interventions cannot be drawn to date. In forensic outpatient care, low treatment adherence and a predominant focus on cognitive control in most treatment programs may entail some of the factors impeding treatment. Technology-based interventions may address some of these treatment challenges.

Objective: The aim of this study is to explore whether a new technology-based biocueing intervention, the Sense-IT app, can be a valuable addition to aggression regulation treatment programs in forensic outpatient care. The Sense-IT app, which provides the user with real-time physiological feedback and behavioral support, is developed to strengthen emotional awareness and facilitate real-life practice. In this study, we aim to develop and evaluate an updated version of the Sense-IT app that is suitable for forensic outpatients with aggressive behavior.

Methods: First, we conducted a design study to assess the attitudes of forensic professionals and patients toward biocueing and to collect requirements for a biocueing app for this specific population. On the basis of this information, we developed an updated version of the Sense-IT app. In an evaluation study, 10 forensic outpatients used the app for 2 weeks. The app's acceptability, usability, and clinical outcomes (aggression, anger, and recognition of bodily signals related to anger) were measured pre- and postintervention using both quantitative and qualitative measures.

Results: The design study revealed a cautiously positive attitude toward the use of biocueing as an addition to aggression regulation therapy. The evaluation study among forensic outpatients demonstrated moderate acceptability and adequate usability for the new version of the Sense-IT app. Exploratory analysis revealed a significant decrease in trait aggression postintervention; no significant changes were found in other anger-related clinical outcomes. To further increase acceptability and usability, a stable, functioning app with self-adjustable settings, the use of smartwatches with a longer battery life, and the use of the patient's own smartphone devices were recommended.

Conclusions: This study, which is one of the first attempts to enroll and evaluate the real-life use of a biocueing intervention among forensic outpatients, emphasized the importance of involving both patients and therapists throughout the development and implementation process. In the future, experimental studies, including single-

case experimental designs using ecological momentary assessment, should be performed to evaluate the effectiveness of the Sense-IT intervention on clinical outcomes. An open attitude toward new technology, allowing exploration of the potential benefits of the Sense-IT app case-by-case and training of therapists in using the app are some of the measures expected to facilitate its integration in therapy.

INTRODUCTION

Background

Aggression and violent behavior are associated with substantial problems, especially for the victims and the offenders. While victims of violence are at a high risk of developing psychological and behavioral problems such as depression, anxiety, posttraumatic stress, and alcohol abuse (Bouffard & Koeppel, 2014; Krug et al., 2002), offenders show increased rates of developing psychiatric disorders, such as psychotic, mood, and substance use disorders (Ogloff, Talevski, Lemphers, Wood, & Simmons, 2015; Steadman, Osher, Robbins, Case, & Samuels, 2009). In addition, the offenders' imprisonment often leads to more unfavorable situations for them after release, such as job loss, housing problems, and a lack of social support. Consequently, aggressive behavior is a high burden for professionals working in the mental health care and the judicial system, resulting in inflated costs for both health care and the society in general (Rubio-Valera et al., 2015; Schmitt, Warner, & Gupta, 2010). The impact of aggressive behavior on both individual lives and society in general highlights the importance of early and effective treatment for forensic psychiatric patients with problematic aggressive behavior. Given the current trend of preferring outpatient interventions over residential treatment, the importance of real-life, out-of-session practice of behavioral alternatives (Kazantzis et al., 2016), and the developments in the use of digital technology in psychological treatment (Fairburn & Patel, 2017), technology-based interventions are of interest to improve and support aggression regulation among forensic (outpatient) populations.

Over the years, several therapeutic interventions have been developed to reduce aggressive behavior and criminal recidivism among forensic in- and outpatients. Most offender treatment programs are based on the principles of aggression replacement training (ART) (Glick & Gibbs, 2010), in which behavioral, affective, and cognitive components are combined to improve anger and aggression regulation. In forensic psychiatry, these cognitive behavioral therapy (CBT) programs are broadly considered as promising rehabilitative treatments for antisocial behavior (Landenberger & Lipsey, 2005; Lipsey, Landenberger, & Wilson, 2007). However, mixed findings have been reported regarding the effectiveness of these treatment programs. A meta-analysis of 14 CBT-informed anger management studies revealed an overall 28% risk reduction in violent recidivism after treatment, with a 56% reduction among those who completed the treatment. In half of the studies, significant differences in violent reoffence were reported, when compared with control conditions (Henwood et al., 2015). In a systematic review, including 16 ART studies, researchers stated that generalizable conclusions could not be drawn owing to, among other factors, differences in the severity of psychopathology, low methodological quality, and limited follow-up information (Brännström et al., 2016).

The limited effectiveness of current treatment programs is also related to challenges specific to forensic populations. First, because of severe psychopathology, a lack of problem awareness, and motivational difficulties, treatment engagement and adherence are often low. Among forensic populations, the rates of pretreatment drop out and treatment attrition are high. A large meta-analysis revealed an overall treatment attrition rate of 27.1% across all offender programs, with a rate of 37.8% for domestic violence offenders (Olver, Stockdale, & Wormith, 2011). Research results indicate that noncompletion of treatment is associated with lower reductions in general and violent recidivism (Henwood et al., 2015). Furthermore, homework and registration assignments—an important part of all CBT programs—are often not completed in forensic outpatient populations. This negatively affects the transfer of psychological interventions from the therapist room to daily practice (Fletcher et al., 2011). Second, the focus on cognitive control over emotional processes—a core element of most current treatment programs—may not fit the capacities of the patients. Forensic psychiatric patients often lack insight into their emotions (Roberton et al., 2015) and have difficulty in observing and interpreting physiological signs of increased inner tension, such as accelerating heartbeat, sweating, or trembling. This limited capability to timely detect (particularly slowly) rising arousal levels increases the chance of suddenly occurring aggressive outbursts. Furthermore, cognitive control processes can be overruled by impulsive aggressive behavior in the case of high physiological arousal (Kahneman, 2003). Therefore, in line with previous literature (Novaco, 2007), therapy should focus more on strengthening awareness of bodily sensations associated with anger, before moving to the enhancement of cognitive control and deliberate responses in anger-provoking situations.

New technological applications may help address some of these treatment challenges. Technology-based interventions, such as mobile biofeedback apps (Mackintosh et al., 2017), serious gaming (Smeijers & Koole, 2019), and virtual reality therapy (Klein Tuente et al., 2020) have the potential to increase adherence to treatment by engaging patients and by increasing maintenance during out-of-session activities (Reiner, 2008). Considering their lack of emotional awareness, interventions that provide the patients with information about their physiological state in real-life situations may help signal heightened arousal in response to emotional events and support adequate self-regulation (Lisetti & Nasoz, 2004; Yucha & Montgomery, 2008). In this study, we aim to explore the potential of a new biocueing intervention, which signals at risk levels of arousal in everyday life, as an addition to current aggression regulation therapy.

Biocueing can be seen as a specific, personalized type of biofeedback (Ter Harmsel, Noordzij, et al., 2021). In the process of biofeedback, instruments monitor physiological parameters (e.g., heart rate, skin conductance, and respiration),

transform these measurements into auditory or visual signals, and present these signals to the user directly (McKee, 2008). During a traditional, nonwearable biofeedback paradigm consisting of multiple on-site sessions, patients are trained to regulate their physiological reactions by consciously alternating their responses to the given feedback. Rapid developments in noninvasive, wearable technology (e.g., breast bands, wrist sensors, smart fibers, and interactive textiles) have opened opportunities for biocueing, which combines real-time measurement in everyday life and just-in-time behavioral support (Nahum-Shani et al., 2018; Riley et al., 2015; Wang, Varma, & Prosperi, 2018).

Traditional biofeedback has proven effective for patients with different psychopathology; however, most studies have been conducted among patients with internalizing problems (Yucha & Montgomery, 2008). Biocueing is relatively new but might be particularly useful for patients who lack insight into the physiological signals that precede dysregulated behavior in everyday life, such as binge-eating episodes (Godfrey, 2018) or self-injurious behavior (Koenig et al., 2017). Focusing on aggression, several pilot studies have provided the first evidence that physiological information can be used as a predictor of aggressive behavior, for example, among youth with autism spectrum disorder (Cumpanasoiu et al., 2018), patients with intellectual disabilities (Palix et al., 2017), and forensic patients (De Looff et al., 2019). Therefore, biocueing might be a helpful tool to increase awareness of high-risk situations and to support patients in practicing behavioral skills that prevent their escalation into aggressive incidents (Cornet et al., 2016). However, there is a gap between these study results and the actual deployment of mobile health (mHealth) interventions, such as a biocueing app for wearables, in forensic clinical practice. To bridge this gap, consideration of the needs of the intended users, as well as usability evaluation in the user's natural environment, is required (McCurdie et al., 2012). The involvement of end users throughout the design process, the core principle of user-centered design, is therefore highly recommended for the development of useful and effective mHealth interventions (Schnall et al., 2016).

Study Aims

Given the potential of biocueing in dealing with the challenges in forensic (outpatient) treatment programs and using the principles of user-centered design, we first explored the attitudes of forensic professionals and patients toward this new intervention as an addition to aggression regulation therapy. In addition, we collected requirements to develop an updated version of the Sense-IT biocueing app (Derks et al., 2019) for use in a forensic outpatient population. Finally, we investigated the acceptability and usability of the revised Sense-IT app and explored changes related to aggression, anger, and interoceptive awareness in a 2-week evaluation study among 10 forensic outpatients with aggressive behavior.

METHODS

Overview

First, we conducted a design study to explore the attitudes toward and specific requirements for a biocueing intervention in a forensic sample. With this information, an updated version of the Sense-IT app was developed. Then, we studied the app's acceptability and usability and its preliminary effects on clinical outcomes in a 2-week evaluation study. The structure of the study has been shown in Figure 1.

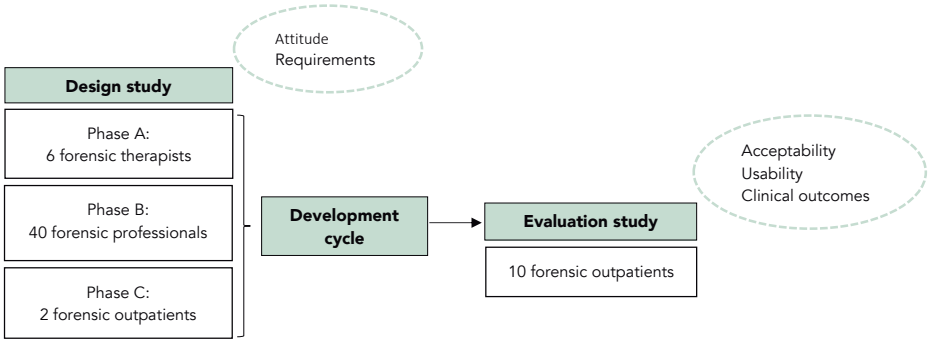

Figure 1. Study design: phases, participants and concepts.

Design Study

From October 2016 to March 2017, 6 forensic therapists, 40 forensic professionals (i.e., therapists, psychiatric nurses, social workers, and probation officers), and 2 forensic outpatients participated in our study. We informed all the participants of the study's content and the voluntary basis for participation. We recruited the forensic therapists by email and the forensic professionals through in-person engagement at a forensic congress. The forensic outpatients were approached after consultation with their therapists, and their signed informed consent was obtained. The forensic therapists and outpatients tested a precursor version of the Sense-IT app for 3 to 7 days, respectively, using a research-owned smartphone and smartwatch. The Sense-IT system provides a visual display of physiological arousal by measuring heart rate, notifies the user of level changes, and delivers a default message when the user's physiological arousal is significantly elevated (SD >2) than their personal baseline. In this design study, the baseline measurement consisted of 300 reliable heart rate measures, with 20 seconds between each measurement. During the baseline measurement, participants could behave normally, without any restrictions. The forensic professionals responded to a short paper-and-pencil survey to increase their knowledge regarding their attitude toward biocueing. None of the participants received any financial compensation for this study.

Given the outcomes of this study, the forensic professionals' attitudes toward biocueing could be considered open and cautiously positive. The participants mentioned awareness of bodily signals accompanying anger (9/40, 22%) and insight into increasing arousal levels, especially in high-risk situations (15/40, 37%), as the most valuable additions to aggression regulation therapy. Furthermore, biocueing was seen as a promising way to open therapeutic conversations about aggressive behavior. According to most forensic therapists (4/6, 67%), the usability of this precursor version of the Sense-IT app was insufficient. The limited battery life of the watch, the sudden watch face changes, the synchronization problems, the questionable reliability of heart rate measurements, the feedback method (too soft and too slow), and the mandatory use of a research phone were listed as items for improvement. Therapists were most satisfied with the visualization of arousal on the smartwatch and the warning function for heightened arousal. Of the 2 forensic outpatients, only one used the app for the entire week. This participant recommended audio-recording because he had difficulty typing notes. He reported an increased awareness of arousal, increased control over his aggressive behavior by the initiation of self-calming strategies, and distraction from inner tension by using the Sense-IT system. The other participant quit the study early because of technological shortcomings in this version of Sense-IT. This participant was frustrated with the app interrupting measurement when the watch face was accidently touched. Given the insufficient usability scores and the increased irritability reported by one of the patients, we initiated a development cycle to resolve these technological shortcomings before further rolling out the app among forensic outpatients.

Development Cycle

Technological stabilization was the most important aim of this development cycle. The recommended improvements were implemented and intermediately tested by the researchers and app developers in 5 iteration rounds between 2017 and 2018. The activation of the Sense-IT app on the smartphone and smartwatch was synchronized and automated to prevent synchronization problems. Furthermore, the connection between the smartwatch and smartphone was made visible on the main screen. A clear on-off slider was incorporated into the main screen. Continuous visualization of the data on the watch face was optimized. Finally, the user was allowed to define during which activity profiles (e.g., driving, cycling, and running) the operation of the Sense-IT should be paused. A description of the revised Sense-IT app has been provided in the next section.

Evaluation Study

Participants

We recruited forensic outpatients receiving aggression regulation therapy at Inforsa for participation from November 2018 to July 2019. Inforsa is a forensic mental health care facility specialized in the treatment of patients with disruptive and criminal behavior. A research associate screened the potential participants for eligibility, in consultation with the patient's therapist. The eligibility criteria included (1) a proven lack of anger management skills, indicated by either a recently committed violent crime and/or a high risk of committing one, (2) assignment to individual outpatient aggression regulation treatment after multidisciplinary consultation, (3) basic understanding of mobile apps, and (4) aged ≥16 years. The exclusion criteria included (1) acute manic or psychotic symptoms, (2) current high risk of suicide, (3) severe addiction problems or other severe conditions requiring immediate intervention or hospitalization, and (4) insufficient understanding of the Dutch language. The first 3 exclusion criteria were assessed using cut-off scores on the corresponding items in the Health of the Nation Outcome Scales (Wing et al., 1998). A total of 10 forensic outpatients were enrolled in the study. An outline of the recruitment and participation flow is displayed in Figure 2.

Procedure

This study was approved by the Medical Ethical Committee of Amsterdam University Medical Centre, the Netherlands (NL63911.029.17). This study was also registered in the Netherlands Trial Register (NL8206). If a patient was eligible and interested in the research project, study participation was offered during a face-to-face appointment with the therapist and the patient. The research associate provided the patient with a brief oral description and full written information on the study. The voluntary nature and the absence of any negative consequences for the patient's refusal to participate were emphasized. If the patient was interested, the next appointment was planned after at least 7 days, providing enough time for consideration. In this appointment, we obtained the informed consent of the participants, and they filled out self-reported questionnaires. The baseline measurement (T0) lasted approximately 45 minutes. After completion of the assessment, participants were provided with a smartwatch and a mobile phone with the Sense-IT app. The participants were shown how to use the devices and were given tips on charging and using the system safely. They also received a user manual. The participants used the devices independently during the following 2 weeks. They were encouraged to call the research associates if any problems occurred. After the 2-week intervention period, another 45-minute assessment (T1) was planned. We used the same measurements as at T0, supplemented with qualitative interviews and quantitative usability measures.

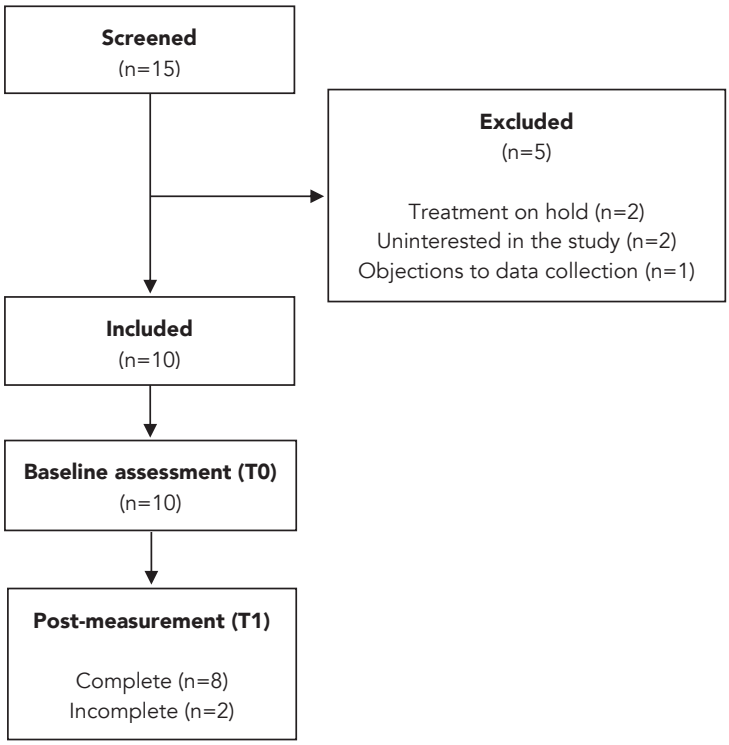

Figure 2. Flow chart of recruitment and participation in the evaluation study.

Materials

Demographics

We collected demographic and clinical information at T0 using a 23-item self-developed questionnaire. The variables assessed included gender, ethnicity, judicial history, care history, education, family background, and social situation.

Mobile Phones and Smartwatches

The participants received both a smartwatch and a mobile phone. In this evaluation study, we used the Ticwatch E (Mobvoi, Ltd), a new smartwatch that had good reviews on reliability and cost-effectiveness and had a longer battery life than the smartwatches we used in the design study (Moto 360 2nd Gen; Lenovo Group, Ltd). The smartwatches were equipped with a photoplethysmography (PPG) sensor, by which the blood volume pulse can be measured and the heart rate can be derived. Connection with the mobile phone, the Moto C Plus (with Android 8.0 operating system; Google, LLC), was established via Bluetooth. We provided the participants with research-owned mobile phones to maintain control over the app settings and to account for secure data extraction.

Sense-IT App

The newly developed version of the Sense-IT app, version 2.13, was preinstalled on all smartwatches and mobile phones before distribution. The Sense-IT app was originally developed by researchers at the University of Twente in co-operation with Scelta, an expert center for psychiatric patients with personality disorders(Derks et al., 2019; Derks, Visser, Bohlmeijer, & Noordzij, 2017). The Sense-IT system reads the physiological data measured by the photoplethysmography (PPG) sensor and stores the data in a local database on the smartphone itself.

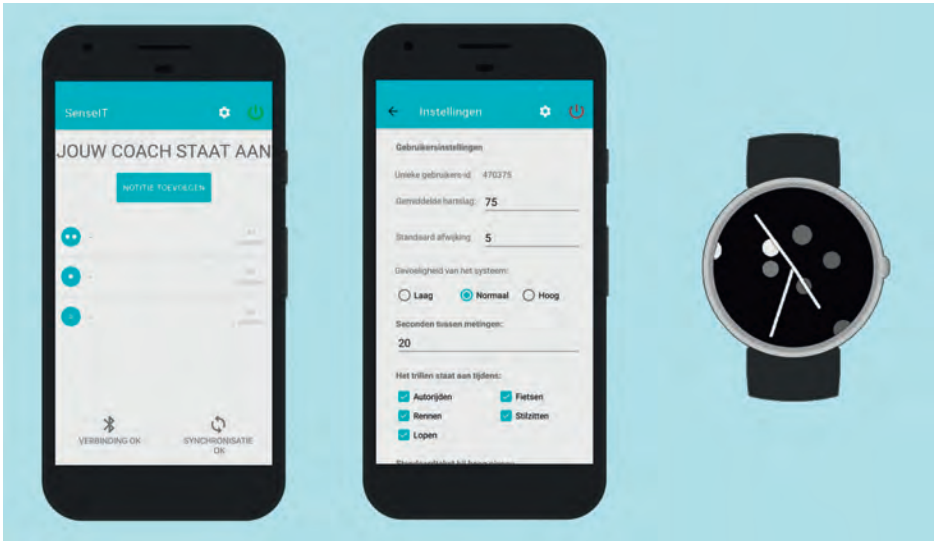

Figure 3. Screenshots of the Sense-IT app (version 2.13): main screen with measurements, settings screen, and the watch face.

The built-in algorithm compares the current heart rate of a user with their mean heart rate at baseline and calculates a level between −3 and 5 using the SD of the baseline measurement. In this study, the determination of the user's baseline was started at the end of the T0 measurement and lasted until the PPG sensor received 200 reliable heart rate measures, with 20 seconds between each measurement. During baseline measurement, participants could behave as they normally would, except for any intense physical activity. After this measurement, the level of their current heart rate was visually displayed on the smartwatch and was changed when the heart rate decreased or increased by ≥1 SD. For this study, notifying vibrations were sent to the users at every change in their physiological level. The Sense-IT app detects (physical) activity categories using the accelerometer and Google activity recognition algorithms, allowing the user to receive notifications for certain

activity profiles (e.g., sitting still and driving a car) only. From the user interface on the smartphone, users can turn the app on and off, opening a timeline of all the measurement events and level changes detected by the system. Users can add notifications to events in the timeline and report their subjective level of arousal, which might be particularly useful when the user is notified of level changes. Users can also define a personalized message that is displayed when their physiological arousal exceeds a predefined level. In this study, we used a default message (i.e., "your heart rate is higher than average"), which was only displayed at levels 3, 4, and 5 (SD>2) above baseline. The app's user interface also presents information about the connection and synchronization status, as well as a settings page protected by a password to prevent unwarranted changes. Screenshots of the Sense-IT app are displayed in Figure 3.

Acceptability

In a semi-structured qualitative interview developed by the study team, the participants' attitude toward technological interventions and their perceived proficiency in using new technology were assessed using a 5- and 10-point Likert scale, respectively. Closed-ended and open-ended questions assessed whether the participants would use the Sense-IT app in the future and whether they expected others to do so. The total number of heart rate measurements, measured every 20 seconds by the PPG sensor of the smartwatch, was used as an indicator of the actual use of the Sense-IT system. The damage, loss, and theft of the devices were recorded.

Usability

We administered the System Usability Scale (SUS), a short, commonly used questionnaire for quick and reliable assessment of product usability (Brooke, 1996), at T1. The SUS consists of 10 statements that can be scored on a 5-point Likert scale, ranging from 1 (totally disagree) to 5 (totally agree). The SUS yields an overall score between 0 and 100, with higher scores indicating better usability. In the original study, 68 was used as a cut-off score. According to more recent research (Bangor, Kortum, & Miller, 2008), a product is acceptable with scores above 70; better products score in the high 70s to upper 80s and superior products score above 90. Products with scores lower than 70 should be considered as candidates for improvement.

Furthermore, we evaluated usability qualitatively by using semi-structured interviews. The interview included Likert scale questions about the attractiveness of the devices, the ease-of-use of the app, the clarity of watch faces, and the evaluation of feedback notifications. Open questions assessed the advantages and disadvantages of Sense-IT and any recommendations for its further improvement.

Aggression

We assessed for aggressive behavior using the Dutch version (Hornsveld, Muris, Kraaimaat, & Meesters, 2009) of the Aggression Questionnaire-Short Form (AQ-SF) (Buss & Perry, 1992). The AQ-SF is a self-report questionnaire, in which participants respond to 12 statements regarding aggression on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The AQ-SF distinguishes 4 subscales: physical aggression, verbal aggression, anger, and hostility. The internal consistency coefficients for the total score of the Dutch AQ-SF ranged between 0.72 and 0.88 in a forensic population. Significant test-retest correlations after 4 weeks were found for the AQ-SF total and subscale scores, except for the physical aggression subscale. The AQ-SF was administered at T0 and T1.

Anger

We assessed anger and its subcomponents using the Dutch version (Hovens, Lievaart, & Rodenburg, 2014) of the State-Trait Anger Expression Inventory-2 (STAXI-2) (Spielberger, Sydeman, Owen, & Marsh, 1999). The STAXI-2 is a 57-item self-report questionnaire, in which items are coded on a 4-point Likert scale ranging from 1 (almost never) to 4 (almost always). The questionnaire consists of 3 main scales: state anger, trait anger, and anger expression and anger control. The internal consistency, assessed in an inmate sample, was considered good, with Cronbach α ranging from .79 to .88. For the original version of the STAXI, the test-retest coefficients were acceptable, except for the State Anger scale. We administered the full STAXI-2 at T0; at T1, we administered only the state and trait anger scales because of time constraints.

Bodily Sensations Related to Anger

We measured bodily sensations related to anger in interpersonal situations using the Dutch version of a recently developed self-reported questionnaire called the Anger Bodily Sensations Questionnaire (ABSQ) (Zwets et al., 2014). In this 18-item self-report questionnaire, participants can rate their experience of physiological responses during anger-provoking interpersonal situations on a Likert scale, ranging from 1 (not at all) to 5 (very much). The internal consistency (Cronbach α) for the total score was .93 in an offender population for this study. The total score had good 1-week test-retest reliability within the offender sample. The ABSQ was administered at T0 and T1.

Data Analysis

We analyzed the quantitative data using SPSS version 25 (IBM, Corp). Although this evaluation study was not intended for inferential statistics, we exploratively compared the pre-post scores, after checking the normality assumptions, with the nonparametric equivalent of the paired t test, the Wilcoxon Matched Pairs test. We analyzed the qualitative data using Microsoft Word and Excel. Textual responses

were first inspected for theme analysis, then coded into categories and described as relative results. Categorical responses were described as relative results.

RESULTS

Demographics

Of the 10 forensic outpatients participating in this study, the majority (9/10, 90%) were male, in line with the usual male-female distribution in forensic populations. Although all participants were born in the Netherlands, out of 10 participants, 6 (60%) had parents originating from another country. Furthermore, 60% (6/10) reported problems such as domestic violence, substance abuse, or psychological problems in the families they grew up in. Most of the participants were referred to Inforsa for mandatory treatment as part of a conditional sentence and had been convicted multiple times in the past. The descriptive characteristics of the participants have been summarized in Table 1.

Table 1. Summary of demographic characteristics of the participants[a] (N=10)

Demographic characteristics	Values
Age, mean (SD)	34.90 (13.29)
Gender, n (%)	9 (90)
Male	1 (90)
Female	
Educational background, n (%)	
Primary school	2 (20)
Secondary school	2 (20
Secondary vocational education	6 (60)
Living conditions, n (%)	
Private home	4 (40)
Assisted living facility	4 (40)
Social care	2 (20)
Index offence	
Violent crime	5 (50)
Gun crime	1 (10)
No index offence	4 (10)
Multiple convictions, n (%)	8 (80)
Mandatory treatment, n (%)	6 (60)
Previous ART[b] treatment, n (%)	5 (50)

[a] Number of participants measured at T0.
[b] ART: aggression replacement training.

Acceptability

The participants were provided with the Sense-IT system for 2 weeks. All participants returned these research-owned smartwatches and mobile phones. Although we noticed some superficial user damage and had to buy new charging cables, none of the devices had to be replaced because of damage, loss, or theft. Half of the participants (5/10, 50%) fully agreed with the statement that they liked to use technology or technological gadgets, a substantial number (4/10, 40%) claimed a neutral position and 1 participant (1/10, 10%) disagreed with the statement. On a 10-point Likert scale, the participants rated themselves as proficient in using new technologies (mean 7.1, SD 2.5 participants). At T1, it appeared that one participant had not used the Sense-IT app at all; the T1-responses of this participant were therefore excluded from further analysis. Among the other participants, the total amount of heart rate measurements (in hours) was used to indicate actual app use. As some participants showed very large numbers of measurements per day, we corrected the data for very low heart rates (<50 beats per minute) and measurements during nighttime (from midnight until 6 AM). The corrected actual app usage was significantly different (mean 62.19, SD 38.63 hours; range 3.49-127.02 hours). Higher heart rate measurements were found among older participants, $r_8 = .768$, $p = .016$. No significant correlations were found among the attitude toward new technology, the perceived proficiency, and the indicator of actual app use. Furthermore, out of 9 participants at T1, 6 (67%) reported that they would like to use the Sense-IT app in the future. All the participants expected others to use the app in the future.

Usability

Participants who said they would not use the Sense-IT app in the future reported that the app had no added value for them because, for example, they did not regard themselves as aggressive or they already claimed to know their personal precursors for aggressive behavior. One participant therefore recommended the addition of the Sense-IT app in the early phases of treatment. The participants who would use the app in the future listed several conditions that could be considered as recommendations to further improve the Sense-IT app. The average score on the SUS for the group was above the cut-off value (mean 73.1, SD 16.2). Significantly higher system usability scores were reported by participants with a more positive attitude toward new technology, $r_9 = .857$, $p = .002$; no significant correlations were found between the usability scores and perceived proficiency in using new technology. Most participants (8/9, 89%) did not report difficulty using the Sense-IT app on the smartphone. The watch faces on the smartwatch were reported to be clearly visible by the participants. The design of the Sense-IT app on the smartphone was considered neutral by half of the participants and (quite to very) attractive by the other half; some participants reported that they would like a more colorful design. Considering the messages shown when the physiological

values exceeded a predefined level, out of 9 participants, 6 (67%) said they would like to use a default text message; the other participants (3/9, 33%) preferred a personalized message. The number of notifying vibrations (delivered at every level change) was considered too large by 56% (5/9) of the participants and was therefore most often mentioned as a point of improvement. Furthermore, improved accuracy, longer smartwatch battery life, and the possibility of using the Sense-IT app on their own smartphones were recommended.

Clinical Outcomes

We performed an exploratory analysis on the clinical outcome measures. Given the small sample size, the Shapiro-Wilk test was used to evaluate for normality of the data. As expected, the normality assumption was not met for several subscales of the measures used. Therefore, the Wilcoxon Matched Pairs test was used. No significant changes were found on the AQ-SF and ABSQ. Between baseline (median 2.35) and postmeasurement (median 1.90), trait anger measured with the STAXI-2 decreased significantly ($Z = -2.388$; $p = .017$). Explorative visual analysis of the data showed that the scores of most of the participants (7/9, 78%) decreased. None of the participants showed elevated scores at postmeasurement compared with baseline. No significant correlations were found between this trait anger decrease and other variables such as attitude toward new technology, perceived proficiency in using new technology, and usability of the Sense-IT app. All clinical outcomes are shown in Table 2.

Table 2. Summary of the clinical outcomes.

Clinical outcome scores	Time points T0 (n=10), mean (SD)	T1 (n=9), mean (SD)
Aggression (AQ-SF[a])	2.36 (0.78)	2.41 (0.85)
Physical aggression	2.23 (1.21)	2.23 (1.32)
Verbal aggression	2.23 (0.96)	2.63 (0.78)
Anger	2.87 (1.00)	2.73 (1.31)
Hostility	2.10 (1.03)	2.03 (1.08)
Anger (STAXI-II[b])	1.91 (0.35)	-[c]
State Anger	1.05 (0.13)	1.02 (0.05)
Trait Anger	2.21 (0.65)	1.98 (0.72)
Anger Expression and Control	2.22 (0.48)	-
Bodily sensations related to anger (ABSQ[d])	2.34 (0.93)	2.49 (0.95)

[a] AQ-SF: Aggression Questionnaire-Short Form.
[b] STAXI-2: State-Trait Anger Expression Inventory-2.
[c] Missing data.
[d] ABSQ: Anger Bodily Sensations Questionnaire.

DISCUSSION

Principal Findings

To our knowledge, this study is one of the first attempts to enroll and evaluate a smartwatch-based biocueing intervention in a forensic outpatient population with aggression regulation difficulties (Ter Harmsel, Noordzij, et al., 2021). Our study revealed a cautiously positive attitude toward the use of biocueing as an addition to regular therapy. Requirements for improvement were processed in a development cycle, resulting in an updated version of the Sense-IT app. The results of our 2-week evaluation study showed adequate usability scores, although the actual use of the app and its expected future use did not entirely match these outcomes. Furthermore, a significant decrease in trait anger was observed postintervention. Valuable recommendations were obtained for further improvement in Sense-IT. Considering the aim of our study, we were able to collect relevant information for the further development and enrollment of technology-based interventions as adjuncts to treatment, even in populations with lower treatment adherence.

In accordance with the principles of user-centered design for mHealth applications (Schnall et al., 2016), which had also been applied in the earlier development phases of the Sense-IT app (Derks et al., 2019; Derks et al., 2017), we involved patients, therapists, and other forensic professionals in the development process of Sense-IT. The recommendations collected in the design study were mainly related to technological issues impeding the ease-of-use, such as synchronization problems and limitations in the battery life of the smartwatch. As the usability of the precursor version of the Sense-IT turned out to be inadequate for extensive testing among forensic outpatients, its further development was initiated. To generate more input for this development cycle, the professionals' attitudes toward the use of a biocueing app for this particular group were more thoroughly assessed. Our design study indicated that forensic professionals had an open and positive attitude toward biocueing, recognizing the potential disadvantages or risks. This is important, because openness toward new treatment possibilities and a belief that the intervention might be beneficial to patients are, among others, considered as facilitators of the use of mHealth technology (Feijt, de Kort, Bongers, & IJsselsteijn, 2018; Gagnon, Ngangue, Payne-Gagnon, & Desmartis, 2015).

Patients' adoption of mHealth applications is also known to be a result of several factors, such as perceived usefulness and ease-of-use, influencing their individual attitude and behavioral intention, mediated by age (Zhao, Ni, & Zhou, 2018). Other results suggest that the perceived mobile technology identity, related information technology experience, and self-efficacy are associated with higher adoption rates (Balapour, Reychav, Sabherwal, & Azuri, 2019). In our evaluation study, the users' perceived proficiency was not associated with the actual use

and the perceived usability of Sense-IT. Actual use seemed higher among older participants, contrary to the mediating influence of age, as mentioned in other studies. However, the higher usability scores being reported by patients with a more positive attitude toward new technology was consistent with these earlier findings. Furthermore, we encountered some skepticism when we first presented our idea to investigate a biocueing intervention among forensic outpatients by providing them with a smartwatch and smartphone. Contrary to expectations, none of the devices had to be replaced because of loss, damage, or theft, supporting a recent study among homeless youth (Schueller et al., 2019). The total amount of heart rate measurements, used as an indicator for the actual app usage, varied widely among the participants. Most participants used the Sense-IT quite often, but a few participants showed very low adherence to the app. This limited adherence to technology-based interventions is a common issue in eHealth and mHealth studies, even in samples that are more open to treatment. Many users of self-help applications show inconsistent use patterns (Nelson, Sools, Vollenbroek-Hutten, Verhagen, & Noordzij, 2020), do not continue their use after completion of one exercise or module (Fleming et al., 2018), or stop using a health app after 2 weeks, especially when their preferences and goals are not met (Torous et al., 2019). Given the answers regarding the future use of the Sense-IT app, actual usage of the app might have decreased even more if the duration of our study had been extended to more than 2 weeks. Nevertheless, considering the motivational problems and the high dropout rates in forensic populations, outpatients who often fail to practice outside the treatment setting would be encouraged to reflect on their behavior in real life.

Furthermore, the Sense-IT app received acceptable system usability scores, which means that the ease-of-use was considered good enough for further development and can be rolled out in this population. The participants provided valuable recommendations for a new development cycle. The number of notifying vibrations, which were considered disturbing by most of the participants, was most often mentioned as a point for improvement. For some patients, this feature of the app led to increased irritability, a possibility that has already been mentioned in previous literature (Cornet et al., 2017; Howell et al., 2018; Owens & Cribb, 2019). In the future, this drawback can easily be remedied by adjusting the levels at which notifying vibrations are provided and by allowing users to customize the settings themselves. Furthermore, our study revealed that some participants had difficulty coming up with a personalized message, which could be shown when their physiological values were elevated. Therefore, their preference for the default text message might have been a choice out of convenience. Further integration of the Sense-IT app in therapy may help to overcome this difficulty. At the design level, desired improvements, such as the addition of multiple colors, were mostly mentioned by younger participants. Furthermore, several participants would

have liked to use Sense-IT on their own mobile phones. For clinical use, outside a research context with privacy constraints, this would certainly be possible and might facilitate the acceptability and usability of the app. Finally, technological hardware improvements, such as the extended battery life of the smartwatch, could further enhance adherence to Sense-IT.

To investigate whether the 2 weeks of using the Sense-IT biocueing app were associated with clinically relevant changes, we performed exploratory analysis on the pre and post measurement outcomes of aggression, anger, and anger bodily sensations. In line with the literature indicating the difficulty of changing aggressive behavior (Brännström et al., 2016) and given the small sample size and short intervention period of our study, no significant changes were found in the overall scores. Considering the concepts of state and trait anger, in this study, change might theoretically occur on state anger. Interestingly, trait anger diminished significantly between pre- and post-measurements. No change was found in the state anger. However, this might have been affected by the fact that state anger was only measured at 2 specific moments in time, when the participants were generally in a resting state. Regarding the change in trait anger, social desirability might offer a partial explanation for this finding. In a study among forensic inpatients, participants with high scores on impression management reported significantly lower levels of trait anger (McEwan, Davis, MacKenzie, & Mullen, 2009). To explore whether this finding reflects a true change in the frequency of experiencing angry feelings should therefore be more thoroughly assessed within a longitudinal research design, using assessment methods that are more sensitive to minor changes and less susceptible to social desirability.

Limitations

Our study had several limitations. First, the number of forensic outpatients participating in the design and evaluation study was low. In line with the early phase of biocueing research and the often-encountered difficulties in studies among forensic patients, this may have affected the findings of our study. Second, we used a small subset of questionnaires in our evaluation study, focusing on anger and aggression. Therefore, we might have overlooked other relevant changes, for example, in emotion regulation in general. In addition, we did not use the full STAXI-2 at T1, which should have been preferred to prevent data loss. Furthermore, the questionnaires we used might have been susceptible to social desirability. In any case, the most used questionnaires to assess aggressive behavior are not designed to detect small changes over short periods. In this regard, the short duration of the intervention and the absence of a follow-up measurement complicate the interpretation of our findings. Third, because we used a pretest-posttest design without a control group, we were not able to disentangle the impact of the use of the Sense-IT biocueing intervention from aggression regulation therapy and from

the distribution of mobile phones and smartwatches, which might be considered an intervention itself. Fourth, in some cases, Sense-IT seemed to be measuring data while not being actually worn by the participants. This complicated the interpretation of the actual usage of the device. Fifth, as Sense-IT could not be used on the participants' own phones, owing to privacy constraints in research, it might have had a restrictive effect on adherence. Sixth, the explanation and handing out of the devices was done by research associates in the absence of their therapists. In addition, both patients and therapists were not able to adjust the settings during the study. These restrictions, associated with the research design, might have limited the adoption of the Sense-IT app by therapists, an important driver for the integration of mHealth interventions in clinical practice (Feijt et al., 2018).

Implications for Future Research and Practice

This development and usability study has several key implications for future research. First, it emphasized the importance of the involvement of both patients and therapists in the development of effective mHealth interventions (McCurdie et al., 2012). Second, the evaluation study yielded new recommendations for the improvement of the Sense-IT app. At the technological level, stabilization of the app should remain a critical area for improvement. The number of notifying vibrations and the levels at which SMS text messages are sent should be adjustable to the wishes and needs of patients. In addition, the ease-of-use of recording subjective arousal levels should be enhanced. At the design level, the clarity of the main screen should be improved, and the measurement screen should be updated with a semi-graphical representation. To further enhance the attractiveness of Sense-IT, some patients would like to choose different background colors. Meanwhile, the recommendations were processed in a new development cycle, resulting in an updated version of Sense-IT, as shown in Figure 4. Changes in app settings and the use of new smartwatches should be considered to improve the battery life and, thereby, usability. Third, experimental studies should be performed to evaluate the effectiveness of the Sense-IT intervention on clinical outcomes. Single-case experimental designs should be considered as well, because these types of designs might be better able to detect minor changes over short periods by, for example, using ecological momentary assessment (Maric & van der Werff, 2020; Smith, 2012). Laboratory tasks could also be considered to gain a broader insight into the response to biocueing. Fourth, the integration of therapy should be enhanced. To experience the potential benefits of this biocueing intervention, therapists should first be trained in working with Sense-IT and familiarizing themselves with the app. Furthermore, both therapists and patients should be able to adjust the settings to explore the optimal level of sensitivity of the system. Fifth, the Sense-IT app should preferably be added to treatment in the early phases of aggression regulation therapy, focusing on the recognition of anger bodily signals. The use of new technological interventions might have a positive influence on treatment

motivation (Klein Tuente et al., 2020), especially among patients with a positive attitude toward new technology.

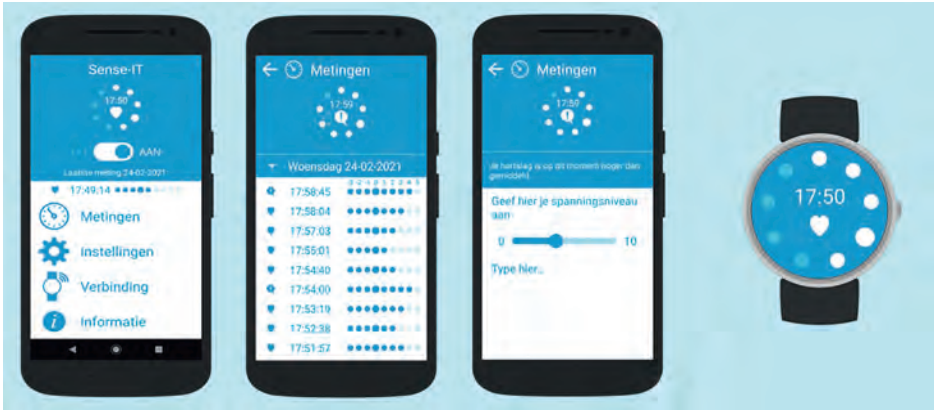

Figure 4. Screenshots of the Sense-IT app after further development (version 2.57): main screen, measurement screen, note screen, and the watch face.

Conclusions

This study revealed a cautiously positive attitude toward the use of biocueing as an addition to regular aggression regulation therapy in forensic psychiatry. In the evaluation study among forensic outpatients, the revised version of the Sense-IT app demonstrated moderate acceptability and adequate usability. Furthermore, a significant decrease in trait anger was found postintervention, which should be further explored in future research using appropriate research designs. Valuable recommendations for improvement of Sense-IT, both at the technological and design levels, were obtained in this study. For patients and therapists, a stable functioning app, with few synchronization disruptions and a self-adjustable number of notifications, seemed most important. Implementing new smartwatches with a longer battery life and using Sense-IT on the user's own smartphone are expected to increase adherence in the future. Considering the actual use of Sense-IT, the app seemed to have facilitated out-of-session practice and might therefore represent an alternative for more traditional paper-and-pencil registration assignments. The extent to which users actually reflect on their behavior and whether they feel supported by Sense-IT to practice behavioral alternatives needs further examination. Furthermore, this study provided some evidence that the deployment of Sense-IT is most useful in the first phase of aggression regulation therapy. Finally, to enhance the app's integration in treatment, therapists should be trained in the use of the app to facilitate exploration of the potential benefits of these kinds of new mHealth interventions with their patients.

CHAPTER 4

Exploring the Effects of a Wearable Biocueing App (Sense-IT) as an Addition to Aggression Regulation Therapy in Forensic Psychiatric Outpatients

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ABSTRACT

Objective: Preventing and reducing violence is of high importance for both individuals and society. However, the overall efficacy of current treatment interventions aimed at reducing aggressive behavior is limited. New technological-based interventions may enhance treatment outcomes, for instance by facilitating out-of-session practice and providing just-in-time support. Therefore, the aim of this study was to assess the effects of the Sense-IT biocueing app as an addition to Aggression Regulation Therapy (ART) on interoceptive awareness, emotion regulation, and aggressive behavior among forensic outpatients.

Methods: A combination of methods was used. Quantitatively, a pretest-posttest design was applied to explore group changes in aggression, emotion regulation, and anger bodily sensations associated with the combination of biocueing intervention and ART. Measures were assessed at pretest, after four weeks posttest, and after one-month follow-up. During the four weeks, a single-case experimental ABA design was applied for each participant. Biocueing was added in the intervention phase. During all phases anger, aggressive thoughts, aggressive behavior, behavioral control, and physical tension were assessed twice a day, and heart rate was measured continuously. Qualitative information regarding interoceptive awareness, coping, and aggression was collected at posttest. 25 forensic outpatients participated.

Results: A significant decrease in self-reported aggression was found between pre- and posttest. Furthermore, three-quarters of participants reported increased interoceptive awareness associated with the biocueing intervention. However, the repeated ambulatory measurements of the single-case experimental designs did not indicate a clear effect favoring the addition of biocueing. On group level, no significant effects were found. On the individual level, effects favoring the intervention were only found for two participants. Overall, effect sizes were small.

Conclusion: In sum, biocueing seems a helpful addition to increase interoceptive awareness among forensic outpatients. However, not all patients benefit from the current intervention and, more specifically, from its behavioral support component aimed at enhancing emotion regulation. Future studies should therefore focus on increasing usability, tailoring the intervention to individual needs, and on integration into therapy. Individual characteristics associated with effective support by a biocueing intervention should be further investigated, as the use of personalized and technological-based treatment interventions is expected to increase in the coming years.

INTRODUCTION

Reducing aggressive behavior and criminal recidivism is an important goal in forensic psychiatry. For this purpose, several treatment interventions have been developed over the last decades. Most of these interventions are based on cognitive behavioral therapeutic principles and could be considered derivates of Aggression Replacement Training (Glick & Gibbs, 2010; Goldstein et al., 1998): a treatment program in which behavioral, affective, and cognitive components are combined to improve aggression regulation. However, although risk reductions in violent recidivism have been reported in several studies (Henwood et al., 2015), the overall efficacy of these treatment interventions aimed at reducing aggressive behavior has been found to be limited (Brännström et al., 2016; McIntosh, Janes, O'Rourke, & Thomson, 2021). Since risk reductions are more pronounced among treatment completers (Brännström et al., 2016; Henwood et al., 2015), part of the limited effectivity of the current programs is probably related to low treatment adherence. Important to note is that low adherence may not only result in dropout but might also constrain the transfer of therapeutic skills into daily practice by impairing the completion of out-of-session assignments (Fletcher et al., 2011; Kazantzis et al., 2016). Furthermore, by focusing on achievement of cognitive control over emotional responses, current treatment programs might pay insufficient attention to other prerequisites of adequate anger regulation, such as awareness and recognition of psychophysiological signals associated with aggression and other challenging behaviors (Bellemans et al., 2019; McDonnell et al., 2015; Price & Hooven, 2018).

Over the last years, the number of studies focusing on the psychophysiological correlates of antisocial spectrum behavior, including aggression, has increased. In aggression research, psychophysiological measures such as heart rate (HR), skin conductance level (SCL), and heart rate variability (HRV) are used as indicators of, respectively, the general activity of the autonomic nervous system (ANS) and its two branches: the accelerating sympathetic nervous system (SNS) and the inhibitory parasympathetic nervous system (PNS). To understand the underlying mechanisms of aggressive behavior, ANS patterns of patients with aggression regulation difficulties have been compared to those of healthy controls, both at rest as well as in response to arousal-inducing events (i.e., reactivity measures). Recent meta-analyses demonstrated that lower HR at rest has most consistently been found to be positively related to antisocial behavior in general and proactive aggression in particular, although the overall effect size is small (De Looff et al., 2021a; Portnoy & Farrington, 2015). The research findings for reactivity measures are mixed. Regarding overall ANS reactivity, previous studies have shown increases in HR reactivity in response to emotional stimuli (Lorber, 2004; Ortiz & Raine, 2004) and provocation, associated with reactive aggression (Crozier et al., 2008). Other research results demonstrated blunted HR reactivity, suggesting diminished sensitivity to stressors

such as threat or punishment associated with proactive aggression (Van Goozen, Fairchild, Snoek, & Harold, 2007). Furthermore, there is some evidence that reactive aggression is related to heightened SNS reactivity (Armstrong et al., 2019; Murray-Close et al., 2017; Thomson et al., 2021) and proactive aggression to blunted SNS and PNS reactivity (Armstrong et al., 2019; Moore et al., 2018; Patrick, 2014). However, null findings for one or both associations have also been reported (Centifanti et al., 2013; Ter Harmsel et al., 2022; Wagner & Abaied, 2015; Zijlmans, Marhe, et al., 2021). With researchers stressing the importance of studying the interaction between SNS and PNS to understand proactive and reactive aggression, instead of hypo- or hyperreactivity of the subsystems alone (Branje & Koot, 2018; Moore et al., 2018; Puhalla & McCloskey, 2020), the psychophysiological reactivity results remain largely inconclusive to date.

Psychophysiological measures are not only used to understand aggressive behavior but can also be used to predict aggressive incidents in real life. For a long time most studies aimed at identifying these physiological biomarkers were conducted in laboratory settings (Adams et al., 2017). However, in recent years first pioneering studies have been conducted in clinical settings, among inpatients with aggressive behavior. In a naturalistic study among patients with intellectual disabilities and behavioral problems, non-linear fluctuations in HRV (i.e., decreases in the first levels of increasing tension and a sudden increase when reaching extreme agitation) were found prior to outbursts (Palix et al., 2017). Studies among children and adolescents with autism spectrum disorders demonstrated that challenging or aggressive behaviors could be predicted approximately 1 min before occurrence using biosensor HR data of the preceding minutes (Goodwin et al., 2019; Nuske et al., 2019). Furthermore, aggressive incidents among forensic inpatients turned out to be preceded by significant increases in HR and SCL up to 20 minutes before manifestation (De Looff et al., 2019).

Some of the beforementioned challenges in treatment of forensic outpatients with aggressive behavior, such as the difficulties in recognizing physiological signals that precede aggressive incidents and the limitations in out-of-session practice, might be addressed by implementing the psychophysiological research results facilitated by the fast developments in e- and m-health technology. New interventions, such as serious gaming (Smeijers & Koole, 2019), virtual reality therapy (Klein Tuente et al., 2020), and mobile biofeedback or biocueing apps (Mackintosh et al., 2017), create opportunities to increase treatment adherence by enhancing motivation and by lowering barriers for out-of-session practice. Whereas serious gaming and virtual reality therapy are delivered on-site, at home, or in a clinical setting, biocueing could provide the patient with just-in-time behavioral support by real-time measurement in everyday life (Nahum-Shani et al., 2018; Riley et al., 2015).

This new intervention, biocueing, can be considered a derivate of traditional biofeedback, in which users are provided with real-time physiological information and trained to influence physiological parameters, such as HRV (Lehrer, 2013) or cardiac coherence (McCraty & Zayas, 2014), by consciously alternating their (breathing) responses to the given feedback. In the process of biocueing wearable and mobile devices are used to collect and display the physiological biomarkers to the user in a direct way (Ter Harmsel, Noordzij, et al., 2021). In contrast with traditional biofeedback, biocueing is more focused on aiding and enhancing momentary awareness of physiological sensations (i.e., interoceptive awareness) and internal emotional experiences (i.e., emotional awareness), and to a lesser extent on deliberate training of regulation techniques. In biocueing, the training component is restricted to the moments when physiological tension elevates and the user receives a just-in-time message encouraging the use of adequate coping strategies (Nahum-Shani et al., 2018). Both components of biocueing interventions – increasing interoceptive awareness and delivering just-in-time behavioral support – may be helpful to reduce and prevent aggressive incidents among forensics outpatients (Cornet et al., 2017; Ter Harmsel, Noordzij, et al., 2021).

Given the potential of biocueing for the forensic population, we investigated the acceptability, usability, and clinical changes associated with the use of an earlier version of the Sense-IT biocueing app (Derks et al., 2019) in a two-week evaluation study among forensic outpatients (Ter Harmsel, Van der Pol, et al., 2021). Using the feedback of these end-users, a new version of the app was developed. The aim of the current study was to assess the effects of the new version of the Sense-IT biocueing app as an addition to Aggression Regulation Therapy (ART) on interoceptive awareness, emotion regulation, and aggressive behavior among forensic outpatients. Quantitatively, we expected that the combination of biocueing intervention and ART would be associated with positive group changes between pretest, posttest, and follow-up on measures of aggression, emotion regulation and insight in anger bodily sensations (pretest-posttest design). Furthermore, we hypothesized group and individual increases in behavioral control and decreases in aggressive behavior as well as changes in exploratory measures anger, aggressive thoughts, physical tension and heart rate favoring the biocueing intervention phase (single-case experimental designs). For the qualitative part of this study, perceived effectivity would be indicated by patient-reported increases in interoceptive awareness, use of coping strategies and prevention of aggressive incidents associated with the use of the Sense-IT app.

MATERIALS AND METHODS

Design

In this study, we used a combination of methods to answer the research question. Forensic outpatients receiving ART were invited to use the Sense-IT app (Derks et al., 2019; Derks et al., 2017) for four weeks. A pretest-posttest design was applied to examine changes on group level. Quantitative data were administered at the start (T0), after the four weeks (T1), and after one-month follow-up (T2). During the four week period a single-case experimental ABA design was applied for each participant, in which a baseline phase (A_1), was followed by an intervention phase (B) and a follow-up phase (A_2). In the two-week intervention phase, biocueing was added. Initially, we planned to randomize the start of the B-phase to either 5, 7, or 9 days after the start of phase A_1 for each group of three participants. However, since this procedure could not be aligned to the routines and schedules of potential participants, we had to let go of this multiple baseline aspect of the design. During all phases, the emotional state of the participants was assessed twice a day and heart rate was continuously measured. Qualitative data was collected at T1 via semi-structured interviews, enabling us to obtain a deeper understanding of patients' experiences concerning the effectivity of the Sense-IT. The study protocol and subsequent amendments were approved by the Medical Ethical Committee of Amsterdam University Medical Centre, Vrije Universiteit, the Netherlands (NL63911.029.17). The study was registered in the Netherlands Trial Register (NL8206).

Participants

Forensic outpatients, receiving Aggression Regulation Therapy (ART) at Inforsa, were recruited for participation in this study from January 2020 to March 2022. Potential participants were screened for eligibility by a research associate, consulting the patients' therapist. The eligibility criteria included: 1) a proven lack of anger management skills, indicated by either a recently committed violent crime and/or a high risk of committing one; 2) assignment to individual outpatient ART after multidisciplinary consultation; 3) basic understanding of mobile applications; and 4) an age of 16 years or above. The exclusion criteria included: 1) acute manic or psychotic symptoms; 2) current high risk of suicide; 3) severe addiction problems or other severe conditions requiring immediate intervention or hospitalization; and 4) insufficient understanding of the Dutch language. The first three exclusion criteria were assessed by consulting the patients' therapist, using cut-off scores on the corresponding items of the Health of the Nations Outcome Scales (HoNOS) (Wing et al., 1998). After screening and presenting the research project to eligible patients, 25 patients were willing to participate and enrolled in the study. Reasons for drop-out were: premature study termination due to COVID-19 regulations, reported stress increase related to participation in the study, other problems or obligations

requiring attention, and insufficient stability. An outline of the recruitment and participation flow is displayed in Figure 1.

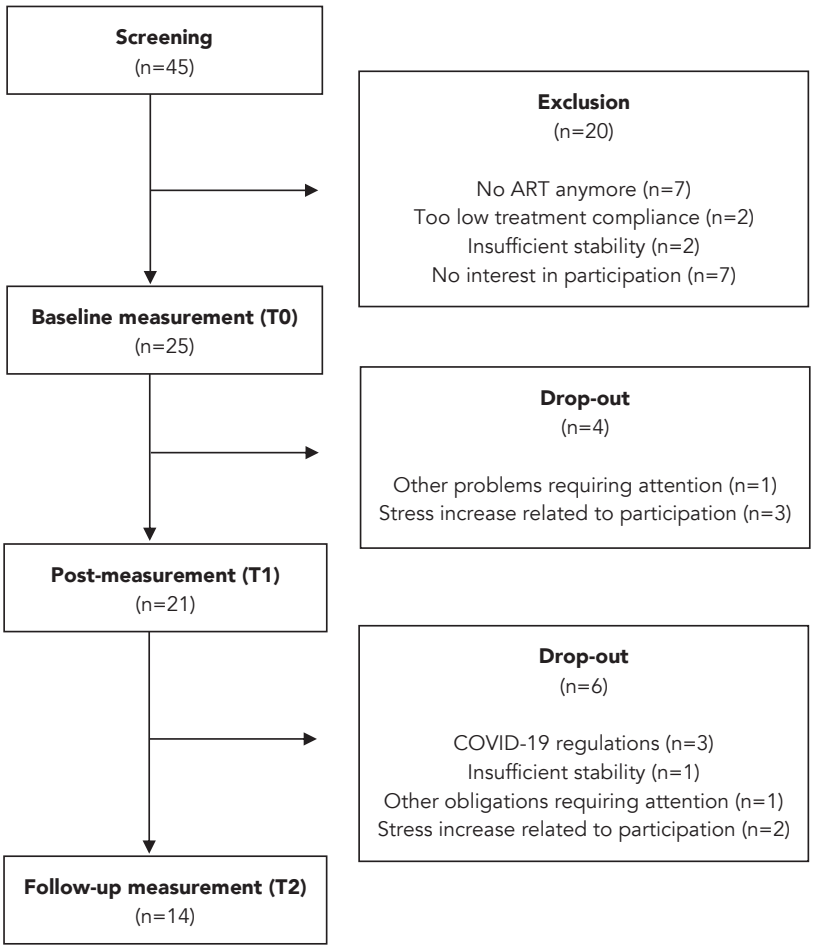

Figure 1. Flow chart of recruitment and participation.

Procedure

Eligible patients expressing interest in the research project received a face-to-face appointment in the presence of their therapist to discuss study participation. The research associate provided the patient with a brief oral description and full written information about the study. The voluntary nature and the absence of any negative consequences refusing participation were emphasized. When the patient expressed willingness to participate, the next appointment was planned after at least seven days, providing enough time for consideration. In this appointment

written informed consent was obtained and baseline measurement (T0) was administered, which lasted approximately 60 minutes. After completion of the questionnaires, participants were provided with a smartwatch and mobile phone with the Sense-IT app. Participants were shown how to use the devices and were advised on charging and using the system safely. They also received a user manual. Participants used the devices independently during the following four weeks. They were encouraged to call the research associates if any problem occurred. During these weeks, the research associate met with the participants twice; once to start the intervention phase (B) and once to start the follow-up phase (A_2). In these short appointments questions were answered, if applicable, and participants were reminded to answer the daily questions. After these four weeks, another 60 minutes assessment (T1) was planned, in which both qualitative and quantitative measures were administered. One month after T1-assessment, a 30 minutes follow-up assessment (T2) was scheduled. An overview of outcomes and their moment of assessment is presented in Table 1.

Table 1. Overview of outcomes, measures and moment of assessment.

Outcome	**Measure**	**T0**	**Tx** (during SCED)	**T1**	**T2**
Aggressive behavior	AQ-SF	+		+	+
	STAXI-2	+			
	MOAS	+		+	+
Heart rate measures	Biosensor		+		
Emotional state	EMA		+		
Emotion regulation	DERS	+		+	+
Anger bodily sensations	ABSQ	+		+	+
Aggression type	RPQ	+			
Psychopathy	YPI-s	+			
Judicial history	File information	+			
Demographic information	DQ	+			
Evaluation of the Sense-IT	Interview			+	+
System usability	SUS			+	

Abbreviations. AQ-SF, Aggression Questionnaire-Short Form; STAXI-2, State-Trait Anger Expression Inventory; MOAS, Modified Overt Aggression Scale; EMA, Ecological Momentary Assessment; DERS, Difficulties in Emotion Regulation Scale; ABSQ, Anger Bodily Sensations Questionnaire; RPQ, Reactive Proactive Questionnaire; YPI-s, Youth Psychopathic Traits Inventory-Short Version; DQ, Demographic Questionnaire; SUS, System Usability Scale.

Materials

Sense-IT

The newly developed version of the Sense-IT app, version 2.57 (with some minor bug fixes), was preinstalled on all smartwatches and mobile phones before distribution. The Sense-IT app was originally developed by the University of Twente and Scelta, an expert center for psychiatric patients with personality disorders (Derks et al., 2019; Derks et al., 2017) and modified to fit the needs of forensic outpatients assessed in an earlier study (Ter Harmsel, Van der Pol, et al., 2021). In the current study, we replaced the Ticwatch E, which we also used in our previous study, with the Ticwatch E2 (Mobvoi, Ltd). Compared to its predecessor the E2 is sleeker, more sophisticated, and has a slightly longer battery life. Connection with the mobile phone, the Moto C Plus or the Moto E6 Play (Google, LLC), was established via Bluetooth. The Sense-IT system reads the physiological data measured by the PPG sensor and stores the data in a local database on the smartphone itself. The build-in algorithm compares the current heart rate (HR) to the user's mean HR at baseline and calculates a level between -3 and 5 using the standard deviation of the baseline measurement. In the current study, we further refined the baseline measurement procedure. Ultimately, baseline measurement was performed during T0, included at least 1 minute of sitting in quiet, 1 minute of social interaction, and 1 min of walking activity to account for sufficient variation, and lasted until the PPG sensor received 500 reliable HR measures. Our starting values for HR and heart rate variance thresholds were in line with published norms indicating a mean HR around 80 (SD ~ 7) (Umetani, Singer, McCraty, & Atkinson, 1998). More information on the baseline procedure can be found in Appendix B. After baseline measurement, the real-time HR level is visually displayed on the smartwatch and changes when the HR level decreases or increases more than one level. After evert three participants, we checked whether we had to refine the settings to improve usability, for example accounting for feedback about receiving too many notifications. Ultimately, the sensitivity of the app was set to low (expanding the ranges between levels by multiplying the standard deviation with a 1.5 factor) and the notifying vibrations were given at levels 4 and 5 above baseline. The Sense-IT app also detects (physical) activity categories using the accelerometer and Google activity recognition algorithms, allowing the user to receive notifications for certain activity profiles. In this study, we ended up offering notifications for low activity profiles (i.e., sitting still, walking) only. In the user interface on the smartphone, users can turn the app on and off, and open a timeline of all measurement events and level changes detected by the system. Users can add notifications to events in the timeline and report their subjective level of arousal, which might particularly be useful when tension increases. Users can also define a personalized message that is displayed when their physiological arousal exceeds a predefined level. In this study, this supportive message and an accompanying question to rate subjective stress

were displayed at levels 4 and 5. The user interface also presented information about connection and synchronization, as well as a settings page which was protected by a password to prevent unwarranted changes. Screenshots of the Sense-IT app are displayed in Figure 2.

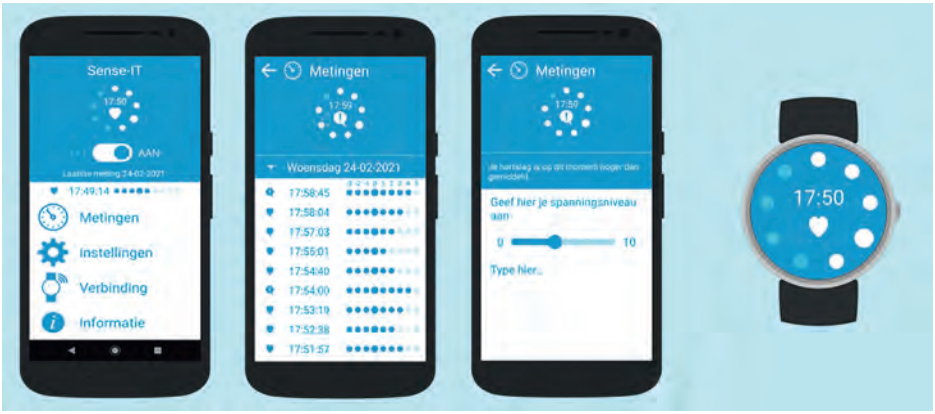

Figure 2. Screenshots of the Sense-IT app (version 2.57) with the main screen, measurement screen, notes screen and one of the watch faces.

Quantitative measures

Pretest-posttest design

Change measures: At T0, T1 and T2 primary and secondary measures were administered to explore relevant changes on group level. The Aggression Questionnaire-Short Form (AQ-SF) (Buss & Perry, 1992), a 12-item 5-point Likert scale self-report questionnaire, was used to assess changes in different types of aggressive behavior over the past four weeks: physical aggression, verbal aggression, anger, and hostility. Therapists evaluated aggressive behavior of their patients during the same period with the Modified Overt Aggression Scale (MOAS) (Knoedler, 1989), a 4-item observation scale differentiating verbal aggression, aggression against property, auto-aggression, and physical aggression. Another self-report measure, the Anger Bodily Sensations Questionnaire (ABSQ) (Zwets et al., 2014), consisting of 18 items with a 5-point Likert scale, was administered to assess changes in psychophysiological awareness. Furthermore, the Difficulties in Emotion Regulation Scale (DERS) (Gratz & Roemer, 2004), a 36-item 5-point Likert scale self-report questionnaire, was administered. This questionnaire is used to assess six dimensions of emotional processing: nonacceptance of emotional responses, difficulty engaging in goal-directed behavior, impulse control difficulties, lack of emotional awareness, limited access to emotion regulation strategies, and lack of emotional clarity.

Descriptive measures: At T0, several other secondary measures were administered to describe the sample. A self-developed demographic questionnaire was used to gather information regarding age, gender, ethnicity, education, and past offenses. The most recent DSM-5 main psychiatric diagnosis for each participant was retrieved from the electronic patient record. To gain a better understanding of the type and nature of aggressive and antisocial behavior, three other self-report measures were administered at baseline: the Reactive Proactive Questionnaire (RPQ) (Raine et al., 2006), the Youth Psychopathic Traits Inventory-Short Version (YPI-s) (van Baardewijk et al., 2010) and the State-Trait Anger Expression Inventory (STAXI-2) (Spielberger et al., 1999).

Single-case experimental designs

Self-report measures: During the four weeks of the ABA design, Ecological Momentary Assessment (EMA) was used to assess the emotional state of the participants. For this reason, six questions were designed based on the items of the Positive and Negative Affect Schedule (PANAS) (Watson, Clark, & Tellegen, 1988). Participants received prompts to answer these questions twice a day, at predetermined times fitting into the daily schedule of the particular participant. They were asked to rate the extent to which they experienced behavioral control and aggressive behavior (primary measures) as well as anger, aggressive thoughts and physical tension (exploratory measures) during the preceding part of the day. A question investigating feelings of happiness was added to balance the questions. A 5-point Likert scale was used for each question, reaching from 'very slightly/not at all' to 'extremely'.

Physiological measures: During the four weeks of the ABA design, heart rate (HR) was continuously measured while the Sense-IT app was used. The Sense-IT app also registered the baseline settings, kept track of the levels (i.e., a value between -3 and 5) and the activity profiles (i.e., running, cycling, sitting still), and whether biocueing was active (phase B) or not (phases A_1 and A_2).

Qualitative measures

At T1, a semi-structured interview was conducted. This interview included questions about feasibility and usability of the devices, advantages and disadvantages of the Sense-IT app, and recommendations for further improvement. In this article, we focused on three questions regarding the perceived effectivity of the Sense-IT app on interoceptive awareness, use of coping strategies, and prevention of aggressive incidents. More information regarding patients' perspectives on use and implementation of the Sense-IT app will be presented elsewhere (Ter Harmsel, Smulders et al., submitted).

Data analysis

Quantitative data analyses

Pretest-posttest design

The quantitative data (AQ-SF, MOAS, ABSQ, DERS) were analyzed using SPSS (version 27, IBM Corp). After checking the normality assumptions for main scales and subscales and given the small sample size (particularly for the comparisons with T2), we decided to use the nonparametric equivalent of the paired t-test, the Wilcoxon Matched Pairs Test. To make efficient use of the available data two missing items on the DERS, for two different participants, were replaced by imputing the individual mean score on this questionnaire at that moment of assessment.

Single-case experimental designs

In order to analyze the SCED data, all EMA and HR measures were divided into the three phases (A_1, B, and A_2), using the track record of the Sense-IT app. For EMA, responses were considered as belonging to the last preceding prompt, unless the response was given less than 30 minutes before the next prompt. In case of multiple responses within 30 minutes, the response that deviated the most from the specified prompting time was discarded. In case of phase ambiguities, EMA responses were assigned to the phase to which the majority (> 50%) of the period over which they reported (i.e., the time between prompts) belonged. For HR, measurements with specific activity profiles (i.e., running, cycling, car driving) were disregarded from the measurements to focus on HR data in no (i.e., sitting) to limited (i.e., walking) movement scenarios. Furthermore, the HR data was corrected for very low and high values (< 50 BPM and > 190 BPM). To calculate mean and standard deviation per daypart, HR-data was split into daytime (08:00 AM – 04:59 PM) and evening measures (05:00 PM - 01:59 AM). A daypart was considered missing when less than 500 HR measures were present. When participants had no access to the Sense-IT app and its associated devices for at least three days (e.g., due to vacation), the corresponding period was not included in the analysis.

After data preprocessing a visual analysis, considered as the primary method in SCED research (Kazdin, 2019), was performed on the selected EMA variables (i.e., anger, physiological stress, aggressive thoughts, aggressive behavior and behavioral control) and HR variables (i.e., mean and standard deviation). For participants with at least 5 data points per phase (Bolger & Laurenceau, 2013), we graphically compared the direction and rate of change (i.e., the slopes of the regression lines) between the different phases for each variable. We made plots for each participant separately as well as for the entire group of eligible participants. First, we used R (R Core Team, 2021) 'lme' function from the 'nlme' package (Pinheiro & Bates, 2000) to apply a multilevel (two-level) piecewise regression approach analyzing the effects between phases per variable, for all the eligible participants on group-

level. Second, we performed (one-level) piecewise regression analyses per variable for each participant using the R-based MultiSCED web application (Declercq et al., 2020). The unstandardized parameter estimates of each variable at the start of the study (intercept, B0), the developmental effect in the variable over time in a particular phase (time, B1), an immediate variable change when transitioning into the intervention phase (phase, B2) and a comparison of variable change over time in the intervention phase compared to the other phases (time x phase, B3) were calculated. For results, we reported the estimates B1 (for both baseline and intervention phase), B2, and B3. In addition, we assessed effect sizes at group and individual level for the EMA-variables for which we expected a specific direction of change (i.e., behavioral control and aggressive behavior) by calculating the Improvement Rate Index (IRD) (Parker, Vannest, & Brown, 2009). We calculated this nonparametric overlapping index, comparing the improvement rate between two phases, using an online single-case effect size calculator (Pustejovsky, Chen, & Swan, 2021).

Qualitative data analyses

We organized and analyzed the data of the qualitative interview using Microsoft Excel. Dichotomous responses were described as relative results. Two researchers (JtH and LS) independently ranked the three most informative textual responses regarding interoceptive awareness, use of coping strategies, and prevention of aggressive incidents. The final quotations were selected by discussion between two researchers (JtH and LS), until consensus was reached, and translated from Dutch into English.

RESULTS

Descriptive characteristics

The majority of the 25 forensic outpatients who participated in this study was male (92%) and born in the Netherlands (92%). For most of them, treatment was a mandatory part of their conditional sentence (64%), mainly imposed because of a violent index offense (94%). A large proportion (73%) reported problems in the family of origin: domestic violence and substance abuse were most frequently reported, but criminal behavior and psychological problems were also mentioned. All descriptive characteristics are summarized in Table 2.

Table 2. Demographic characteristics (N=25).

Outcome	**Mean *(SD)***	**n *(%)***
Age	29.88 *(10.51)*	
Gender		
Male		23 *(92%)*
Female		2 *(8%)*
Cultural background		
Western background		9 *(36%)*
Non-western background		9 *(36%)*
Mixed background		7 *(28%)*
Educational background		
None		1 *(4%)*
Primary education		4 *(16%)*
Junior secondary education		14 *(56%)*
Senior secondary education		6 *(24%)*
Indication of mild intellectual disability		9 *(36%)*
Main psychiatric classification according to DSM-5		
Disruptive disorder		10 *(40%)*
Substance use disorder		2 *(8%)*
Posttraumatic stress disorder		2 *(8%)*
Borderline personality disorder		2 *(8%)*
Other specified personality disorder		7 *(28%)*
Other disorder		2 *(8%)*
Mandatory treatment		16 *(64%)*
Past offenses (official records)		
0		8 *(32%)*
1 or 2		6 *(24%)*
3 to 5		4 *(16%)*
6 to 10		3 *(12%)*
more than 10		4 *(16%)*
Aggression type (RPQ)		
Reactive aggression	14.72 (4.39)	
Proactive aggression	7.53 (4.61)	
Anger and anger regulation (STAXI-2)		
State anger	18.80 (6.85)	
Trait anger	23.76 (6.97)	
Anger Expression Index	50.72 (10.81)	
Psychopathy (YPI-s)		
Interpersonal dimension	12.40 (4.73)	
Affective dimension	11.48 (4.39)	
Behavioral dimension	15.56 (3.35)	

Abbreviations. RPQ, Reactive Proactive Questionnaire; STAXI-2, State-Trait Anger Expression Inventory; YPI-s, Youth Psychopathic Traits Inventory-Short Version.

Pretest-posttest results

First, we analyzed the results of the quasi-experimental designs with pre-, post-, and follow-up measurements. The mean scores and standard deviations on clinical outcomes aggression (AQ-SF and MOAS), insight in anger bodily sensations (ABSQ), and emotion regulation difficulties (DERS), for each moment of assessment, are presented in Table 2. For statistical testing, data of 20 participants could be used to explore the difference between T0 and T1; and data of 14 participants for the differences between T0 and T2, and T1 and T2. The results of Wilcoxon Matched Pairs tests indicated that self-reported aggression decreased significantly between T0 (*Mdn* = 35.5) and T1 (*Mdn* = 31.5); Z = -2.043, p = .041. No significant decreases in aggression were found between the other moments of assessment. For therapist reported aggression level, emotion regulation difficulties, and insight in anger bodily sensations no significant differences were found between pre-, post- and follow-up assessment. For this sample, three of the outcome measures changed in the expected direction between T0 and T1, and one measure (anger bodily sensations) changed in the opposite direction. The mean scores and standard deviations for all outcomes at each moment of assessment are presented in Table 3.

Table 3. Overview of clinical outcomes at pre-, post- and follow-up measurement.

Outcome	**T0 (N = 25)** Mean *(SD)*	**T1 (N = 20)** Mean *(SD)*	**T2 (N = 14)** Mean *(SD)*
Aggression, self-report (AQ-SF)	32.44 *(9.51)*	30.80 *(8.68)*	28.07 *(10.40)*
Aggression, therapist-report (MOAS)	5.24 *(5.46)*	3.48 *(3.30)*	4.92 *(6.46)*
Emotion regulation difficulties (DERS)	100.40 *(25.55)*	93.14 *(25.52)*	89.20 *(24.98)*
Anger bodily sensations (ABSQ)	49.96 *(16.12)*	45.70 *(13.74)*	42.07 *(14.11)*

Abbreviations. AQ-SF, Aggression Questionnaire-Short Form; MOAS, Modified Overt Aggression Scale; DERS, Difficulties in Emotion Regulation Scale; ABSQ, Anger Bodily Sensations Questionnaire.

SCED results

Next, we analyzed the results of the ABA designs. In order to select the participants with sufficient data points, we started by investigating data availability. One participant did not start using the Sense-IT app, one participant quit after phase A_1 and seven participants stopped using the app after phase B. The compliance to EMA, defined as the ratio of the number of completed EMA questions in relation to the total number of EMA prompts per phase, ranged from 43.7% in Phase A_1, to 24.7% in Phase B and 16.0% in Phase A_2. For EMA, only 3 participants met the criterion of at least 5 data points for all phases. The compliance to HR measurement, the ratio of available daytime or evening measures in relation to the maximum amount of these measures per phase, ranged from 38.5% in Phase A_1, to 29.9% in Phase B and 13.5% in Phase A_2. For HR, none of the participants had sufficient measurements in all phases. Therefore, only the results of the baseline phase (A_1)

and intervention phase (B) were used for further analysis: for EMA, 9 participants had sufficient data in phase A_1 and B; for HR this applied to 10 participants.

First, we applied a multilevel piecewise regression approach (two-level) and visual analyses to analyze the effects between phases for five EMA-variables and two HR variables on group level, using the data of all eligible participants. We inspected B1 (for both baseline and intervention phase), B2 and B3. On group level, we found no significant developmental effects (neither for baseline nor for intervention phase), no significant immediate changes when transitioning into the intervention phase, and no significant interaction effects on any of the variables. All group-level parameter estimates are presented in Table 4. The individual and group-level results of the two primary EMA measures, behavioral control and aggressive behavior, are illustrated in Figure 3 and Figure 4. For exploratory measures, see Appendix C. Improvement rate differences (IRDs) for these outcomes on group level were .29 for behavioral control (increasing direction) and .26 for aggressive behavior (decreasing direction), indicating a small effect size of the combination of biocueing intervention and ART on these outcome measures (Parker et al., 2009).

Subsequently, piecewise regression analyses and visual analyses were conducted for each of the eligible participants separately (one-level), using MultiSCED. An overview of all unstandardized parameter estimates for each participant is available upon request from the first author.
First, we investigated the developmental effects in the baseline phase. For behavioral control we found an increase for one participant (P24: *B1* = .131, *SE* = .06, *t* = 2.191, *p* = .046). Regarding aggressive behavior, a decrease was found for one participant (P4: *B1* = -.048, *SE* = .021, *t* = -2.313, *p* = .027) and an increase for another (P8: *B1* = .26, *SE* = .087, *t* = 2.975, *p* = .009). For anger, we found a decrease for one participant (P4: *B1* = -.092, *SE* = .037, *t* = -2.49, *p* = .018) and an increase for another (P8: *B1* = .33, *SE* = .154, *t* = 2.14, *p* = .049). Aggressive thoughts decreased for two participants during the baseline phase (P1: *B1* = -.245, *SE* = .104, *t* = -2.367, *p* = .045 and P4: *B1* = -.119, *SE* = .041, *t* = -2.9, *p* = .007). Furthermore, an increase in mean HR was found for one participant (P10: *B1* = 1.063, *SE* = .389, *t* = 2.728, *p* = .021) and an increase in HR SD for another (P15: *B1* = .695, *SE* = .309, *t* = 2.246, *p* = .036). For all other participants and on all other variables, no significant in- or decreases were found for the baseline phase (all *t*'s ≤ ±2.047, all *p*'s ≥ .059).

Table 4. Summary of unstandardized parameter estimates on SCED measures (two-level analysis)

Variable	Intercept (B0)				Time (B1, phase A_1)				Time (B1, phase B)				Phase B:A_1 (B2)				Time x Phase (B3)			
	Coeff	*SE*	*t*	*p*	*Coeff*	*SE*	*t*	*p*	*Coeff*	*SE*	*t*	*p*	*Coeff*	*SE*	*t*	*p*	*Coeff*	*SE*	*t*	*p*
EMA-measures																				
Anger	1.623	.304	5.344	0	-.037	.012	-1.569	.119	.002	.012	.234	.815	-.060	.271	-.221	.825	.040	.027	1.462	.145
Aggressive thoughts	1.509	.265	5.701	0	-.055	.036	-1.508	.133	.012	.014	.873	.384	-.075	.326	-.229	.820	.066	.036	1.867	.064
Aggressive behavior	1.256	.171	7.330	0	-.012	.016	-.744	.458	.003	.006	.420	.675	-.171	.162	-1.053	.294	.014	.016	.891	.374
Behavioral control	4.076	.313	13.022	0	.045	.029	1.537	.126	-.008	.013	-.601	.549	-.048	.362	-.132	.895	-.053	.032	-1.657	.099
Physical tension	2.565	.405	6.328	0	.019	.024	.797	.427	-.009	.013	-.674	.501	-.398	.287	-1.384	.168	-.028	.029	-.988	.325
HR-measures																				
Mean	90.767	2.620	34.645	0	.112	.212	.527	.598	.079	.071	1.107	.270	-3.001	2.532	-1.185	.237	-.033	.226	-.147	.884
SD	14.688	1.344	10.928	0	-.094	.100	-.933	.352	.038	.043	.874	.383	1.164	1.069	1.089	.277	.131	.103	1.277	.203

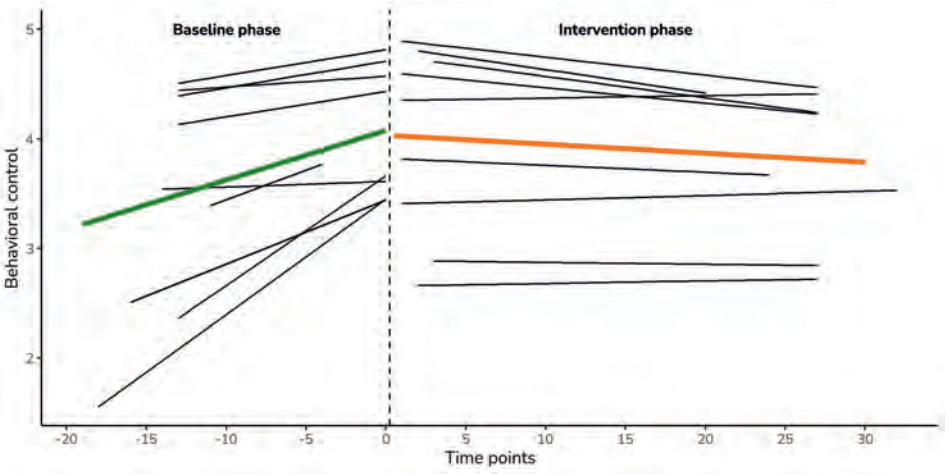

Figure 3. Combination of one- and two-level regression results for primary EMA-measure behavioral control in baseline phase A_1 and intervention phase B.

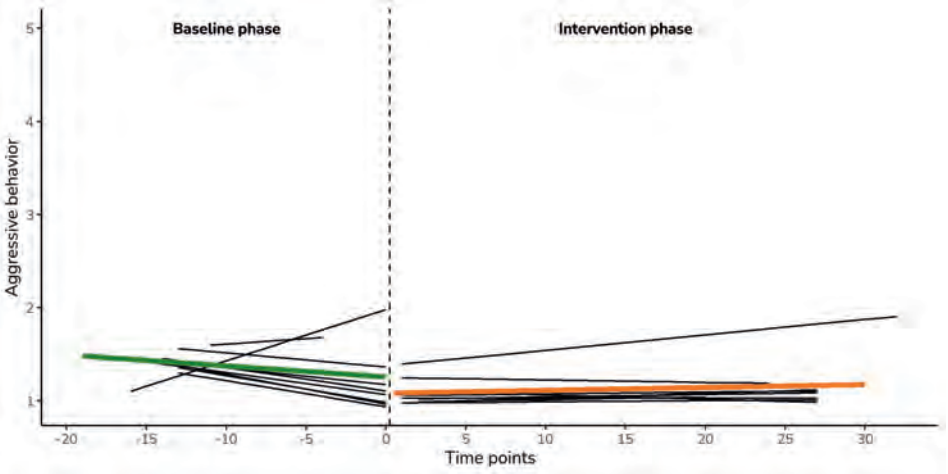

Figure 4. Combination of one- and two-level regression results for primary EMA-measure aggressive behavior in baseline phase A_1 and intervention phase B.

Second, we studied developmental effects in the intervention phase. There were fewer effects in this phase compared to the baseline phase. For aggressive thoughts, an increase was found for one participant (P4: *B1* = .044, *SE* = .017, *t* = 2.505, *p* = .009). Mean HR increased in the intervention phase for one participant (P15: *B1* = .751, *SE* = .311, *t* = 2.412, *p* = .026). For all other participants and on all

other EMA and HR variables, no significant in- or decreases were found for the intervention phase (all *t*'s ≤ ±2.071, all *p*'s ≥ .065).
Third, we studied the immediate changes when transitioning into the intervention phase. In one participant, results indicated an immediate decrease in aggressive behavior and anger at the start of the intervention phase (P8: *B2* = -3.22, *SE* = 1.397, *t* = -2.305, *p* = .036 and *B2* = -2.597, *SE* = .792, *t* = -3.28, *p* = .005 respectively). For all other participants, as well as on all other EMA and HR variables no significant effects were found (all *t*'s ≤ ±1.846, all *p*'s ≥ .086).
Fourth, we studied the interaction effect for time with phase for all variables. Regarding aggressive thoughts, one participant showed a strong increase in the intervention phase compared to a strong decrease in the baseline phase (P4: *B3* = .162, *SE* = .045, *t* = 3.651, *p* = .001). Aggressive behavior slightly decreased in the intervention phase compared to a strong increase in the baseline phase for one participant (P8: *B3* = -.282, *SE* = .089, *t* = -3.169, *p* = .006). In another patient, aggressive behavior decreased less in the intervention phase compared to the baseline phase (P4: *B3* = .048, *SE* = .023, *t* = 2.127, *p* = .041); it is important to note that aggressive behavior was completely absent in the intervention phase and thereby created a floor effect. Regarding anger, one participant showed a strong decrease in the intervention phase compared to an even stronger increase in the baseline phase (P8: *B3* = -.386, *SE* = .157, *t* = -2.462, *p* = .026). In contrast, another participant showed a slight increase in anger in the intervention phase compared to a stronger decrease in anger in the baseline phase (P4: *B3* = .1, *SE* = .04, *t* = 2.482, *p* = .018). For HR-related measures, we found a decrease in mean HR in the intervention phase compared to an increase in the baseline phase for one participant (P10: *B3* = -1.957, *SE* = .582, *t* = -3.365, *p* = .007). For all other participants, as well as on all other EMA and HR measures, no significant interaction effects were found between time and phase (all *t*'s ≤ ±1.949, all *p*'s ≥ .06).
Improvement rate differences (IRDs) for the two primary EMA outcomes on the individual level ranged from .05 to .51 for aggressive behavior (decreasing direction) and from .05 to .55 for behavioral control (increasing direction), indicating small effect sizes with some exceptions to moderate (Parker et al., 2009).

Finally, we zoomed in on the three participants in which we found significant interaction effects to enhance clinical understanding of the results.

Ryan

This 30-year-old man had severe aggression regulation problems. At baseline (T0), Ryan achieved a high score (9th decile) on the AQ-SF compared to other outpatients with violent behavior. He reported predominantly reactive aggression on the RPQ. Furthermore, Ryan experienced many emotion regulation difficulties (DERS). His anger expression index on the STAXI-2 (95th percentile) shows that he tended to express his emotions more outward than inward, and that his ability to regulate his emotions was very low. Using the piecewise regression results and visual analysis (see Figure 5), it becomes clear that his feelings of anger, aggressive thoughts, and aggressive behavior significantly decreased during the baseline phase (A_1). In the intervention phase (B), his aggressive thoughts significantly increased. However, Ryan reported that he did not express these thoughts in aggressive behavior, as indicated by the flat line. When the patterns in both phases were compared, his outcomes regarding anger and aggressive thoughts were in favor of the baseline phase. No significant difference between phases was found for heart rate. At post-test (T1) Ryan reported a substantially lower score on the AQ-SF (6th decile) compared to baseline, but a higher score on the DERS. He reported that the Sense-IT biocueing app did not work for him. He noticed no effect of using the Sense-IT on his awareness of physiological signals of tension, use of adequate coping, or prevention of aggressive behavior. Ryan mentioned that the Sense-IT app signaled tension when there was none and did not signal tension when there was; questioning the accuracy of the feedback.

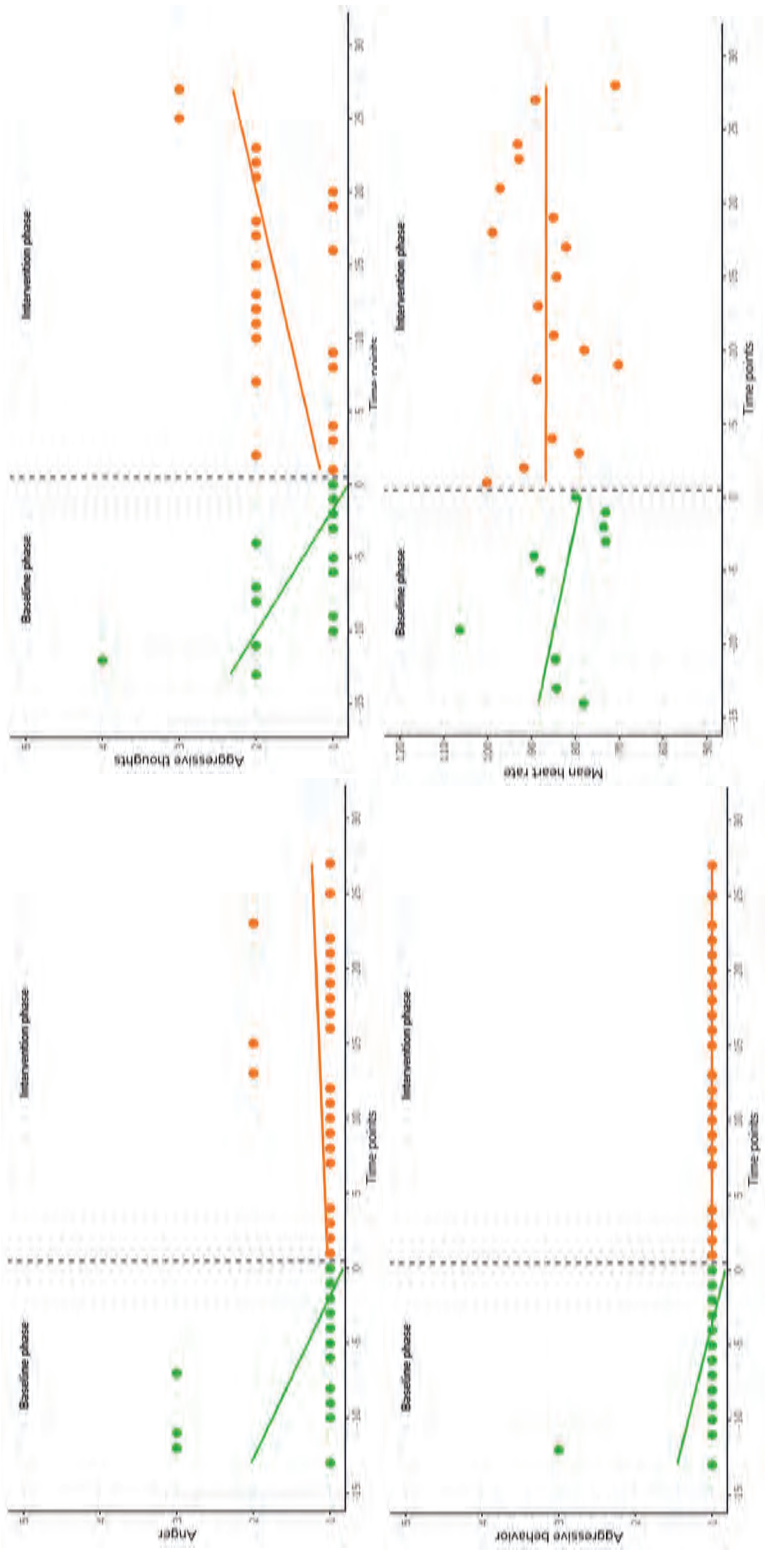

Figure 5. Representation of Ryan's EMA-measures (anger, aggressive thoughts and aggressive behavior) and HR (average) in baseline (A_1) and intervention phase (B).

Eric

This 40-year-old man also struggled with aggression regulation problems. At baseline, he scored average on the AQ-SF compared to the norm group (6th decile). Eric also reported predominantly reactive aggression on the RPQ. He experienced emotion regulation difficulties (DERS) to an average degree. The anger expression index (81st percentile) indicates that Eric also tended to direct his anger more outward than inside, and that his regulation skills were quite low. The piecewise regression results and visual analysis (see Figure 6) illustrate that anger and aggressive behavior significantly increased in the baseline phase (A_1). In the intervention phase (B), no significant in- or decreases were found. When the patterns in anger and aggressive behavior were compared between both phases, his outcomes did favor the intervention phase. For aggressive thoughts and heart rate, no significant differences were found between phases. Compared to baseline, Eric also achieved a lower score on the AQ-SF (4th decile) at post-test. His score on the DERS remained the same. Eric reported no effect of the Sense-IT on his awareness of physiological signals of tension, use of adequate coping, or prevention of aggressive behavior. He stated that he was not inclined to act upon the physiological feedback he received.

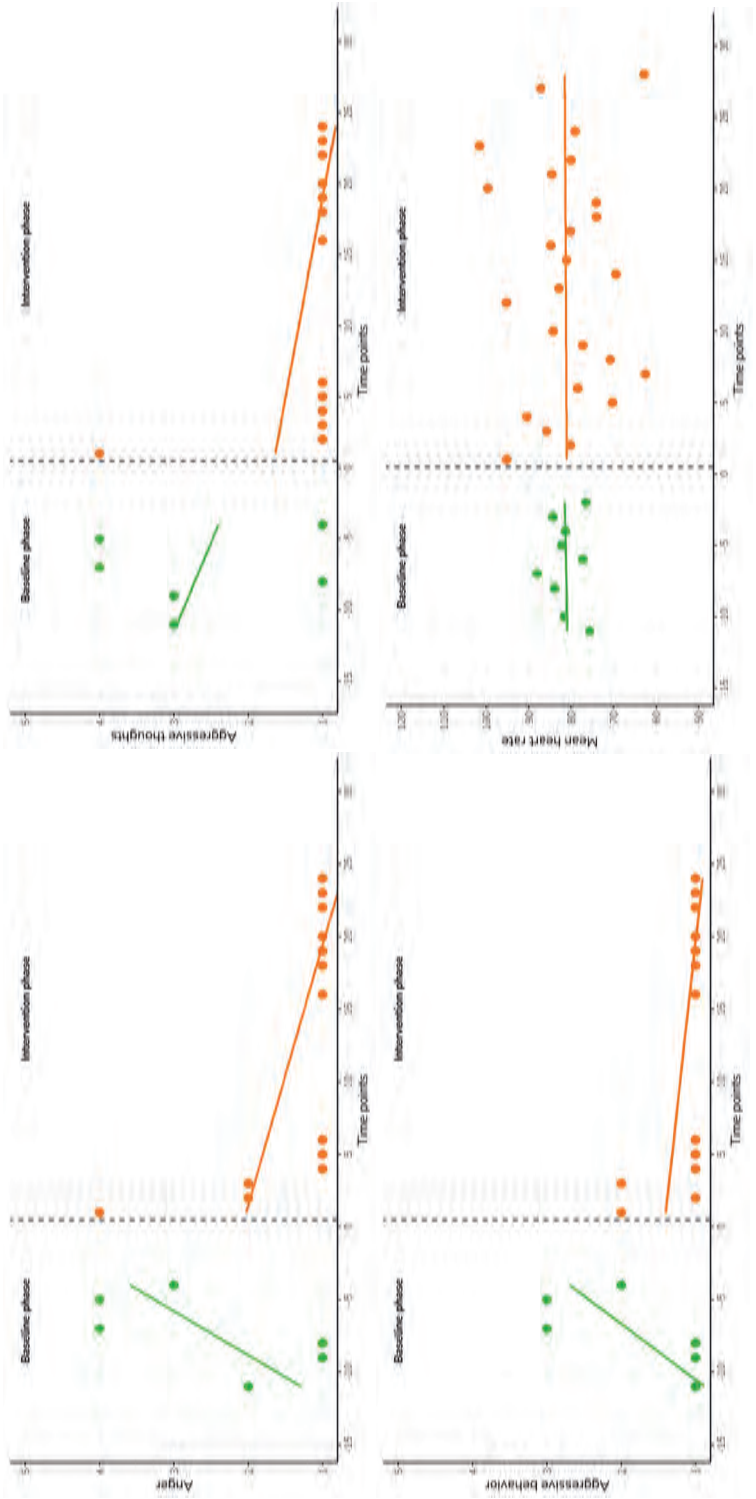

Figure 6. Representation of Eric's EMA-measures (anger, aggressive thoughts and aggressive behavior) and HR (average) in baseline (A_1) and intervention phase (B).

Joshua

This 20-year-old boy also had aggression regulation problems. At baseline, Joshua scored average compared to other outpatients with violent behavior (6th decile). He reported similar levels of reactive and proactive aggression on the RPQ. Joshua experienced emotion regulation problems (DERS) to an average degree. His anger expression index (60th percentile) indicated that he expressed his anger in both directions, and more inward compared to the other Ryan and Eric. His regulation skills were average to good. The piecewise regression results and visual analysis (see Figure 7) revealed that he had experienced little anger, aggressive thoughts, and aggressive behavior. No significant in- or decreases in phases and no significantly different patterns between phases were found for these variables. However, the decrease in median heart rate in the intervention phase (B) significantly differs from the increase in phase A_1, which might favor the intervention phase. Compared to baseline, Joshua scored slightly lower on the AQ-SF (5th decile) at post-test. The score on the DERS also decreased slightly, but was still in the same range. Joshua did notice a positive effect of the Sense-IT on his awareness physiological signals of tension. He explained that the app helped him not to get stuck in anger by using adequate coping strategies, such as seeking distraction and clearing his mind. He did not notice an effect on prevention of aggressive behavior, as he felt he had not been aggressive during the research period.

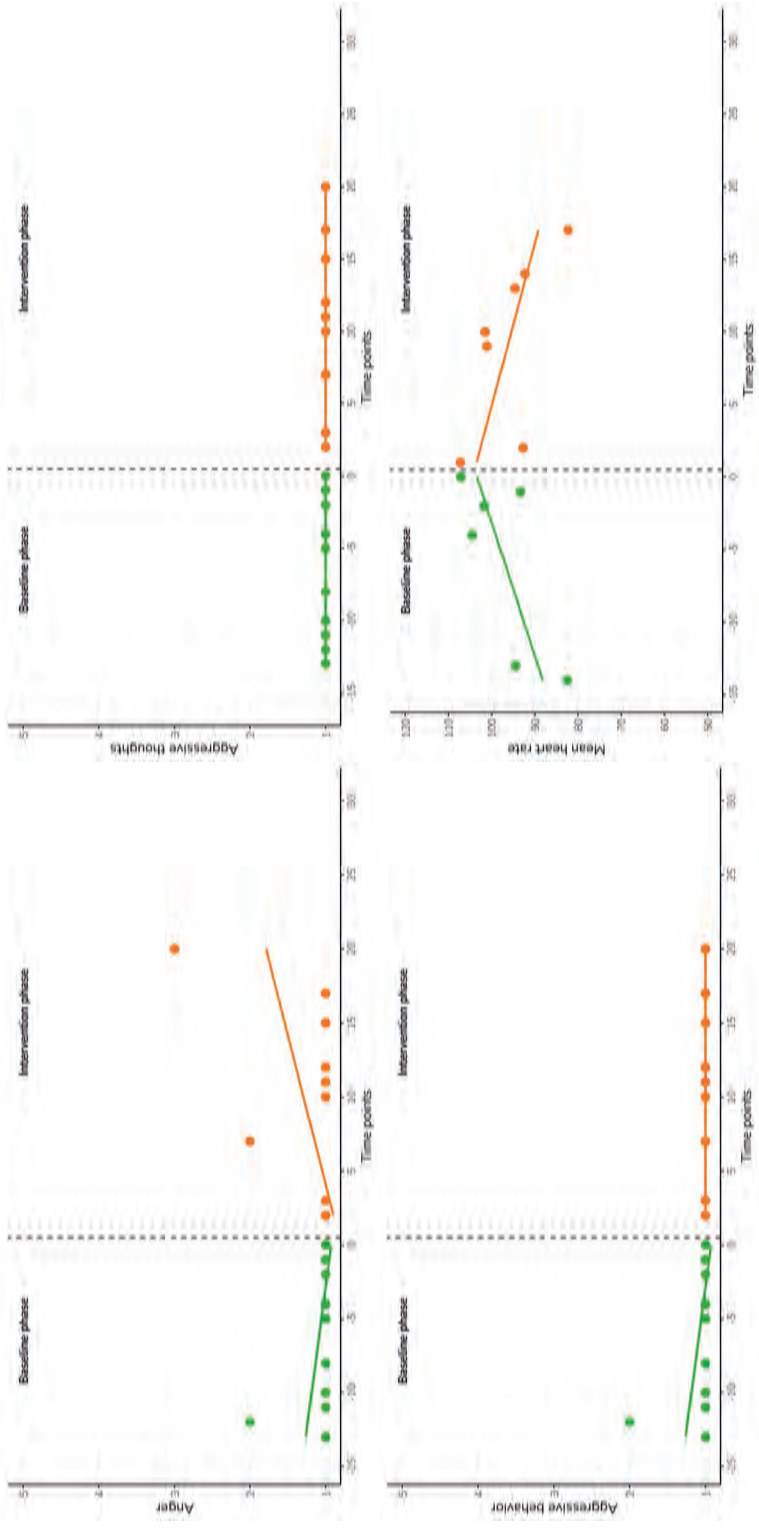

Figure 7. Representation of Joshua's EMA-measures (anger, aggressive thoughts and aggressive behavior) and HR (average) in baseline (A_1) and intervention phase (B).

Qualitative results

Qualitatively, we focused on the perspectives of patients regarding the perceived effectivity of the Sense-IT app on interoceptive awareness, use of coping strategies, and prevention of aggressive behavior. The responses of the participants can be found in Figure 8. As shown, the majority of the forensic outpatients (76%) reported increased insight into physiological signals of tension after using the app. For example, one of these participants mentioned: *"I felt the tension building and when it [the watch] started to vibrate I recognized that I was angry and went to do something else"* (P16) and another reported: *"That my heart rate is often high even though I don't think so myself."* (P3) However, other patients indicated: *"I was often alerted to tension when I already knew it."* (P21) and "*The app sends false notifications: it vibrates while nothing is going on and not when you are stressed out"* (P1). Approximately half of the participants (48%) felt supported by the Sense-IT app to use coping strategies in order to reduce stress. For example, one participant reported: *"When the watch vibrated I took the notification into account, for example by coming to myself and taking a breath."* (P17) and another said: *"I went to do something else and cleared my mind instead of dwelling in anger."* (P10). In some cases, the coping strategies used may have shed light on less adequate behavioral patterns:*"[When the watch vibrated] I went to smoke a joint and got calmer. I also went gaming."* (P9). One other participant mentioned: *"I will not be guided by a watch. Did look at the notification, but did not react to it. Screw it, I'll just stay angry."*(P8), indicating that at least some motivation to change behavior and openness to feedback are necessary prerequisites to benefit from the app. Moreover, it shows that it can be difficult for some patients to distinguish anger from aggression. Finally, about one-third of the participants (38%) reported that using the app might have helped them to prevent aggressive behavior in some cases. One participant responded: "*Maybe. By participating in this study, I became more aware to reduce my anger when the watch indicated, for example when stressed at work."* (P25). Other participants mentioned that they were able to calm themselves in some cases, but not in all: *"Sometimes I took it easy, but sometimes I was just angry and didn't do anything."* (P9) or: *"Sometimes you don't think about the watch, then things go fast and something happens."* (P7). Another participant stressed the boundaries of an app: *"It takes more than that. When I am very aggressive, I will not be stopped by a vibrating watch or a mobile with questions"* (P16). Furthermore, several participants reported increased stress and irritation by the number of notifications and the perceived inaccuracy of the app: *"Actually, it increased my frustration and irritation. I had to actively suppress not throwing the thing away."*(P21). Other participants indicated that this last question was difficult to answer as they had not experienced aggressive outbursts in the past period.

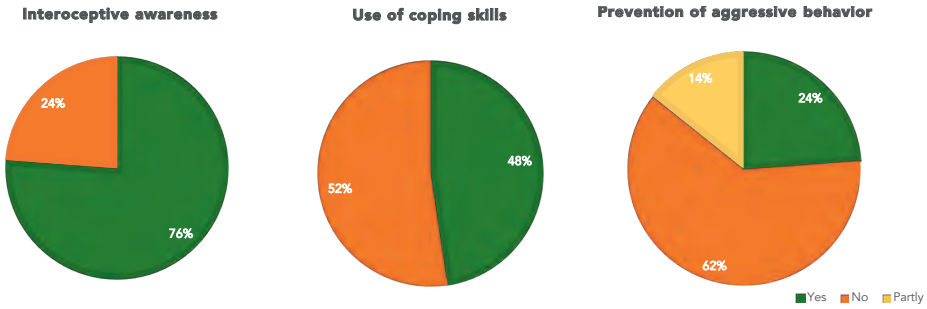

Figure 8: Perceived effectivity of the Sense-IT app on three levels according to forensic outpatients.

DISCUSSION

In the current study, we explored the effects of a new version of the Sense-IT biocueing app on interoceptive awareness, emotion regulation, and aggressive behavior in a forensic outpatient population. In this study, the Sense-IT app was added to regular aggression regulation therapy (ART). Quantitatively, we examined group changes on measures of aggression, emotion regulation and insight in anger bodily sensations between pretest, posttest, and follow-up (pretest-posttest design), as well as group and individual changes in behavioral control, aggressive behavior, anger, aggressive thoughts, physiological tension and heart rate in the intervention phase compared to the baseline phase (single-case experimental designs). In addition, we qualitatively assessed patient-reported changes in interoceptive awareness, use of coping strategies, and prevention of aggressive incidents associated with the use of the Sense-IT app.

The results of the pretest-posttest design showed a significant decrease in self-reported aggression between pretest and posttest, indicating a positive effect associated with the combination of the Sense-IT biocueing intervention and ART. In addition, although on visual inspection emotion regulation difficulties decreased in this sample, no significant effects were found. Furthermore, no significant differences were found for therapist-reported aggression level and insight into anger bodily sensations. The quasi-experimental nature of this design prohibits attribution of the found effect to either the Sense-IT app or the regular therapy. However, the fact that the significant decrease in aggression was only found between pretest and posttest (the period the Sense-IT app was added) and not for the comparison with follow-up (the period regular therapy was continued without the Sense-IT app), might suggest some additive value for the combination of biocueing intervention and ART.

Due to low compliance to EMA and a low amount of sufficient HR measures per daypart, data analysis of the single-case experimental designs was limited to EMA data of 9 participants and HR data of 10 participants. Noteworthy, positive developmental effects were found in the baseline phase, but not in the intervention phase. Immediate positive changes when transitioning into the intervention phase were demonstrated for anger and aggressive behavior in one participant. Interaction effects favoring the biocueing intervention were found for one participant (decreases in anger and aggressive behavior in the intervention phase compared to increases in the baseline phase); however, the reverse pattern was found in another participant (increases in anger and aggressive thoughts in the intervention phase compared to decreases in the baseline phase). For one other participant, HR measures decreased in the intervention phase compared to an increase in the baseline phase. On group level, we found no significant developmental effects in the baseline and intervention phase, no significant immediate changes when transitioning into the intervention phase, and no significant interaction effects on any of the variables. Overall, effect sizes were small, with some individual exceptions to moderate.

In contrast, the qualitative results do indicate positive changes related to the use of the Sense-IT biocueing app, such as increased interoceptive awareness among the majority of the participants, perceived support in the use of coping strategies by half of the participants, and prevention of some aggressive incidents by one-third. Although most participants reported increased insight into physiological signals of tension, results show that the step from insight toward adequate emotion regulation requires more attention. Furthermore, results seem to indicate that a certain amount of motivation to change behavior and openness to feedback are necessary to benefit from the just-in-time behavioral support delivered by the Sense-IT app. Although the usability of the Sense-IT app was acceptable (Ter Harmsel, Smulders et al., submitted), some patients reported increased stress and irritation by the number of notifications and the perceived inaccuracy of the app.

In sum, out of the subgroup of patients who qualitatively reported positive changes associated with the use of the biocueing intervention, we only found a significant quantitative change favoring the intervention phase for one patient with sufficient data for single-case analysis. We therefore conclude that, whereas the quantitative results of the pretest-posttest design and the qualitative results indicated positive changes associated with the combination of biocueing intervention and ART, the repeated ambulatory measurements of the single-case experimental designs do not indicate a clear effect favoring the addition of a biocueing intervention.

First of all, we would like to shed some light on the findings related to interoceptive awareness. The awareness of bodily sensations has been identified as an important

component in the process of emotional awareness (Calì et al., 2015; Lane & Schwartz, 1987), which is, in turn, an essential building block for adequate emotion regulation (Füstös et al., 2013; Gross & Jazaieri, 2014). In our study, the majority of patients qualitatively reported increased interoceptive awareness, although quantitively no significant difference and insight in anger bodily sensations was found. Several factors might have contributed to this finding. First, patients might have developed a more accurate view of their physiological sensations in angry interactions by using the biocueing intervention. Second, while interoceptive awareness primarily concerns perception, anger- related interoceptive awareness also entails some interpretation of bodily signals (Bellemans et al., 2018), and can therefore be considered a more demanding skill. Third, some patients had difficulty differentiating between components of the Sense-IT biocueing app (delivering a real-time visualization of their heart rate level and just-in-time behavioral support) and the integrated daily EMA questions that were used for research purposes. Since some patients reported that 'the questions' (unspecified) were really helpful to reflect on their emotional state, the qualitative measure of interoceptive awareness associated with the use of the biocueing intervention may have been somewhat diluted by perceived increases in emotional awareness by responding to the EMA questions across all phases. Fourth, recent research states that (Forkmann et al., 2016; Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015) interoceptive awareness should be considered as a metacognitive process, integrating both interoceptive sensibility (i.e., self-evaluated assessment of subjective interoception) and interoceptive accuracy (i.e., performance on objective tests of heartbeat detection). According to this model of interoception, our study focused on the facet of interoceptive sensibility and thereby lacked information regarding interoceptive accuracy and interoceptive awareness as a metacognitive process. Since the feedback was perceived as inaccurate by a substantial part of the patients, which may be partly related to technical issues but may also be explained by limited interoceptive capabilities, understanding the role of interoception in using biocueing among forensic outpatients could have been enhanced if we had included an interoceptive accuracy measure and had used a clearer definition of interoceptive terms (Khoury et al., 2018).

Second, we would like to focus on the findings regarding emotion regulation. Although half of the participants qualitatively reported that they felt supported by the app to use coping strategies in order to reduce stress, and on visual inspection emotion regulation difficulties decreased in this sample, no significant effects associated with the combination of biocueing intervention and ART were found in the pretest-posttest design. We also found no group or individual increases in behavioral control favoring the biocueing intervention in the single-case experimental designs. Several factors might have contributed to these findings. First, motivation to change and feedback receptivity varied among the

participants. Although these factors might not be required to take advantage of the component of the Sense-IT app aimed at increasing interoceptive awareness, feedback receptivity turned out to be quite essential to benefit from the behavioral support component of the Sense-IT app, even among non-psychiatric samples without motivational difficulties (Lentferink et al., 2021). For future use, it is therefore important to assess whether patients are open to receiving feedback and willing to try out different emotion regulation strategies. Related to this, some patients had (very) high expectations of what the app should deliver, which might have led to disappointment when subjectively experienced tension was not noticed or when they received behavioral support messages while they felt relaxed and did not notice tension. Although biocueing interventions can identify substantial increases in arousal by measuring heart rate, they are unable to provide a flawless recognition of subjectively experienced stress and cannot determine valence in order to specify emotion categories (Siegel et al., 2018). As suggested in recent research in which patients' reported similar feedback (Bosch, Chakhssi, & Noordzij, 2022), a more detailed explanation of biocueing might help to let patients realize that additional appraisal has to be exerted by themselves. Since some patients reported less adaptive coping behaviors in response to behavioral support messages, discussing and drafting the personalized message should be integrated into therapy and given more attention. Furthermore, some patients might benefit more from integrated relaxation exercises or gamified interventions instead of a text message (Bakker & Kazantzis, 2016). This all emphasizes the need to integrate new interventions in regular treatment and to tailor these interventions to patient-specific needs (Kip, Bouman, Kelders, & van Gemert-Pijnen, 2018).

Third, we would like to reflect on the findings regarding aggressive behavior. First of all, as patients reported in the qualitative part of the study, it is hard to determine if (hypothetical) aggressive incidents had been prevented and if so, whether that could be associated with the use of the biocueing intervention. Regarding aggression, the pretest-posttest results did indicate a significant decrease in aggression associated with the combination of biocueing intervention and ART. A significant decline in aggressive behavior favoring the biocueing intervention was found in one participant in the single-case experimental designs. However, no group effects were found using the repeated ambulatory measurements of the single-case experimental designs, and findings were not supported by therapist- reported aggression level. Several factors are worth noting. First, the EMA responses showed a low prevalence of aggressive behavior in most patients. This created a bottom effect in some patients. Whether this is related to social desirability, lack of concept clarity, or an actual low incidence rate remains unclear. Second, the added value of therapist-reported aggression levels should be considered limited as these scores were not based on actually observed aggressive incidents but on patients' reports thereof during the weekly therapy sessions. As some social desirability

might have been at play in both therapist- and patient-reported aggression (Barry, Lui, & Anderson, 2017), patients' reports may have rendered even more accurate information on aggressive behavior in this study given the perceived anonymity of these reports (Lobbestael, 2015). All these factors emphasize the challenges of aggression assessment among forensic outpatients, especially in outpatient settings (Lobbestael, 2015). Furthermore, some patients seemed to mix up anger and aggressive behavior, as if their treatment goal was never to experience anger again. This again stresses the need for integration of the app into therapy and the importance of psycho-education, problematizing aggressive behavior but normalizing feelings of anger. Finally, as the findings of the case studies provide insufficient support for the idea that biocueing interventions might be particularly beneficial for patients with predominant reactive aggression, this topic needs further investigation.

Strengths and limitations

Several strengths and limitations could be applied to this study. A noteworthy strength is that this study is one of the first in which a biocueing intervention, using psychophysiological measures, is used as an addition to regular treatment in a complex forensic outpatient sample with anger regulation difficulties. As main end-users, the forensic outpatients were involved throughout the developmental process, delivering us with valuable feedback and recommendations for future use of the app. Another strength is the use of a mixed-methods design. Integrating quantitative and qualitative data, on group and individual level, enabled us to explore the effects of the combination of a biocueing intervention and ART and to extract relevant information for further development and implementation in clinical practice.

Our study also had several limitations. One first limitation is related to compliance. For example, not all patients started with the biocueing intervention and several participants had difficulty answering the EMA-questions twice a day. Since we expected these challenges, given the characteristics of forensic outpatient populations, we tried to enhance compliance by sending reminders and contingency management (doubling the amount on the gift card when more than 75% of the EMA questions was answered), as suggested in experience sampling literature (Myin-Germeys & Kuppens, 2021). Despite these efforts, compliance to the intervention and the single-case experimental research designs remained low, particularly in the follow-up phase (A_2). Therefore, only the results of the baseline phase (A_1) and intervention phase (B) could be analyzed, for a select group of patients. Fortunately, most patients, including those who prematurely stopped using the app, still participated in the post-measurements of the pretest-posttest design. Although we thereby reduced the risk of bias in the quantitative and qualitative group results, some patients with negative experiences did still just

return their devices and reported that they did not want to participate anymore. Another limitation related to the single-case experimental designs is the fact that we were unable to (randomly) assign participants to different lengths of the baseline phase. Since we had already difficulty engaging participants, we had to let go of specific days that would match the research design but would not fit in the schedule of the participants. Since we only found small effects the impact of the missing multiple baseline analysis seems negligible. Third, limitations in the usability of the Sense-IT app may have overshadowed the effects of this additive intervention. Connectivity issues, other design preferences, restricted ability to customize the settings, use of a research-owned smartphone, and limited battery life of the smartwatch are disadvantages that are extensively discussed in another study (Ter Harmsel, Smulders et al., submitted). For now, we highlight the fact that participants kept reporting that they received too many notifications, even after we adapted the sensitivity, the levels at which notifying vibrations were given, and the activity categories in which notifications were provided. Some participants reported that they received many notifications when they engaged in only minor physical activities. Others reported that they received many notifications in intense physical activities (e.g., sports, intensive work), indicating that these were not recognized by the activity recognition algorithms. Furthermore, displayed activity profiles not always corresponded with their actual activity. In some patients, these notifications increased stress, led to frustration, and may have resulted in early termination of the research project. Important to note is that, outside of a strict research setting, patients would be able to adapt the sensitivity, levels, and activity profiles themselves, as well as to use the app on their own smartphone, which is expected to increase usability. Furthermore, the presentation of activity profiles, as recognized by the smartwatch using Google algorithms, has been modified in a new version of the Sense-IT app. As the number of notifications is directly related to the standard deviation of the baseline measurement, further refinement (e.g., a longer measurement with increased heart rate variety) of the here introduced baseline measurement procedure should be part of future biocueing studies. Fourth, the use of EMA questions may not only have had an impact on the qualitative measure of interoceptive awareness, but might also have impacted the entire ABA design. More specifically, the fact that forensic outpatients who often have difficulty reflecting on their emotions and behaviors were facilitated by the daily questions to do so, may have increased awareness of emotions, which may have had therapeutic effects as well. The interpretation of the effects of the biocueing intervention may therefore have been complicated by the use of experienced sampling in this research design. Fifth, although patients and therapists were involved in the entire developmental process of the Sense-IT app, the app was not an integral part of therapy in this study. This limited integration in therapy may have had a negative impact on the results.

Implications for research and clinical practice

Since it is known that a lot of end-users stop using a mental health app if their goals and preferences are not met (Torous et al., 2019), it is important to create more realistic expectations by providing patients with a more detailed explanation of biocueing as well as to improve the usability of the Sense-IT app. A substantial amount of recommendations have yet already been implemented in a new version of the Sense-IT app. Further refinement of the baseline measurement procedure is an important and necessary step, both to increase usability and to facilitate therapists and patients. Some other usability issues, e.g. the limited battery life of the smartwatches and imperfections in activity recognition, might get solved by technological advances in the future. For future research, it would be relevant to further investigate which patients benefit from a biocueing intervention that is integrated in therapy. Important characteristics to be considered are for instance aggression type, feedback receptivity, and mandatory or voluntary treatment. In addition, it should be assessed when and for how long the intervention should preferably be used. These research directions are in line with the shift toward developing and delivering personalized interventions precisely at moments of need (Bidargaddi, Schrader, Klasnja, Licinio, & Murphy, 2020). In forensic populations, where demanding traditional research methods are often not feasible, single-case experimental designs should be considered. Given our experiences, we recommended selecting measures that are less sensitive to floor or ceiling effects. When EMA is used, our advice would be to clearly distinguish the research component from the studied intervention. Furthermore, to gain a deeper understanding of the role of interoception in biocueing, we suggest using a combination of measures related to different facets of this concept. Finally, we cannot stress enough the importance of integration of the intervention in therapy. In line with the feedback of the forensic outpatients indicating a need for more personalized use (i.e., on their own smartphone, only in specific circumstances, for longer or shorter periods, with the ability to customize the settings themselves), we encourage therapists and patients to use and evaluate the Sense-IT biocueing app in everyday practice.

Conclusion

In sum, the qualitative results indicate that the use of a biocueing intervention as an addition to regular aggression regulation therapy could be considered a helpful means to increase interoceptive awareness among forensic outpatients. Furthermore, during the combination of this new intervention and regular ART significant decreases in self-reported aggressive behavior were observed. However, results of the repeated ambulatory measurements of the single-case experimental designs do not indicate a clear effect favoring the addition of a biocueing intervention. On the individual level, effects favoring the intervention condition were only found for two participants. On group level, no significant effects were found.

Decreasing compliance to the demanding research design, the possible therapeutic effects of the daily EMA questions, and limitations in both usability and integration in therapy, might have impacted the results and hampered interpretability. Future research and development should focus on increasing usability, tailoring the intervention to individual needs, and on integration into therapy. Furthermore, research should further investigate the individual characteristics (i.e., aggression type, feedback receptivity) associated with effective support by the Sense-IT app, as the use of personalized treatment interventions in clinical practice, including new technological interventions, is only expected to increase in the coming years.

CHAPTER 5

Forensic Psychiatric Outpatients' and Therapists' Perspectives on a Wearable Biocueing App (Sense-IT) as an Addition to Aggression Regulation Therapy: A Qualitative Study

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ABSTRACT

Background: Given the increased use of smart devices and the advantages of individual behavioral monitoring and assessment over time, wearable sensor-based mHealth apps are expected to become an important part of future mental healthcare. For successful implementation in clinical practice, consideration of barriers and facilitators is of utmost importance. The aim of the current study was to provide insight into the perspectives of both psychiatric outpatients and therapists in a forensic setting on the use and implementation of the Sense-IT biocueing app in aggression regulation therapy (ART).

Methods: A combination of qualitative methods was used. First, we assessed the perspectives of forensic outpatients on the use of the Sense-IT biocueing app using semi-structured interviews. Next, two focus groups with forensic therapists were conducted to gain a more in-depth understanding of their perspectives on facilitators and barriers to implementation.

Results: Forensic outpatients (N=21) and therapists (N=15) showed a primarily positive attitude toward the addition of the biocueing intervention in therapy, with increased interoceptive and emotional awareness as most frequently mentioned advantage in both groups. In the semi-structured interviews patients mainly reported barriers related to technical or innovation problems (i.e., connection and notification issues, perceived inaccuracy of the feedback, and limitations in the ability to personalize settings). In the focus groups with therapists, 92 facilitator/barrier codes were identified and categorized into technical or innovation level (n=13), individual therapist level (n=28), individual patient level (n=33), and environmental and organizational level (n=18). Predominant barriers were limitations in usability of the app, patients' motivation, and both therapists' and patients' knowledge and skills. Integration in treatment, expertise within the therapists' team, and the provision of time and materials were identified as facilitators.

Conclusions: The chances of successful implementation and continued use of new mHealth interventions, such as the Sense-IT biocueing app, can be increased by considering the barriers and facilitators from patients' and therapists' perspectives. Technical or innovation-related barriers, such as usability issues, should be addressed first. On the level of the therapists, increasing integration in daily routines and enhancing affinity with the intervention are highly recommended for successful implementation. Future research is expected to be focused on further development and personalization of biocueing interventions, considering what works for whom at what time, in line with the trend toward personalizing treatment interventions in mental healthcare.

INTRODUCTION

Background

Over the last years, services that use information and communication strategies to improve and support health – eHealth – have tremendously grown due to rapid technological changes (Fairburn & Patel, 2017; Patrick et al., 2016). In mental healthcare, a wide array of eHealth devices and programs are used, such as electronic patient records, internet-based therapy programs, and interventions using new technology (e.g., virtual reality and serious gaming) (Andersson, Cuijpers, Carlbring, Riper, & Hedman, 2014; Naslund, Marsch, McHugo, & Bartels, 2015; Park, Kim, Lee, Na, & Jeon, 2019). More recently mHealth, deploying smartphones and wearables devices to support health and health-related behaviors, has been added as a specific subcategory of eHealth (Luxton, McCann, Bush, Mishkind, & Reger, 2011; Nicholas et al., 2017).

Many eHealth interventions have been demonstrated to be feasible and acceptable (Naslund et al., 2015). Positive influences on healthcare outcomes and cost-effectiveness are reported for specific populations (Massoudi, Holvast, Bockting, Burger, & Blanker, 2019). However, to date, no firm conclusions can be drawn regarding the overall effectiveness of the use of eHealth in mental healthcare (Fairburn & Patel, 2017; Naslund et al., 2015). Concerning the use of mHealth interventions, overview studies identified several benefits, such as patient empowerment, self-monitoring, reduction of stigma, improved communication, and enhanced psychological services (East & Havard, 2015; Luxton et al., 2011). However, a recent review evaluating the usability of sensor-based mHealth apps reported insufficient acceptance by patients and recommended more rigorous research designs to investigate the effects of these particular interventions (Seppälä et al., 2019). The usability and clinical effectiveness of mHealth interventions therefore need further assessment. Given the increasing use of smart devices and the advantages of individual behavioral monitoring and personal assessment over time, researchers expect mobile phone and wearable sensor-based mHealth apps to become an increasingly important part of future personalized treatment (Luxton et al., 2011; Seppälä et al., 2019).

In forensic psychiatry, personalized treatment interventions are highly relevant since a considerable amount of forensic patients does not benefit from current treatment programs (Brännström et al., 2016; Henwood et al., 2015). Limitations in effectivity might not only be related to characteristics associated with forensic populations such as motivational difficulties and psychiatric complexity, but also to limited interoceptive awareness and insufficient transfer to out-of-session practice (Bellemans, Didden, Korzilius, & van Busschbach, 2020; Kazantzis et al., 2016; Price & Hooven, 2018). New technological interventions like wearable biocueing apps

might help to overcome these challenges. Biocueing apps provide the patient with real-time physiological feedback and just-in-time behavioral support messages when physiological tension elevates, encouraging the use of adequate emotion regulation strategies in everyday life (Ter Harmsel, Noordzij, et al., 2021). Another recent review supported the potential of eHealth for forensic populations given the positive effects reported in most studies and the ability to tailor interventions to patient-specific needs (Kip et al., 2018). However, this review also points out that the advantages of eHealth heavily depend on integration in treatment and fit with the needs and preferences of patients and therapists.

Considering the needs and preferences of intended users is one of the main prerequisites to bridge the gap between promising results of e- and mHealth studies on the one hand, and actual deployment of these interventions in mental healthcare on the other hand (McCurdie et al., 2012). In addition to specific characteristics of patients and therapists, technological aspects, internal implementation climate, and external policy incentives also contribute to the uptake of new interventions (Granja, Janssen, & Johansen, 2018; Ross, Stevenson, Lau, & Murray, 2016). These factors share many similarities with the levels of an often-used implementation model designed to understand and inform the process of change in healthcare (Grol & Wensing, 2004). According to this model, barriers and incentives of change can be categorized into six different levels: innovation (e.g., feasibility, accessibility), individual professional (e.g., awareness, knowledge, behavioral routines), individual patient (e.g., skills, attitude, compliance), social context (e.g. opinion of colleagues, collaboration), organizational context (e.g., organization of care processes, staff, resources), and economic and political context (e.g., financial arrangements, policies). In a recent systematic review, three levels of barriers and success factors concerning the implementation of eHealth services were identified: technical factors (e.g. usability, security, support), individual factors (e.g., cognition, motivation, trust), and environmental and organizational factors (e.g., financing, proof of effectiveness, fit into organizational structures) (Schreiweis et al., 2019). Basically, this seems to be a more parsimonious model, as individual levels are merged and internal and external organizational barriers are combined.

Aim of this study

With this study, we aim to provide insight into the perspectives of both forensic outpatients (Study 1) and therapists (Study 2) on the use and implementation of a new mHealth intervention, the Sense-IT biocueing app, in aggression regulation therapy. More specifically, we focused on facilitators and barriers to implementation, as identified by previous models. As we expected the feedback of forensic outpatients to be mainly centered on the technical or innovation level and individual patient level, we included forensic therapists to provide us with information on all levels of the implementation model.

METHODS

Study 1

Design

The perspectives of forensic outpatients on the use of the Sense-IT biocueing app were explored using a qualitative semi-structured interview. In addition, usability was determined using a quantitative usability score. Data was collected at post-measurement (T1) within a larger quasi-experimental study in which patients used the Sense-IT app for four weeks. More specific information on the design of this study can be found in another paper (Ter Harmsel, Noordzij et al., in preparation).

Recruitment

Forensic outpatients who received aggression regulation therapy (ART) at Inforsa, a forensic mental healthcare organization in Amsterdam, the Netherlands, were recruited for participation between January 2020 and March 2022. First, patients were screened for eligibility by a research assistant, consulting the patients' therapist. Patients were eligible for participation when they had a lack of anger management skills, were assigned to individual ART, had a basic understanding of mobile applications, and were 16 years or older. Patients were excluded in case of acute manic or psychotic symptoms, high risk of suicide, severe physical conditions requiring immediate intervention, or insufficient understanding of the Dutch language. If a patient turned out to be eligible and interested in the research project, study participation was offered in a face-to-face appointment, in which a brief oral description and full written information were provided. Patients were carefully informed about the anonymous use of data, the voluntary nature of the study, and the absence of any negative consequences in case of refusal or early termination. All patients provided written informed consent prior to participation. This study was approved by the Medical Ethical Committee of the Amsterdam University Medical Centre (NL63911.029.17).

Procedure

After screening and informing the patients about the research project, 25 patients were eligible and willing to participate. All patients participated in a baseline measurement (T0), in which demographic characteristics, attitude toward new technologies, and perceived proficiency in using new technologies were assessed. Next, they were provided with the Sense-IT app for four weeks, in which they received biocueing for two weeks. The System Usability Scale (SUS) and the semi-structured interview were assessed after four weeks, at post-measurement (T1). The SUS is a short, widely used Likert scale questionnaire for quick and reliable assessment of usability (Brooke, 1996), yielding an overall score between 0 and 100. According to recent research, a product with scores above 70 is acceptable,

whereas better products score in the high 70s to upper 80s and superior products score above 90 (Bangor et al., 2008). The semi-structured interview consisted of 27 questions, investigating attitudes toward new technology, usability, and efficacy. For this study, we focused on five open questions regarding advantages and disadvantages of the Sense-IT app, specific situations in which the app was assessed as (not) pleasant or useful, and suggestions regarding future use. Patients received a gift card of €10 and an additional €10 at T1 when at least 75% of the repeated experience sampling questions (not further reported here) were answered.

Data-analysis

We organized the qualitative data of the outpatients using Microsoft Excel. For categorical responses, cumulative frequencies were calculated with SPSS (version 27, IBM Corp). For open responses, content analysis was used. First, textual responses were inspected by the first author (JtH) to gain familiarity with the data and establish a coding scheme. Next, the first and second author (JtH and LSm) independently coded the responses into predefined categories. Discrepancies were discussed between both authors until consensus was reached. Discussion was also used to refine categories and code descriptions in order to increase interpretation of the codes. Quotes were jointly selected by both authors, considering their informative value and their ability to illustrate the category. Finally, selected quotes were translated from Dutch into English by JtH and LSm.

Study 2

Design

The perspectives of forensic therapists on the implementation of the Sense-IT biocueing app were explored using focus groups. This study was designed to investigate the added value of the app from a therapist point of view, to gain a better understanding of the perceived facilitators and barriers to implementation, and to collect suggestions for implementation.

Recruitment

Forensic therapists working within outpatient teams at Inforsa were recruited by email in February 2022. Therapists were eligible and invited for participation if they were trained in aggression regulation therapy (ART). No other in- or exclusion criteria were applied. Therapists were informed that participation was voluntary, that information would be processed anonymously, and that the data would be used for research and policy purposes, as well as for enhancement of the implementation process of the Sense-IT app. Prior to participation, therapists received an informative e-mail and an informed consent form. All therapists who participated in the focus groups provided written informed consent.

Procedure

Two focus groups were carried out in February and March 2022. Both focus groups were scheduled within the existing structure of team meetings to avoid time burdens and added workload, thereby enhancing the chances of participation. In line with this structure (and also relevant from a content perspective), separate focus groups were organized for therapists working with young adults and for therapists working with adults. Due to COVID-19 regulations, some therapists participated on-site and others online. The planned group size was six to eight participants, to allow optimal interaction between participants (Krueger & Casey, 2002). The focus groups were conducted by a moderator (JtH) and an assistant (LSm). The moderator is a licensed healthcare psychologist with extensive training in interviewing skills and techniques. The moderator and assistant are both affiliated with Inforsa as scientist-practitioners. They were not employed as therapists in the teams at the time the focus groups were held.

At the start of the focus groups, a brief overview of the Sense-IT project was presented, including background information, screenshots of the app, and some qualitative results of earlier studies. After that, therapists completed a short form assessing demographic characteristics, the attitude toward both mHealth in mental healthcare and new technologies, as well as the perceived proficiency in using new technologies. In both focus groups, the same questioning route was used (see Appendix D). The moderator structured the discussion to cover key themes, but was also responsive to issues emerging in the focus groups. The questioning route was developed by the researchers and adapted using the feedback of important stakeholders. For assessment of added value, specific questions were used to discuss the impact on therapist, patient, and treatment level. Questions to assess the perceived barriers and facilitators of implementing the Sense-IT app were aligned to the two implementation models described above (Grol & Wensing, 2004; Schreiweis et al., 2019). The focus groups lasted approximately one hour. Participating therapists did not receive financial reimbursement, although some refreshments were provided during the focus groups.

Data-analysis

Focus groups were video- and audiotaped, transcribed in full by LSm, and analyzed by JtH and LSm using content analysis. We used a combination of open and axial coding in a process of constant comparison (Scheepers, Tobi, & Boeije, 2016). First, JtH and LSm both read the verbatim transcriptions to gain familiarity with the data. Next, JtH established an initial coding scheme to categorize responses into the predefined levels. JtH and LSm independently categorized and open coded the responses using MAXQDA 2022 (VERBI Software, 2021). The assigned categories (levels) and codes (subthemes) were compared using the merge function in MAXQDA. JtH and LSm first reached intercoder agreement on levels

by discussing the disagreements in categorization until consensus was reached. Next, researchers discussed the codes, resulting in joint axial coding and refinement of the subthemes. After that, subthemes were jointly categorized into main themes, thereby connecting individual subthemes with the predefined levels. Finally, both researchers reached consensus on the facilitator/barrier annotations of the codes. The refined coding scheme and completed analysis were verified by the last author (TvdP). Discrepancies were discussed by JtH, LSm, and TvdP until consensus was reached. Finally, important themes and subthemes were identified and informative quotations that could enhance interpretation of the results were selected and translated from Dutch to English by JtH and LSm.

RESULTS

Study 1

Descriptive statistics

In sum, 21 (19 male, 2 female) forensic outpatients filled in the SUS and participated in the interview at T1. The majority of the participants (66.7%) received mandatory treatment, as a part of a conditional sentence. The most frequently classified main psychiatric disorders according to DSM-5 criteria were disruptive disorders (42.9%) and personality disorders (37.1%). Some participants were diagnosed with intellectual disability or scored below the cutoff on a screener for mild intellectual disability (38.1%). At posttest, forensic outpatients evaluated the usability of the Sense-IT app as acceptable (M=73.13; SD=13.35). System usability was not significantly correlated with age, attitude toward new technology, or perceived proficiency in using new technologies. Noteworthy, all patients returned the borrowed materials, except for two patients who reported that they lost their smartwatch due to robbery. All descriptive characteristics are summarized in Table 1.

Table 1. Descriptive characteristics of forensic outpatients (Study 1).

Variable	M *(SD)* or n *(%)*
Age, M *(SD)*	29.76 *(10.60)*
Males, n *(%)*	19 *(90.5%)*
Cultural background, n *(%)*	
Western	7 *(33.3%)*
Non-western	7 *(33.3%)*
Mixed	7 *(33.3%)*
Educational background, n *(%)*	
None	1 *(4.8%)*
Primary education	3 *(14.3%)*
Junior secondary education	12 *(57.1%)*
Senior secondary education	5 *(23.8%)*
Attitude toward new technologies, M *(SD)* [a]	4.33 *(.86)*
Perceived proficiency in using new technologies, M *(SD)* [b]	8.00 *(1.05)*

Note. [a] Measured on a 5-point Likert scale with score 1 indicating a (very) negative attitude and 5 indicating a (very) positive attitude. [b] Graded on a 10-point scale, with 1 indicating no proficiency and 10 indicating excellent proficiency.

Results

Forensic outpatients identified a wide range of advantages and disadvantages of the Sense-IT app. More than once mentioned responses, which could be grouped into categories, are presented in Table 2.

As advantages, clarity and simplicity of the app, as well as support in interoceptive and emotional awareness, were most frequently reported. Most patients reported no difficulty in understanding how to use the app, and some explicitly indicated that the app was clear and well-organized. Furthermore, patients indicated that the app supported them to become more aware of physical tension and that the questions in the app assisted them to reflect on their emotions and behavior during the day. One participant reported:

> *[The app helped me] to reflect on how things were going; I never really did that, but now I was aware whether I had a good day or a not so good day.* [P10]

Connectivity issues, notification issues, and perceived inaccuracy were mostly mentioned as disadvantages. Regarding connectivity issues, patients reported disturbance by interruptions in the Bluetooth connection, for example when the

distance between smartphone and smartwatch was too large. As a potential solution, one patient suggested running the app stand-alone on the smartwatch itself, so no Bluetooth connection would be needed. Furthermore, a substantial part of the participants reported that they received too many notifications or notifications that they perceived as either too soon or too late. Besides the ability to adjust the (maximum) amount of notifications, patients suggested sending notifications only when a higher heart rate was registered over a longer time. One participant recommended:

> *Add a button to put the app on pause, as a time-out, when you get irritated by the number of notifications, or when you already know [that you are tense].* [P21]

Related to this, several patients indicated that they would have preferred to customize the settings of the app themselves; their ability to do so was restricted in this study. For example, they would have liked to be able to adjust the number of notifications as well as the frequency and content of the daily questions according to their preferences. Furthermore, patients questioned the accuracy of the feedback provided by the app. Patients mentioned both elevations in heart rate when they did not subjectively experience stress, as well as subjectively experienced stress without detected elevations in heart rate. Patients reported that activity profiles were not always recognized correctly by the Sense-IT. Furthermore, patients reported missing specific design features, such as the use of colors (e.g., red color to signal high tension), graphical overviews, and more variety in watchfaces (ranging from a very clear watchface with the actual heart rate to a watchface that is less easy to interpret for others). Other frequently mentioned disadvantages were the use of a research-owned smartphone and the limited battery life of the smartwatch.

Furthermore, we assessed in which specific situations the app was described as (not) pleasant or useful. Half of the patients (11/21, 52.4%) reported no specific situations, or no situations at all, in which they perceived the app as pleasant or useful. In retrospect, the app was perceived most useful (mentioned by 7 out of 21 patients, 33.3%) in or shortly after discussions, confrontations, and other situations with a lot of tension, in order to support awareness and emotion regulation. Related to this, the app was judged not pleasant or useful in relaxed settings in which (perceived inaccurate) notifications were reported as disturbing (5/21 patients, 23.8%), during exercise of other physical activities (6/21, 28.6%), or when patients already felt too stressed or tired (3/21 patients, 14.3%). One participant summarized:

> *In places where you have a lot of tension: it is good to put it [the smartwatch] on just then, and not in situations when you are calm.* [P25].

Table 2. Advantages and disadvantages of the Sense-IT app, and the frequency each code was identified in the responses of the forensic outpatients (Study 1).

Code	Code frequency	Definition
Advantages		
Rationale	n=4	The idea or rationale behind the app, its functionality.
Simplicity	n=7	The clarity and simplicity of the app and its functions.
Awareness	n=8	The helpfulness of the app to increase both interoceptive and emotional awareness.
Behavioral support	n=2	The helpfulness of the behavioral support messages.
Disadvantages		
Perceived inaccuracy	n=7	The perceived inaccuracy of the HR measurements and/or the recognized activity profiles, or perceived limitations of the app to detect subjectively experienced stress.
Notification issues	n=8	Problems related to the amount (too much) or the moment (too soon, too late) of notifications received.
Connectivity issues	n=8	Problems related to instability of the connection between smartwatch and smartphone.
Use of a research-phone	n=5	Problems related to the use of the app on a research-owned smartphone.
Limited adaptive functionalities	n=6	Limitations in the ability to personalize settings during the study.
Design-related issues	n=6	Problems related to personal design-related preferences.
Other software issues	n=4	Other problems related to the functions of the app.
Limited battery life	n=4	Limitations in the battery life of the smartwatch.
Other hardware issues	n=4	Other problems related to the smartwatch.

Study 2

Descriptive statistics

In total, 21 forensic therapists were invited to participate in one of the focus groups. Five therapists pre-announced they were unable to participate due to practical reasons. One new therapist, who did not receive the invitation, indicated willingness to participate

and joined the focus group. Eventually, two other therapists did not participate. Two focus groups were conducted, one for therapists working with young adult patients (focus group I, N=6) and one for therapists working with adult patients (focus group II, N=9). In Table 3, descriptive characteristics of the participants are presented.

Table 3: Descriptive characteristics of forensic therapists (Study 2)

Variable	**Focus group I (N=6)**	**Focus group II (N=9)**
Age, M *(SD)*	35.00 *(5.55)*	35.11 *(7.99)*
Females, n *(%)*	5 *(83.3%)*	8 *(88.9%)*
Position, n *(%)*		
Master psychologist or pedagogue	4 *(66.7%)*	3 *(33.3%)*
Healthcare psychologist (in training)	-	3 *(33.3%)*
Clinical psychologist (in training)	1 *(16.7%)*	3 *(33.3%)*
Systemic therapist	1 *(16.7%)*	-
Working experience, in years, n *(%)*		
< 5 years	1 *(16.7%)*	3 *(33.3%)*
5-10 years	2 *(33.3%)*	1 *(11.1%)*
> 10 years	3 *(50%)*	5 *(55.6%)*
Working experience forensic psychiatry, in years, n *(%)*		
< 5 years	4 *(66.7%)*	9 *(100%)*
5-10 years	1 *(16.7%)*	-
> 10 years	1 *(16.7%)*	-
Attitude toward mHealth in mental healthcare, M *(SD)* [a]	4.67 *(.52)*	3.89 *(.93)*
Attitude toward new technologies, M *(SD)* [a]	4.50 *(.55)*	3.22 *(1.30)*
Perceived proficiency in using new technologies, M *(SD)* [b]	7.75 *(1.41)*	6.72 *(2.68)*

Note. [a] Measured on a 5-point Likert scale with score 1 indicating a (very) negative attitude and 5 indicating a (very) positive attitude. [b] Graded on a 10-point scale, with 1 indicating no proficiency and 10 indicating excellent proficiency.

Results

Added value

In the first step of our analysis, we retrieved 39 codes from the two focus groups related to the added value of the Sense-IT app from therapists' perspective. These codes were categorized in themes and linked to the pre-defined levels in the questioning route. An overview of the results of this part of the coding process is presented in Figure 2.

On the therapist level, using the app to open up conversations was mentioned most frequently. One therapist noted:

I believe it's great to be able to discuss with patients, who sometimes already forgot what they did yesterday, (…) to zoom in on specific moments, to start talking about it. [T1, F1]

On the patient level, increasing interoceptive and emotional awareness was mentioned most. Therapists supposed the app could help patients to learn and experience how their body and mental state are connected, and that reminders could help to be aware of the signals the body is giving in everyday life. Furthermore, one therapist stressed the importance of these basal skills in the first stages of treatment:

I realize that body awareness precedes all those cognitive things. [T4, F2]

On the level of treatment itself, therapists most frequently mentioned the impact on out-of-session practice, thereby increasing transfer to everyday life. Therapists noted that wearing the smartwatch and using the app may also function as reminders for patients that they are in a process of learning to control their aggressive responses. They reported:

I suppose it can also help patients to be engaged in their treatment outside the therapy session. So it's easier to generalize what you are doing [in therapy]. [T4, F2]

The therapy does not end in the room, but continues in daily life. The watch could also be a reminder for patients. [T1, F2].

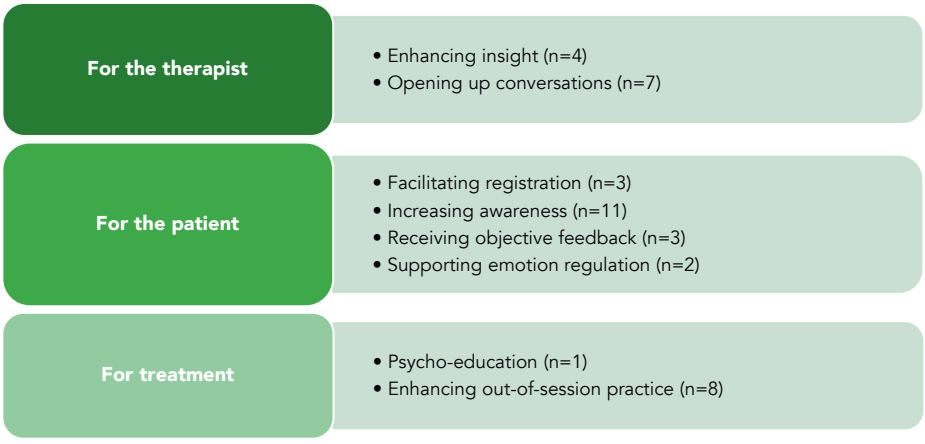

Figure 2. Patterns of meaningful responses (with code frequency) regarding the added value of the Sense-IT according to forensic therapists (Study 2).

Facilitators and barriers

In the second step of our analysis, 92 codes were retrieved on facilitators and barriers of implementation of the Sense-IT app in current treatment. The coded subthemes, as well as the later defined themes, were linked to the previously described levels (Grol & Wensing, 2004; Schreiweis et al., 2019). An overview of the results of this coding process is presented in Table 3.

Technical or innovation level

Usability was identified as an important issue for implementation. The limited ease of use of the app on a research-owned smartphone was discussed as a barrier in both focus groups. The use of the app on the patients' own smartphone was explicitly mentioned as a facilitator by the therapists of the young adult group. They explained that these patients almost never lose sight of their own phone. Therapists in this group also reported potential problems with the materials, such as loss or damage of the devices or charging cables. Furthermore, the simplicity of the rationale of the app – delivering concrete, real-time physiological feedback – was mentioned as a facilitator. Both groups discussed whether the design of the app was easy enough for patients with intellectual disabilities. However, the therapists did not reach a conclusion regarding the ease of use for this group, indicating that accessibility of the app for patients with intellectual disabilities might need further investigation.

Perceived accuracy of the app was also discussed as an essential factor. In the focus group among therapists working with adults, limitations in the perceived accuracy of the feedback were mentioned as a barrier. One of the therapists mentioned that receiving too many or perceived inaccurate notifications may reduce the likelihood of continued use of the app:

> *The app should provide notifications at the right moments (…) so that patients continue to take the app seriously.* [T1, F2]

Individual level – therapist

Workload was expected to be increased by implementing the app, and therefore identified as a barrier in both focus groups. Therapists expressed some concerns regarding the time and continuous attention needed for implementation of the app in their current routines. Therapists noted that there are already a lot of other topics to discuss during a therapy session. In order to maintain the use of a new intervention by patients, therapists reported that they would need to address this frequently during sessions. One therapist explained the investment of time would be large in the beginning, but probably less over time when therapists can take a more distant position.

Integration in treatment was mentioned as a facilitator of implementation in both focus groups. One therapist explained that it would be valuable to view a graphical overview of the patients' physiological values and notes over the last week, before or at the start of a therapy session, and discuss this with the patient. In the group among therapists of the adult population, integration of the Sense-IT app in creating a personal monitoring plan was suggested. Furthermore, therapists mentioned that the use of the Sense-IT app has to be an integral part of their treatment plan. These therapists indicated a need for criteria and guidelines, helping them to indicate whether the intervention would be beneficial for a particular patient.

Knowledge and skills of therapists were also identified as important factors. Limited proficiency in using technological interventions was mentioned as a barrier in both groups. In the focus group among therapists of young adults, the facilitating impact of technological skills and a positive attitude toward new technologies was also mentioned. In both groups, therapists expressed interest in and supported the relevance of becoming more familiar with the app by using it themselves. One therapist explained:

> *I can imagine that it helps if you can say, from your own perspective, that using the app can be a bit irritating at times. It might be useful to relate from your own experience.* [T6, F2]

Individual level – patient

Factors related to motivation were discussed in both groups. A lack of problem insight, or disagreement on the aggressive nature of specific behaviors, was identified as a barrier to implementation in one focus group. Both focus groups mentioned a certain amount of motivation (or at least ambivalence) to change as a facilitator and a lack thereof as a barrier. In one of the focus groups, using the app to increase motivation and problem insight was also discussed. Therapists also mentioned the ability to be open and receptive to feedback, which could be confronting or annoying, as an important issue. One therapist explained:

> *You need to have the courage to start looking at yourself.* [T3, F1].

Specific problems might also complicate implementation. In both groups, the feeling of being controlled by others was seen as a contra-indication for use of the app. Besides delusional and other psychotic disorders, disorders that involved an excessive focus on physiological sensations, for instance hypochondria, were also mentioned as barriers. Furthermore, therapists perceived the apps as most useful for patients with reactive aggression, and not indicated for patients with predominant instrumental or proactive aggression.

Knowledge and skills of patients were also discussed as important issues. Proficiency in using technological interventions was mentioned as a facilitator in both groups; and lack thereof as a barrier. Cognitive problems or intellectual disabilities were identified as barriers in both groups, although the app was also perceived as particularly helpful for this group of patients since they often lack insight into the (physiological) signals that precede aggressive behavior. Therapists in both groups expressed some concerns that patients would lose or sell the devices. They therefore discussed the ability to take adequate care of the devices and a certain degree of responsibility for others' belongings as prerequisites for borrowing materials. In the young adult group, practical issues related to unstable circumstances such as homelessness, were also mentioned as barriers.

Environmental and organizational level – social context
Expertise within the team was seen as an important facilitator (and lack thereof as a barrier) for sustainable use of the app in both groups. Therapists discussed the risk of dilution in case no one within the therapists' team felt ownership of the app. One therapist suggested a special interest group, whereas another proposed to appoint one therapist per team as an expert in using the app. This last suggestion that was supported by the members of the other focus group. One therapist stressed the importance of expertise, by reporting:

> *If all therapists just occasionally use the watch, then all lack proficiency* [T3, F1].

Environmental and organizational level – organizational context
Time to get familiar with the app was explicitly mentioned as a facilitator in one of the focus groups. This is related to the expectation of added workload associated with the addition of the app in current therapy. One therapist reported:

> *If spending a lot of time on the app at the start is facilitated at the organizational level, then it can be done.* [T4, F1]

Materials were also discussed in both teams. Therapists working with young adults stressed the facilitating impact of having the devices directly available in their offices. They explained that this is not only helpful to introduce the app to their patients, but also to initiate using the app when the moment is right. Therapists made clear that they have no desire to fill in (extensive) application forms; they would like the organization to provide them with materials in an uncomplicated way. Furthermore, both groups discussed the lack of clear agreement on use of devices by patients as barriers. Therapists in both groups explained that it would be helpful if the organization provided a kind of contract in which agreements on loss, theft, and liability are included.

Environmental and organizational level – political context
Knowledge and insight were briefly mentioned in both groups. Knowledge of effectiveness was mentioned as a facilitator in one group; whereas insight into costs and benefits was discussed as a facilitator and barrier in the other group. These therapists explained that more proof of the effectiveness of the app, and more information on the costs compared to treatment as usual, would increase their willingness to use the app and, thereby, the likelihood of successful implementation.

Other suggestions
The therapists provided us with a lot of other valuable suggestions regarding use and implementation of the Sense-IT app, which will be used to inform the further process. In the context of this paper, two topics are highlighted. First, most therapists recommended the use of the app in the first phases of treatment, in order to increase awareness of physiological signals that precede aggressive behavior. Fewer therapists suggested the use of the app in later phases of treatment; one therapist reported focusing on motivation first, whereas another suggested using the app during therapy sessions to evaluate different emotion regulation strategies. Second, therapists working with young adults explored the opportunities of a more systemic approach. Therapists mentioned that the use of the Sense-IT could probably increase awareness among system members as well, and might help to enable system members to adequately support the patient in moments when physiological tension elevates.

Table 3: Results of the coding process of facilitators and barriers of implementation of the Sense-IT app in current treatment, as mentioned by forensic therapists (Study 2)

					Focus group I		Focus group II	
Levels Schreiweis et al. (2019)	**Levels** Grol & Wensing (2004)	**Codes** (n=92)	**Themes**	**Subthemes**	**F**	**B**	**F**	**B**
Technical	**Innovation**	n=13	Usability	(Limited) ease of use	x	x		x
				Problems with materials		x		
				(Limited) simplicity	x	x	x	
			Perceived accuracy	Limited perceived accuracy				x
Individual	**Therapist**	n=28	Workload	Added workload		x		x
			Integration in treatment	Integration in treatment	x		x	
			Knowledge and skills	(Limited) technological skills	x	x		x
				Familiarity with the app	x		x	
	Patient	n=33	Motivation	Lack of problem insight		x		
				(Limited) openness to feedback	x	x		x
				(Limited) motivation	x	x	x	x
			Specific problems	Feeling controlled		x		x
				Specific psychiatric characteristics		x	x	x
			Knowledge and skills	(Limited) technological skills	x	x	x	x
				Cognitive problems		x		x
				(Not) taking care of materials	x	x		x
				Practical issues		x		
Environmental organizational	**Social context**	n=3	Expertise	(Limited) expertise in team	x	x	x	x
	Organizational context	n=12	Time	Providing sufficient time	x			
			Materials	(Lack of) clear agreements	x	x	x	
				(Problems in) providing materials	x	x	x	
	Political and economic factors	n=3	Knowledge and insight	Knowledge of effectiveness			x	
				(Limited) insight into costs and benefits	x	x		

Note. Therapists working with young adults participated in focus group I and therapists working with adults in focus group II. F refers to facilitators and B to barriers of implementation.

DISCUSSION

Principal findings

The aim of the current study was to provide insight into the perspectives of both forensic psychiatric outpatients and therapists on the use and implementation of the Sense-IT biocueing app in aggression regulation therapy (ART). More specifically, we aimed to obtain a more in-depth understanding of facilitators and barriers to implementation, which could be used as guideposts for future research and clinical practice. Findings from both studies indicate an overall positive attitude toward the addition of a biocueing intervention in forensic therapy, with increased interoceptive and emotional awareness as most frequently and commonly mentioned advantage. Main barriers on the technical or innovation level mentioned by both patients and therapists were several usability issues (i.e., limitations in the ease of use such as connectivity and notification issues, limitations in the ability to personalize settings, problems related to the devices such as a limited battery life of the smartwatch) as well as limitations in the perceived accuracy of the feedback. For the individual therapist, added workload and limited technological skills were perceived as barriers, while integration in treatment and familiarity with the app were mentioned as facilitators. For the individual patient, motivation, and knowledge and skills were discussed as both barriers and facilitators of implementation success. Specific psychiatric problems (i.e., paranoia, hypochondria) were identified as barriers.

On the environmental and organizational level, sufficient expertise within the therapists' team was seen as a prerequisite for implementation. For organizations, providing time to get familiar with the innovation and providing (clear agreement on use of) materials were identified as important facilitators. More knowledge and insight into (cost-)effectiveness of the intervention was identified as a political or economic factor influencing uptake by therapists.

The findings regarding the perceived advantages of the Sense-IT biocueing app resonate with the results of previous mHealth studies. Increased awareness (mentioned by both patients and therapists) and the ability to open up conversations by zooming in on specific situations (mentioned by therapists) align with earlier described benefits of mHealth (Gagnon et al., 2015; Schreiweis et al., 2019). Extending the reach of therapy by out-of-session practice (mentioned by therapists), thereby enhancing treatment adherence and facilitating the treatment process, has also been identified as one of the unique opportunities of mobile apps (Price et al., 2014). This is particularly important, since motivation, problem insight, and treatment adherence are typically low in forensic populations. The potential of e- and mHealth for forensic populations (Kip et al., 2018) seems also supported by the positive attitude toward new technologies and perceived proficiency in using these technologies of the participating forensic outpatients and therapists working with young adults.

Barriers and facilitators identified in the focus groups were linked to the three factors associated with eHealth implementation (Schreiweis et al., 2019) and the levels of a more general implementation model (Grol & Wensing, 2004).

The disadvantages mentioned by the patients corresponded to a large extent to the barriers on the technical or innovation level discussed by the therapists. Since the forensic outpatients actually used the Sense-IT app, they could provide us with more specific information on the limitations in usability and perceived accuracy of the feedback. Important usability issues were connectivity and notification issues, restricted ability to customize settings, other design preferences, limited battery life, and the use of a research-phone. Although the overall usability of the app turned out acceptable, it is important to resolve these issues since end-users tend to stop using a health app when their preferences and goals are not met (Torous et al., 2019). One patient suggested running the app on the smartwatch itself, which has been implemented in a new version of the app. Outside the research context patients will be able to use their own smartphones and to customize the settings themselves, which is also believed to enhance usability. Self-adjustment of the settings, as well as the suggested pause button, could also help to reduce irritation and disappointment caused by the number of notifications and perceived inaccurate feedback. Although irritation might be partly explained by limitations in frustration tolerance among forensic outpatients, feelings of disappointment might also originate from (very) high expectations of what the app should deliver. Although biocueing interventions can identify substantial increases in arousal by measuring heart rate, they are unable to provide an unique and specific recognition of subjectively experienced stress or specific emotion categories (Siegel et al., 2018). As suggested in recent research in which patients' reported similar feedback (Bosch et al., 2022; Van Doorn et al., 2022), a more detailed explanation of biocueing might help to create more realistic expectations.

The barriers identified at the individual therapist level, added workload and limited technological skills, have been identified in earlier reviews (Price et al., 2014; Schreiweis et al., 2019). Integration of the e- or mHealth intervention in regular treatment and familiarity with the system have also been listed as two of the most important facilitators of implementation (Price et al., 2014; Schreiweis et al., 2019). These factors also relate to the level of adoption of these interventions, as described in the Levels of Adoption of eMental Health Model (Feijt et al., 2018). According to this model, the adoption levels of the majority of the participating therapists could be considered as minimal use (Level 2) or passive use (Level 3); a smaller proportion would fit in the category of active users (Level 4). In the current sample, the highest scores on attitude toward new technology and the use of mHealth, as well as on perceived proficiency in using new technologies, were found among the therapists working with young adults, which might parallel the usually higher efficacy in using new technological interventions found among young people (Zhao et al., 2018).

On the individual patient level, therapists indicated a certain amount of motivation and problem insight as a prerequisite to benefit from the biocueing intervention. However, other therapists also saw potential to use the app as a means to increase problem insight. This difference might be related to the two components of the Sense-IT biocueing app: increasing interoceptive awareness and delivering just-in-time behavioral support. While the second component might require some problem awareness and receptivity to feedback, as demonstrated in another biocueing study (Lentferink et al., 2021), this might not be necessary to benefit from the first component. Regarding knowledge and skills, patients rated their proficiency in using new technologies as high and the simplicity of the app as an advantage. However, therapists discussed whether the current version of the Sense-IT app was accessible enough for patients with intellectual disabilities. Therefore, accessibility and potential adaptations for this particular group could be further assessed in future research (De Looff, Nijman, Didden, & Noordzij, 2021; Korczak & Zwierzchowska, 2020; Vázquez et al., 2018). Concerns of forensic therapists about young adults' ability to take care of the devices should be taken into account, although in this study only two devices were not returned by patients. Furthermore, lack of trust and the sense of feeling controlled by others were identified as contraindications for use of the Sense-IT app. While these feelings may occur in the context of a psychiatric disorder, they might also originate from legitimate concerns to become an object of surveillance and persuasion, as commercial apps often own the right to share and sell collected personal health data (Glenn & Monteith, 2014) and health-related suggestions can start to feel as an invasion of personal space (Lupton, 2012). In our study, we accounted for these issues by ensuring data safety using local storage and by stressing the voluntary nature of participation.

Finally, on the environmental and organizational level, most barriers were addressed in the organizational context. The need expressed by the therapists to be provided with sufficient time and material by their management is also identified as an important implementation factor in literature (Price et al., 2014; Schreiweis et al., 2019). To avoid ambiguities, which might interfere with the therapeutic process, therapists also recommended clear agreements on the use of smartwatches (and smartphones, if applicable) by patients. Also mentioned for successful implementation were the importance of expertise within the therapists' team as well as the need for more information on effectiveness and cost-effectiveness, which has earlier been reported as essential for providing a solid embedding of new interventions in the healthcare system (Titzler, Saruhanjan, Berking, Riper, & Ebert, 2018).

Strengths and limitations

Several strengths are present in the current study. First of all, we were able to assess the experiences and perspectives of forensic outpatients, who are often hard to engage in clinical research. Most participants seemed to enjoy delivering feedback

on how to improve the Sense-IT app. Second, we combined the information of forensic outpatients with the input of forensic therapists, in order to obtain a more complete overview of barriers and facilitators associated with implementation. To do so, we combined a more general implementation model with a more specific e-health implementation model. Finally, this study was well embedded in daily clinical practice, thereby enhancing ecological validity and translation of these research results into real-world situations.

Our study also had several limitations. In both studies, attitudes toward new technologies (and mHealth) as well as perceived proficiency in using those technologies were assessed using self-developed Likert-scale questions. The use of recently developed and validated scales, such as the eMental Health Adoption Readiness scale (Feijt et al., 2021), could have contributed to a more accurate assessment of this highly relevant aspect of e- and m-Health implementation. In the study among forensic outpatients, several factors related to the research design (such as the use of a research-owned smartphone and the restricted ability to customize settings) impeded the usability, which might have influenced the overall experience with the Sense-IT app negatively. Furthermore, as both studies were conducted within one forensic outpatient organization, some barriers and facilitators might not apply to other organizations. Finally, since the moderator has been working as a scientist-practitioner at the organization over the past years, this might have created some positive bias in the responses.

Implications for future research and practice

Besides the suggestions for further improvement of the Sense-IT app and other issues requiring attention (i.e., perceived accuracy of the app, accessibility for patients with mild intellectual disabilities as well as ethical concerns regarding surveillance and persuasion), this study provided a lot of information to guide the further implementation process. Since the implementation of e- and m-Health largely depends on the providers of these interventions (Whitten & Mackert, 2005), the individual and team differences in adoption readiness should be taken into account (Balapour et al., 2019; Feijt et al., 2018). Considering the adoption levels of the majority of the therapists, implementation should first be focused on enhancing integration in daily routines and, after that, on increasing familiarity and affinity with the intervention. Active users could be given a role as experts within the teams, supporting their colleagues to explore the possibilities of the new intervention.

For using the app in clinical practice, therapists and patients provided several suggestions. Important to note is that the application possibilities might be expanded and re-evaluated for new, ameliorated versions of the Sense-IT app. According to the majority of the therapists, the current version of the Sense-IT biocueing app would be most useful in the first phases of treatment, in order to increase interoceptive

awareness. When patients display a certain amount of motivation to change and receptivity to feedback, they might also benefit from the just-in-time behavioral support delivered by the Sense-IT app. Since this involves a reminder to use coping skills to reduce stress, it is necessary that the therapist has already discussed emotion regulation strategies with the patient and that the behavioral support message is prepared in collaboration. Patients indicated that the app was most helpful in difficult situations, and was perceived as disturbing in relaxed situations, during exercise, or when they already felt too stressed or tired. This emphasizes the need to further adapt these new interventions to deliver mental health support at precisely those moments, when they are most likely to be effective (Bidargaddi et al., 2020). Biocueing interventions therefore align well with the already initiated shift toward personalizing treatment in mental healthcare (Berrouiguet et al., 2018; Fröhlich et al., 2018). In development and implementation of these interventions, it is important to aim for an optimal fit between user experience, effectiveness, privacy and data safety, and data integration in treatment routines (Torous et al., 2019).

Conclusions

Forensic outpatients and therapists demonstrated a positive attitude toward the addition of a wearable sensor-based mHealth intervention, the Sense-IT biocueing app, in aggression regulation therapy (ART). Increased interoceptive and emotional awareness were mentioned as advantages by both patients and therapists. However, to maximize the potential of these interventions, several important barriers and facilitators should be addressed. Whereas forensic outpatients mainly reported technical or innovation-related barriers, therapists provided us with a more in-depth understanding of barriers and facilitators on individual and organizational levels. A substantial part of the technical or innovation-related barriers is related to the developmental stage of the app and its use in a research context, and therefore quite easy to address. Furthermore, whereas some individual patient barriers apply specifically to forensic patients, most factors should also be carefully considered in other populations with emotion regulation difficulties. On the individual therapist and organizational level, providing time and materials supporting integration in daily routines and enhancing affinity with the new intervention are identified as important facilitators of implementation, and therefore highly recommended. In the further implementation process, individual and team differences in readiness for adoption of mHealth should be considered, assigning a central role to active users as experts within the teams. Finally, as further development of biocueing interventions is expected, new and personalized application possibilities might be discovered and investigated on the level of the individual patient, aligning with the trend of personalizing treatment interventions in mental healthcare.

CHAPTER 6

Neurobiological Responses toward Stimuli Depicting Aggressive Interactions in Delinquent Young Adults and Controls: No Relation to Reactive and Proactive Aggression

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ABSTRACT

Neurobiological measures underlying aggressive behavior have gained attention due to their potential to inform risk assessment and treatment interventions. Aberrations in responsivity of the autonomic nervous system and electrophysiological responses to arousal-inducing stimuli have been related to emotional dysregulation and aggressive behavior. However, studies have often been performed in community samples, using tasks that induce arousal but not specifically depict aggression. In this study, we examined differences in psychophysiological (i.e., heart rate, respiratory sinus arrhythmia, skin conductance level) and electrophysiological responses (i.e., P3, late positive potential, mu suppression) to aggressive versus neutral scenes in a sample of 118 delinquent young adults and 25 controls (all male, aged 18–27). With respect to group differences, we only found significant higher SCL reactivity during the task in the delinquent group compared to controls, but this was irrespective of condition (aggressive and neutral interactions). Within the delinquent group, we also examined associations between the neurobiological measures and reactive and proactive aggression. No significant associations were found. Therefore, although we found some indication of emotional dysregulation in these delinquent young adults, future studies should further elucidate the neurobiological mechanisms underlying emotional dysregulation in relation to different types of aggression.

INTRODUCTION

Aggressive and violent behavior in young adulthood is a major concern in forensic psychiatry and society, given the negative impact of concomitant social problems and delinquency on victims and perpetrators, as well as the high costs for health care and society (Cohen, 2020; De Looff et al., 2021a). Although treatment-associated risk reductions in violent recidivism have been reported in several studies (Henwood et al., 2015), the current overall efficacy of psychological and psychosocial interventions aimed at reducing aggressive behavior in forensic patients is found to be limited (Brännström et al., 2016; McIntosh et al., 2021).

Over the last years, studies focusing on neurobiological factors of aggression have increased (for an overview, see (Wagels, Habel, Raine, & Clemens, 2022)), aiming to improve risk assessment and treatment of aggressive behavior (Popma & Raine, 2006). One of the underlying mechanisms that is found to be disrupted in aggressive behavior is emotion regulation (Garofalo, Neumann, & Velotti, 2020; Smeijers, Benbouriche, & Garofalo, 2020). Studies on the neurobiology of emotion regulation in delinquents have mostly examined either structural or functional brain correlates or used psychophysiological or electrophysiological measures. Thus, neurobiological measures are rarely jointly studied in relation to aggression (Blankenstein et al., 2021). In addition, studies often have focused on antisocial behavior more generally, leaving aggressive behavior less specifically addressed. For instance, a recent review of neuroimaging of psychopathic traits (Johanson, Vaurio, Tiihonen, & Lähteenvuo, 2020) showed structural and functional impairments in psychopathy, antisocial personality disorder and conduct disorder to be related to frontotemporal, limbic, paralimbic and cerebellar regions. However, in that review, no studies on aggression in general, nor to reactive or proactive aggression more specific were discussed. In the current study, we therefore examined both psychophysiological and electrophysiological responses toward aggressive scenes in delinquent young adults and controls and examined associations between these neurobiological measures and two different types of aggressive behavior.

Aggressive behavior can be classified in multiple ways, for example according to expression (physical vs. verbal aggression) or nature (direct vs. indirect aggression). In treatment of aggression, clarifying the intentions to engage in aggressive behavior is highly relevant. The most used differentiation in aggressive behavior, reactive vs. proactive aggression, is based on this motivational aspect (Dodge & Coie, 1987). Whereas reactive aggression is defined as an impulsive response to a provocation or threat, rooted in the frustration-aggression theory (Berkowitz, 1993), proactive aggression is characterized by instrumental, premeditated behavior to achieve a secondary goal, explained by social learning theory (Bandura, 1978), fearlessness theory (Raine & Jones, 1987) or sensation-seeking theory (Eysenck, 1997). Although

these two dimensions of aggressive behavior, as currently operationalized in self-report questionnaires, are highly correlated (Cima & Raine, 2009; Hubbard, McAuliffe, Morrow, & Romano, 2010; Raine et al., 2006), several studies have demonstrated unique predictors for both constructs. For example, researchers have found that although antisocial behavior is related to both reactive and proactive aggression, reactive aggression is uniquely related to a hostile interpretation bias (Lobbestael, Cima, & Arntz, 2013). Moreover, impulsivity and self-control are found to be uniquely related to reactive aggression (Latzman & Vaidya, 2013), while amongst others, psychopathic personality (Fite, Raine, Stouthamer-Loeber, Loeber, & Pardini, 2010; Raine et al., 2006) and lower attentional bias toward aggressive words (Brugman et al., 2015) are uniquely predictive of proactive aggression. These findings suggest that reactive aggression and proactive aggression may arise from distinct underlying (neurobiological) mechanisms.

Psychophysiological measures

Psychophysiology is a collective term for all neurobiological measures related to the activity of the autonomic nervous system (ANS), the human regulatory system which regulates respiration, heartbeat and sweat secretion. Whereas some measures provide an indication of general ANS functioning, other measures are indicative of activity of one of the branches of the ANS: the sympathetic nervous system (SNS; the 'accelerator') or parasympathetic nervous system (PNS; the 'brake'), which usually cooperate in a reciprocal way. Furthermore, measures can be taken at rest or in response to arousal-inducing events (i.e., reactivity measures), such as exposure to social stressors, provocation or emotion-eliciting pictures or film clips. In aggression research, lower heart rate (HR) at rest has most consistently been found to be positively associated with antisocial behavior in general and proactive aggression, although the overall effect size is found to be small (De Looff et al., 2021a; Portnoy & Farrington, 2015). However, the findings regarding reactivity of the ANS, SNS and PNS, which is the focus of our study, are less robust.

Considering general ANS reactivity, with HR as indicator, meta-studies have shown increased HR during stressor tasks among antisocial youth, see (Ortiz & Raine, 2004) for a meta-analysis, and small positive associations between aggression and HR reactivity to emotional stimuli with a negative valence (Lorber, 2004). Furthermore, increased HR reactivity to provocation is found to be associated with reactive violence, but also with nonviolent delinquency (Crozier et al., 2008). However, other studies did not support these findings (Puhalla & McCloskey, 2020; Wagner & Abaied, 2015). Proactive aggression is found to be uniquely associated with blunted HR activity (Puhalla & McCloskey, 2020), but see (Zijlmans, Marhe, et al., 2021), for contradictory results.

Research results regarding SNS reactivity, indicated by skin conductance level (SCL), are mixed as well. Reactive aggression is found to be associated with heightened SNS reactivity in response to provocation (Armstrong et al., 2019; Moore et al., 2018; Murray-Close et al., 2017; Thomson et al., 2021) and fear (Centifanti et al., 2013). In contrast, proactive aggression has been linked to blunted skin conductance reactivity (Centifanti et al., 2013; Hubbard et al., 2002; Murray-Close et al., 2017), although no association has also been reported (Wagner & Abaied, 2015, 2016).

Research findings for the PNS, with respiratory sinus arrhythmia (RSA) as indicator, are equivocal as well. Increased RSA withdrawal in anger-inducing situations has been linked to externalizing symptoms (Gatzke-Kopp, Greenberg, & Bierman, 2015) and self-regulation deficits in antisocial youths (Beauchaine & Thayer, 2015). With regard to reactive aggression, RSA withdrawal is found to be positively associated with reactive aggression (Zhang & Gao, 2015), although no associations have been reported as well (Wagner & Abaied, 2015, 2016). Proactive aggression is more consistently found to be related to blunted PNS reactivity (Murray-Close et al., 2017; Patrick, 2014; Wagner & Abaied, 2016).

Given these mixed reactivity outcomes, the support for theoretical models stating that reactive aggression is associated with heightened arousal or hyper-reactivity of the ANS and that proactive aggression is related to low arousal or hypo-reactivity of the ANS (Fanti et al., 2019; Puhalla & McCloskey, 2020), is limited. Furthermore, in recent research the association between aggressive behavior, emotion regulation and the interaction of the two branches of the ANS is highlighted (Branje & Koot, 2018; Puhalla & McCloskey, 2020). According to this view, reactive aggression results from coactivation of the SNS and PNS, while proactive aggressive might stem from co-inhibition of both systems (El-Sheikh et al., 2009; Hubbard et al., 2002; Raine, 2008). Building on this, researchers suggest that aggressive behavior can be better predicted by the interaction between SNS and PNS than by hypo- or hyperreactivity of each of these subsystems alone (Moore et al., 2018; Puhalla & McCloskey, 2020).

Electrophysiological measures

Electroencephalography (i.e., EEG) is an electrophysiological measure that assesses electrical activity via electrodes at the scalp level. Common EEG indices are event-related potentials (i.e., ERPs) and frequency power. ERPs are responses to particular events (i.e., stimuli) and are time locked to that event. For instance, two well studied ERPs related to emotion regulation and arousal are the P3 and late positive potential (LPP) between 300 and 700 ms post-stimulus over centro-parietal regions (Lang & Bradley, 2010; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). These ERPs are found to be associated with directed attention and evaluation of stimuli and are also found to be modulated by emotion. This means that when emotional arousal

levels rise, the amplitudes of these ERPs also increase. Therefore, P3 and LPP in affective picture processing tasks are often used as correlates of emotional arousal and emotion regulation indices (Schubring & Schupp, 2019).

Generally, attenuated P3 amplitudes are found to be related to externalizing behavior, including antisocial behavior and aggression (Bernat, Hall, Steffen, & Patrick, 2007; Gao, Raine, Venables, & Mednick, 2013) indicating the ineffective processing of salient affective stimuli. It has been demonstrated that within the normal population, individuals who self-reported as being reactive aggressive, presented with significantly lower P3 amplitude in frontal electrode sites compared with non-aggressive controls (Gerstle, Mathias, & Stanford, 1998). In contrast, proactive aggressors are found not to show this reduced P3 component characteristic of impulsively aggressive individuals (Barratt, Stanford, Kent, & Alan, 1997; Stanford, Houston, Villemarette-Pittman, & Greve, 2003). However, it has also been found that both reactive and proactive aggression are associated with attenuated P3 amplitudes (Helfritz-Sinville & Stanford, 2015).

With respect to the LPP, findings are also mixed. While in one study, it was found that higher aggressive individuals showed an attenuated LPP in reaction to violent pictures (Kunaharan, Halpin, Sitharthan, & Walla, 2019), and that this attenuation was linked to impulsivity scores in that group. Another study (Gagnon et al., 2017), found an increased LPP was associated with impulsive (reactive) aggression in aggressive individuals, indicating more arousal toward these as hostile interpreted situations.

Assessing event-related brain perturbations in terms of its frequency characteristics can provide unique insights into emotional stimulus processing. Specifically, event-related oscillations not only assess stimulus-evoked oscillations akin to the traditional ERP analysis but also induced oscillations, which are not phase locked to the stimulus event. Frequency power is the oscillatory activity measured in a particular frequency band (i.e., delta, theta, alpha, beta and gamma), and activity in each of these frequency bands have been found to be related to particular cognitive characteristics. For instance, theta-band (4–8) oscillations have been found to be associated with memory and cognitive control (Cavanagh & Frank, 2014), while alpha power is generally associated with spatial attention (Otten & Jonas, 2014).

Several studies assessed event-related oscillations associated with emotional stimulus processing. However, findings are difficult to integrate because studies focus on different frequencies, time windows, topographies and variations in task instructions. However, generally the processing of emotionally arousing (pleasant and unpleasant) compared to neutral stimuli (i.e., words; (Otten & Jonas, 2014), facial expressions (Balconi & Mazza, 2009; Furl, Lohse, & Pizzorni-Ferrarese, 2017; Knyazev, Bocharov, Levin, Savostyanov, & Slobodskoj-Plusnin, 2008; Popov, Miller,

Rockstroh, & Weisz, 2013; Popov, Steffen, Weisz, Miller, & Rockstroh, 2012) and images from the International Affective Picture System (IAPS) (Cui, Zhong, Xu, Gong, & He, 2013; De Cesarei & Codispoti, 2011; Mennella, Patron, & Palomba, 2017) are often associated with a decrease in alpha power (i.e., event-related desynchronization; ERD). This indicates that alpha ERD is related to emotional arousal (Schubring & Schupp, 2019, 2021).

With respect to aggression, previous studies using resting-state EEG found decreased alpha power in centro-parietal regions to be related to psychopathic personality in violent offenders (Calzada-Reyes, Alvarez-Amador, Galán-García, & Valdés-Sosa, 2013). A more recent study showed that alpha ERD at frontal sites was related to aggression and retaliation (Wang et al., 2021), providing support for the idea that aggression results from a decrease in self-control, including dysfunctional emotion regulation.

Interestingly to add, both the LPP and alpha ERD have been found to be similarly modulated by affective arousal (De Cesarei & Codispoti, 2011), pointing to the relevance to study those two correlates conjointly. Interestingly, recent findings show alpha desynchronization specifically at central-parietal electrodes (which is sometimes referred to as mu suppression) in the 500–1000 ms time range to be associated with empathy during vicarious pain (Zebarjadi et al., 2021). This time range is consistent with the time window in which the LPP is typically found.

Study aims

In sum, research into the neurobiological mechanisms underlying aggressive behavior has gained attention over the last years due to their potential to inform risk assessment and development of tailored treatment interventions to reduce aggressive behavior. However, studies are often performed in community samples, using resting-state data or neuropsychological tasks that induce arousal but not specifically depict aggressive behavior. Furthermore, results remain inconsistent and neurobiological measures are rarely studied conjointly [10]. Therefore, the aim of our study was to examine differences in psychophysiological (i.e., HR, RSA, SCL) and electrophysiological responses (i.e., P3, LPP, mu suppression) between delinquent young adults and controls in a passive viewing task depicting aggressive and neutral interactions. Within the delinquent group, we also examined associations between these neurobiological measures and reactive and proactive aggression.

In line with the literature, we hypothesized emotion dysregulation to be present in the delinquent group, but not in the control group. Given the mixed findings in previous research, we expected altered reactivity of the ANS measures in the delinquent group compared to the control group. For the electrophysiological measures, we expected decreased ERP amplitudes and less alpha ERD/mu

suppression in the delinquent group compared to the control group. Furthermore, for the psychophysiological reactivity measures, we expected positive associations with reactive aggression (primarily SCL and HR) and negative associations with proactive aggression (primarily RSA). In addition, electrophysiological reactivity measures were expected to be specifically negatively related to reactive aggression.

MATERIALS AND METHODS

Participants

In total, 154 young adult men participated in the neurobiological part of a larger study (Luijks et al., 2017). In 11 participants, both psychophysiological and electrophysiological data were not properly recorded, stored, or otherwise missing. We therefore studied a group of 143 young adults, all male, aged 18–27 years (M = 22.60, SD = 2.43). The experimental group (*N* = 118) consisted of young adults with social, psychological and addiction problems, almost all with a history of delinquent behavior, following a multimodal day-treatment program at De Nieuwe Kans, a day-treatment center in Rotterdam, the Netherlands (Zijlmans, van Duin, et al., 2021). This program employs cognitive behavioral techniques and rehabilitation components, such as cognitive skills training, drug treatment and education [72]. The participants were recruited at the start of their treatment program at De Nieuwe Kans. Age-matched controls (*N* = 25) were recruited at colleges for intermediate vocational training in Rotterdam and selected to have education levels that matched the delinquent sample. Demographic information for each group is displayed in Table 1. All participants provided written informed consent. The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Medical Ethics Committee of the VU University Medical Center (registration number 2013.422–NL46906.029.13). Participants received 30 euros for participation in this part of the study.

Questionnaires

For this study, two questionnaires were selected from a larger test battery. A self-developed questionnaire was used to assess demographic characteristics (age, gender, ethnicity, education level and history of delinquent behavior). To assess the two differently motivated types of aggressive behavior, the Reactive Proactive Questionnaire (RPQ) (Raine et al., 2006), a 23-item self-report measure, was administered. The RPQ uses a 3-point Likert scale (0 = never, 1 = sometimes, 2 = often) to assess physically and verbally aggressive behaviors as well as anger in response to external stimuli. The two-factor structure of the original RPQ was also found for the Dutch version. Convergent validity of this version was reported as adequate (all r's > 0.16) and test–retest stability as good (all ICC's > 0.41) in a validation study (Cima, Raine, Meesters, & Popma, 2013).

Table 1. Demographic variables for delinquent young adults and controls (*N* = 143).

	Delinquent Young Adults (*N* = 118)	**Aged-Matched Controls (*N* = 25)**
Age	22.54 (2.41)	22.86 (2.55)
Ethnicity	21 (17.8)	11 (44.0)
Western	23 (19.5)	6 (24.0)
Surinamese	29 (24.6)	2 (8.0)
Caribbean	20 (16.9)	1 (4.0)
Moroccan	8 (6.8)	-
Cape Verdean	17 (14.4)	5 (20.0)
Other non-Western		
Education	31 (26.3)	17 (68.0)
Senior secondary education	37 (31.3)	7 (28.0)
Junior secondary education	43 (35.4)	1 (4.0)
Primary education	7 (5.9)	-
None		
Past offenses (official records)	23 (19.5)	-
0	55 (46.6)	-
1–5	24 (20.3)	-
5–10	16 (13.6)	-
>10		
Lifetime delinquency (self-report)	79 (67.5)	-
Destruction/public order offense	98 (85.2)	-
Property offense	79 (68.7)	-
Aggression/violent offense	49 (42.6)	-
Weapon offense	71 (61.2)	-
Drug offense	112 (95.7)	-
Any offense		

Note. Values are presented as mean (SD) for continuous variables or *n* (%) for categorical variables

Materials

Passive Picture Viewing Task

To induce arousal, a passive viewing task with pictures of aggressive and neutral interactions was used (see Figure 1). This task was originally developed to assess empathic processing and is described in greater detail by the developers (Van Dongen, Brazil, Van der Veen, & Franken, 2018). The task consists of 40 picture pairs, with either two male protagonists or one male and one female, all between 20 and 25 years of age. The male actors had a white complexion, and the female had a black skin tone. In all but one of the aggression scenes, in which physical, sexual, and verbal aggression were depicted, a male individual was the perpetrator. All neutral pictures were pairwise matched to the aggressive pictures, using the same persons, location, colors and light. Three types of pictures were used in our

experiment: (a) 40 pictures depicting a violent interaction between two individuals; (b) 40 pictures depicting a neutral interaction between two individuals; and (c) 15 pictures depicting neutral objects (i.e., filler items), which were not used for further analyses. A total of 95 pictures were randomly presented for 6 s with intervals of 1.8 s between the pictures. All pictures were presented in full-screen mode on a color monitor located at approximately eye level about 1.5 m in front of the participants. Participants were instructed to passively look at each picture.

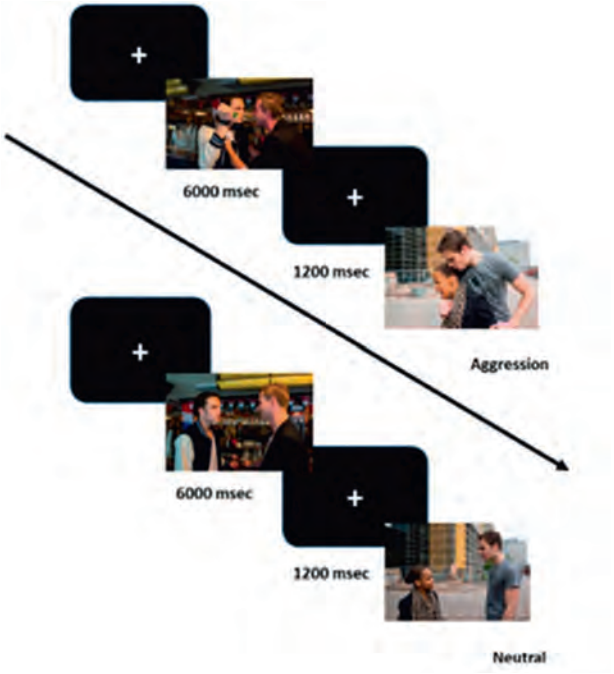


Figure 1. Passive viewing task with pictures of aggressive interactions and neutral interactions serving as control pictures.

Psychophysiological Measures

Psychophysiological measures were collected at the Erasmus Behavioral Laboratory of the Institute for Psychology at the Erasmus University Rotterdam, using the VU Ambulatory Monitoring System (VU-AMS, Amsterdam, The Netherlands) (Klaver, De Geus, & De Vries, 1994). During the neuropsychological test-paradigm, participants were seated in a comfortable chair in a sound-attenuated room with dimmed lights. A sampling rate of 1000 Hz was used. Placement of the five ECG Micropore electrodes (Kendall H98SG) for electrocardiography (ECG) and impedance cardiography (ICG) was carried out according to the VU-AMS manual (http://www.vu-ams.nl/support/instruction-manual/, last accessed on 24 November 2021). Two

skin conductance electrodes (Biopac TSD203) were placed on the medial phalanges of the middle and index finger of the non-dominant hand, using isotonic electrode gel (4 OZ, GEL101). Participants were instructed to move as little as possible and not to touch the electrodes.

Data preparation was performed following the instructions in the VU-AMS manual. In this study, we focused on HR, RSA and SCL during the passing viewing task. HR and RSA were both derived from ECG and ICG measures by the VU-AMS system. HR was assessed by automated counting of R peaks (beats per minute) and RSA was calculated by distracting the shortest period between heart beats during inspiration from by the longest period between heart beats during expiration. SCL (in microSiemens) during the task was automatically registered by the VU-AMS system.

Data processing, including R-peak time series analysis, took place using automated detection algorithms of the VU-AMS Data, Analysis and Management Software (VU-DAMS, Amsterdam, The Netherlands). Suspected Inter Beat Intervals (IBI's), relevant for both HR- and RSA-analysis, were manually checked for artefacts as well as missing or incorrect R-peaks and adjusted if necessary. SCL-data were checked for artefacts and values outside the range recommended in the VU-AMS manual (<1 and >12). Extreme outliers, emerging from outlier analysis, were removed.

Electrophysiological Measures

Brain activity during the task was recorded with EEG using a Biosemi ActiveTwo System amplifier (Biosemi, Amsterdam, the Netherlands) and active Ag/AgCl electrodes at 32 standard (10–20 International System) scalp sites and two additional scalp sites (FCz and CPz). Four additional electrodes were used to measure vertical and horizontal electro-oculogram. They were placed above and below the left eye and at the outer canthi of the eyes, respectively. Two other additional electrodes were placed on the left and right mastoids. All signals were digitized with a sampling rate of 512 Hz and 24-bit analog-to-digital conversion and were filtered offline.

Data were processed offline using the Brain Vision Analyzer software (BVA, Brain Products, Gilching, Germany). First, the EEG signal was re-referenced offline to the linked mastoids. Because we were interested in both time (P3 and LPP) and frequency (alpha ERD) properties, segmentation was done per condition (aggression vs. neutral) in an interval between −200 and 1500 ms (ERPs) and −1000 and 3000 ms (alpha power) relative to stimulus presentation. Subsequently, data were filtered using a bandpass filter ranging from 0.01 Hz to 30Hz (phase shift-free Butterworth filters; 24 dB/octave slope, and the Gratton and Coles algorithm (Gratton, Coles, & Donchin, 1983) was used to correct for eye movements and blinks.

For the ERPs, a baseline correction was performed using a 200 ms pre-stimulus interval, and remaining artifacts (i.e., segments with an EEG signal exceeding an amplitude of 75 V) were removed. Visual inspection of the grand average ERPs at Pz (see Figure 2) revealed a clear positive wave, which was maximal for aggressive pictures between 300–400 ms after stimulus onset (i.e., the P3) and was followed by sustained slow wave activity (i.e., the LPP). For ERP analyses, the P3 amplitude was defined as the mean amplitude at Pz between 300 ms and 400 ms after stimulus onset (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). The LPP was defined by the mean amplitude at Pz between 500 ms and 1000 ms after stimulus onset (Hajcak, Dunning, & Foti, 2009). The average signals per condition were then used for determining ERP characteristics.

Figure 2. Grand average ERPs at Pz.

As we were also interested in the oscillations underlying the processing of these aggression pictures, we used time-frequency analysis to study the total alpha power at central sites (i.e., mu power) using Morlet wavelets. Because the processing of emotions and social interactions (including empathic processing) is most prominent in the right hemisphere (Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003; Singer, Kiebel, Winston, Dolan, & Frith, 2004), electrode site C4 was used for determining

alpha ERD (i.e., mu suppression). After segmentation, ocular correction and filtering, and remaining artifacts (i.e., segments with an EEG signal exceeding an amplitude of 150V) were removed. After preprocessing, we performed a wavelet analysis in the 1- to 80-Hz frequency range to obtain power values for the EEG activity at different time points for each segment and for each condition. We used a complex Gaussian Morlet wavelet (Morlet parameter set to 5) and 60 logarithmic frequency steps and averaged the obtained power values for each time-frequency point. Edge and smearing effects were accounted for by reducing the window of baselining and analyses, respectively, with half the wavelength (Herrmann, Grigutsch, & Busch, 2005). After averaging the total power per condition, we extracted the layer that best fitted the alpha band (between 8 Hz and 13 Hz). During data processing, data of any participant having fewer than 20 clean segments (i.e., half of the maximum number) per condition after artifact rejection were excluded from the analyses.

Data-Analysis

Neurobiological responses during the task and self-reported aggressive behavior were statistically evaluated using IBM SPSS 27 and R 4.0.2. First, we performed a descriptive and comparative analysis using Welch's tests (assuming unequal variances given the difference in sample size between both groups) on the behavioral and neurobiological measures. Second, to account for missing values (47.6% of the cases had missing data on one or more independent variables), multiple imputation was applied for predictors with a maximum missingness of 30%, creating 50 complete sets (White, Royston, & Wood, 2011). No data for dependent variables were imputed. Prior to imputation, Little's Missing Completely At Random (MCAR) test was employed; the data were MCAR ($\chi 2 = 69.730$, df = 199, $p = 1.000$). Datasets were imputed using Multivariate Imputation by Chained Equations (MICE) in R (Van Buuren & Groothuis-Oudshoorn, 2011). Third, predictor variables were tested for normality of distribution, homoscedasticity, linearity and multicollinearity. Residuals were normally and equally distributed and linearity was not violated. Multicollinearity was tested by inspecting Variance Inflation Factors (VIFs). None of the VIFs exceeded 10, indicating no dependency between the variables (Myers & Myers, 1990). Fourth, before running the main analyses, we performed pooled paired-sample t-tests over the entire sample to assess whether the task elicited expected neurobiological reactions during passive viewing of aggressive and neutral scenes. Fifth, we examined differences between delinquent young adults and controls in their neurobiological responses to aggressive and neutral scenes using six pooled Repeated Measures ANOVA's using a 2 (condition; aggression vs. neutral) by 2 (group; delinquent vs. control) design. Sixth, we further investigated whether and how the neurobiological responses were associated with reactive and proactive aggression within the delinquent young adult group. In this group, reactive and proactive aggression were moderately correlated ($r = 0.523$, $p < 0.001$). Since we were interested in the unique explanation of reactive and proactive

aggressive behavior, we performed two independent regression analyses. Two different regression analyses with pooled imputed data were performed, using the difference scores of the six neurobiological measures (aggression-neutral condition) as predictor variables. Cohen's rule of thumb was used to assess effect sizes (Cohen's *d*) with 0.2 being small, 0.5 being moderate, and 0.8 being large (J. Cohen, 1988). An alpha of 0.05 was used.

RESULTS

Descriptive Analysis

After data processing psychophysiological measures of 118 participants and electrophysiological measures of 129 participants were eligible for further analysis. Descriptive statistics and first comparative results of the behavioral and neurobiological measures (original, non-imputed data) are presented in Table 2.

Table 2. Descriptive statistics and comparative results of behavioral and neurobiological measures (N = 143).

	Delinquent Young Adults Mean (SD)	**Aged-Matched Controls Mean (SD)**	**Group Differences *p*-Value**
Behavioral measure	*(N = 118)*	*(N = 25)*	
Reactive aggression	11.38 (4.51)	8.76 (5.23)	0.026 *
Proactive aggression	5.02 (3.89)	4.00 (4.27)	0.280
Total aggression	16.40 (7.34)	12.76 (9.05)	0.069
Psychophysiological measures	*(N = 96)*	*(N = 22)*	0.981
HR-aggressive	65.70 (8.82)	65.75 (8.75)	0.975
HR-neutral	66.44 (8.70)	66.51 (8.63)	0.677
RSA-aggressive	91.24 (34.45)	95.58 (45.28)	0.849
RSA-neutral	95.33 (44.83)	93.40 (41.67)	0.004 **
SCL-aggressive	5.75 (2.65)	4.08 (2.13)	0.004 **
SCL-neutral	5.78 (2.68)	4.09 (2.13)	
Electrophysiological measures	*(N = 110)*	*(N = 19)*	
P3-aggressive	4.43 (6.19)	7.63 (4.57)	0.012 *
P3-neutral	4.72 (6.34)	6.25 (4.64)	0.221
LPP-aggressive	5.63 (4.67)	7.66 (4.47)	0.082
LPP-neutral	2.96 (4.70)	3.13 (4.16)	0.868
Mu power-aggressive	16.72 (14.32)	14.68 (9.27)	0.480
Mu power-neutral	17.58 (12.92)	15.90 (10.44)	0.574

Note. The means, SDs and *p*-values reported here are calculated using the original, non-imputed data. Welch's tests were used to account for the unequal sample sizes. *: significant at $\alpha = 0.05$; **: significant at $\alpha = 0.01$.

Task Validity

After data imputation, pooled paired sample t-tests revealed one significant neurobiological change in response to aggressive versus neutral interactions. LPP amplitude was significantly higher in response to aggressive behaviors compared to neutral behaviors (M = 2.80, t = 7.140, df = 171.19, $p < 0.001$). No significant differences between the two conditions were found for HR (p = 0.119), SCL (p = 0.776), RSA (p = 0.451), P3 (p = 0.725) and alpha power (p = 0.662).

Group Differences

Psychophysiological Measures

Pooled Repeated Measures ANOVAs revealed no significant main effect for HR on condition (p = 0.159) nor group (p = 0.999). No interaction effect between condition and group (p = 0.992) was found.

Analyses of RSA also showed no significant main effect for condition (p = 0.345), nor group (p = 0.729). No interaction effect between condition and group (p = 0.518) was found.

Furthermore, SCL-analyses showed no significant main effect for condition (p = 0.816). However, the main effect for group was significant (F1,114 = –2.142, p = 0.034, d = 0.322), indicating that the delinquent young adults showed higher electrodermal activity compared to the controls, in response to both aggressive and neutral pictures. The interaction effect between group and condition was not significant (p = 0.946).

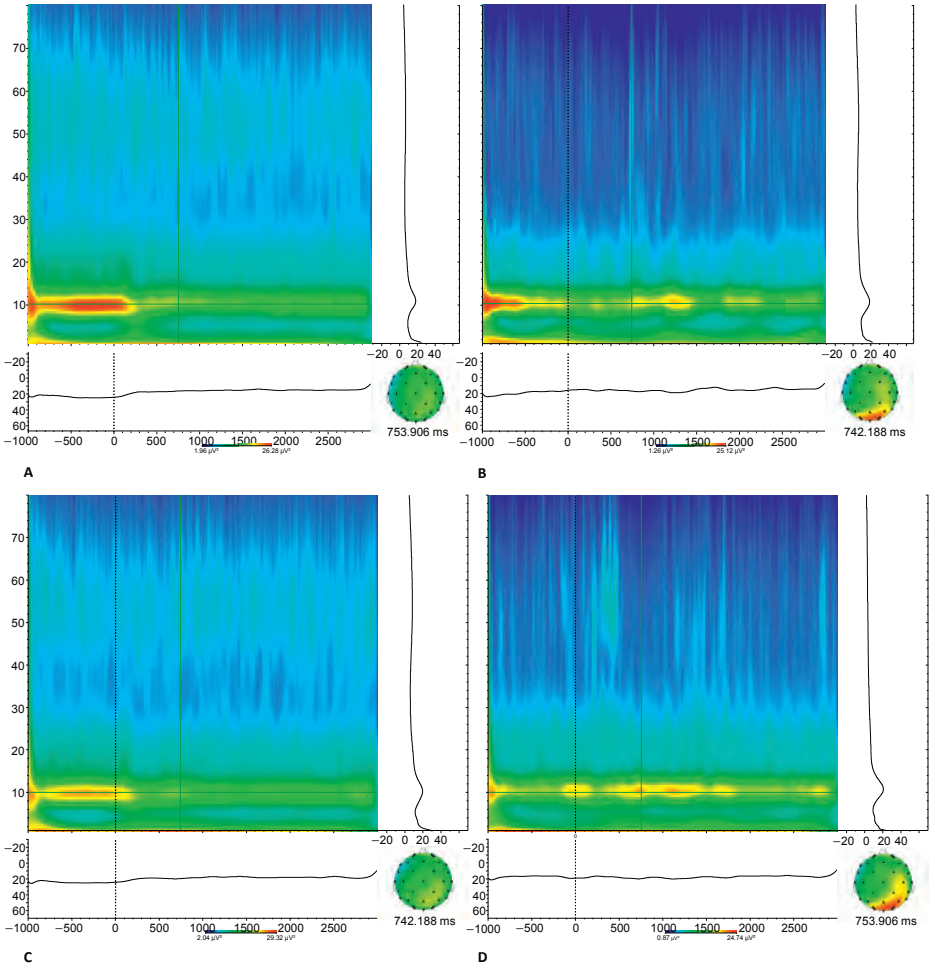


Figure 3. Alpha ERD (at site C4) in aggression condition for the delinquent group (A) and controls (B); and in neutral condition for the delinquent group (C) and controls (D).

Electrophysiological Measures

Pooled Repeated Measures ANOVAs showed no significant main effect for P3 amplitude on condition ($p = 0.451$) nor a main effect for group ($p = 0.457$). No interaction effect between condition and group was found ($p = 0.447$).

Analyses of the LPP amplitude resulted in a significant main effect for condition ($F1,214 = 6.376$, $p < 0.001$, $d = 0.422$), where aggression pictures led to higher LPP amplitudes compared with the neutral pictures in both the groups. No main effect for group was detected ($p = 0.910$). The interaction between condition and group was also not significant ($p = 0.258$).

Additionally, the analysis of the alpha power (see Figure 3) showed no significant main effect of condition ($p = 0.679$), nor a main effect for group ($p = 0.785$) and no interaction effect between condition and group ($p = 0.977$).

Regression Analyses

Pooled regression analyses were performed separately for the model predicting reactive aggression and for the model predicting proactive aggression, within the delinquent group (see Table 3).

The overall model predicting reactive aggression, including all six neurobiological measures, was not significant ($p = 0.929$). None of the neurobiological measures significantly contributed to the explanation of reactive aggression.

The overall model predicting proactive aggression, including all six neurobiological measures, was not significant ($p = 0.920$). None of the neurobiological measures significantly contributed to the explanation of proactive aggression.

Table 3. Results of pooled regression models predicting reactive and proactive aggression.

Outcome	**Predictor**	β	**SE (β)**	***p***	**95% CI β**	
					Lower	**Upper**
Reactive aggression	Intercept	11.565	0.661	0.000	10.252	12.879
	Δ HR	0.035	0.287	0.902	−0.535	0.606
	Δ RSA	0.002	0.015	0.909	−0.028	0.031
	Δ SCL	−3.113	3.274	0.346	−9.667	3.443
	Δ P3	0.093	0.134	0.489	−0.174	0.360
	Δ LPP	−0.136	0.136	0.319	−0.405	0.133
	Δ Mu power	0.029	0.084	0.733	−0.140	0.198
Proactive aggression	Intercept	5.432	0.557	0.000	4.325	6.538
	Δ HR	0.083	0.254	0.745	−0.423	0.589
	Δ RSA	−0.003	0.013	0.828	−0.029	0.023
	Δ SCL	−1.239	2.572	0.631	−6.365	3.886
	Δ P3	0.122	0.127	0.337	−0.130	0.375
	Δ LPP	−0.171	0.124	0.170	−0.418	0.075
	Δ Mu power	0.000	0.090	0.996	−0.182	0.183

DISCUSSION

In this study, we examined differences in psychophysiological and electrophysiological responses between delinquent young adults and controls in a passive viewing task depicting aggressive and neutral interactions. We found one condition effect (significantly higher LPP amplitude while viewing aggressive interactions) and one group effect (higher SCL in the delinquent group compared to controls, irrespective of condition). With respect to the regression analysis, the models including all neurobiological predictors did not significantly predict the variation in reactive and proactive aggression.

The psychophysiological results of the group comparison were partly in line with our expectations. Higher electrodermal activity during an arousal inducing task among delinquent young adults, indicating increased SNS reactivity compared to controls, complies to a certain extent with earlier research (Armstrong et al., 2019; Murray-Close et al., 2017). Interestingly, the delinquent group not only showed increased SNS reactivity in response to aggressive scenarios, but also toward neutral behaviors. This might indicate an overall hyper-activation of the SNS, which might lead to overwhelmed coping resources and emotion dysregulation. However, we did not find evidence for altered overall ANS reactivity (indicated by HR) or PNS reactivity (indicated by RSA) in response to aggressive and neutral behaviors in the delinquent group, compared to the controls. This does not correspond to some earlier studies but is in line with the mixed results from more recent studies (Blankenstein et al., 2021; Zijlmans, Marhe, et al., 2021).

Considering the electrophysiological results, we only found a significant effect of condition for the LPP; however, no significant differences between the groups were found on the P3, LPP and alpha ERD/ mu suppression. The fact that we found a condition effect for only the LPP, and not for the other electrophysiological measures is not in line with prior work using the same task (Sergiou et al., 2021; Van Dongen et al., 2018). Moreover, the fact that no differences between the groups were found was not in line with our expectations, since earlier studies did find attenuated P3 and LPP amplitudes in affective picture viewing to be related to antisocial personality and delinquency (Cheng, Hung, & Decety, 2012; Van Dongen et al., 2018; Venables, Hall, Yancey, & Patrick, 2015). Additionally, although studies have found associations between diminished alpha ERD and antisociality (Calzada-Reyes et al., 2013; Wang et al., 2021), other studies have found no results concerning alpha ERD (and mu suppression more specifically) and antisocial characteristics (Cheng et al., 2012; Van Dongen et al., 2018).

Both regression analyses revealed no significant associations between the different neurobiological predictors and reactive aggression and proactive aggression.

These outcomes were also not expected, but in line with the results found for our group comparisons.

A possible explanation for these findings might be that HR, RSA, and the P3 are less pure measures of emotional arousal compared to SCL and LPP, since they also respond to attentional processes evoked by a task (Hubbard et al., 2002; Klee, Colgan, Hanes, & Oken, 2020). In that case, our results might probably reflect the characteristics of our sample, demonstrating higher levels of emotional dysregulation and reactive aggression in particular. Although we did not find SCL reactivity to be related to either of the aggression types in this study, heightened SCL has mainly been found to be associated with reactive aggression (Armstrong et al., 2019; Thomson et al., 2021).

Furthermore, the results might have been influenced by comorbid addiction problems and the high proportion of non-aggressive offenses (i.e., property crimes) among the delinquent young adults. So, although more than two-thirds of these young adults reported committing an aggressive crime and higher levels of reactive aggression were found in the delinquent group compared to aged-matched controls, our sample could not be considered a severely violent offender group. In a recent meta-analysis, it was shown that psychophysiological effects are largest for the most violent offenders and for psychopathy, and smaller for physical aggression and aggression measured in laboratory tasks (De Looff et al., 2021a). Furthermore, by focusing on indicators of SNS and PNS separately, we might have lost sight of the importance of the cooperation between these two subsystems in understanding emotion dysregulation and aggressive behavior (Branje & Koot, 2018; Moore et al., 2018; Puhalla & McCloskey, 2020).

Finally, the absence of findings we theoretically expected, might also partly be attributed to the limitations of the current study (see below).

This study has several strengths, such as a clinically relevant and large sample of young delinquents, the combination of multiple neurobiological measures, and the use of a task depicting aggressive behaviors instead of more general stressors to induce arousal.

Despite these strengths, our study also had some important limitations. First, the small sample size of the control group created a power problem for the analyses of group differences and complicated interpretability of the results. However, similar group sizes have been used in other studies on emotional dysregulation (Beauchaine, Gatzke-Kopp, & Mead, 2007; De Wied, Van Boxtel, Matthys, & Meeus, 2012). Second, we encountered high missingness in the data for both psychophysiological measures (SCL particularly) and electrophysiological measures.

In our statistical analysis, we used Multiple Imputation to address this problem. Third, the validity of the task to induce emotional arousal in aggression versus neutral conditions was questionable in the current study. However, previous studies using the same picture task did find support for its validity (Sergiou et al., 2021; Van Dongen et al., 2018) [75,87]. It may however be that the passive viewing task is less suitable to induce changes in particular neurobiological indices such as HR and RSA. Moreover, specific cultural characteristics of the protagonists that were depicted in the scenarios of the pictures (i.e., in all but one of the aggression scenes in which a woman was depicted, a male with a white complexion displayed violence toward a woman with a black skin tone), might have influenced results in this culturally diverse sample. Finally, the use of a self-report questionnaire for aggressive behavior might have distorted the results due to socially desirable response tendencies (Barry et al., 2017), especially for proactive aggressive behaviors. Since the correlation between reactive and proactive aggression is lower in observation and computer tasks compared to self-report measures (Smeets et al., 2017), operationalization of both constructs should be carefully considered in future aggression research.

Conclusions

Although differences in psychophysiological and electrophysiological correlates when viewing pictures depicting aggressive interactions (as means to measure emotion regulation) were expected between delinquent young adults and controls, the current study only found an overall increased SCL for the delinquent group. Results also did not support the relation between different neurobiological indices and both reactive and proactive aggression. It is possible that in a (mild) delinquent young adult population, arousal is elevated in general, but not specifically during aggressive situations. However, based on previous literature and theory, it is expected that emotional dysregulation is related to delinquency and other antisocial behaviors, including aggression. In future studies, samples with more severe aggression levels and other types of paradigms and parameters should be considered to elucidate the neurobiological mechanism of emotional dysregulation associated with different types of aggression.

CHAPTER 7

Summary and General discussion

SUMMARY

The main aim of the studies in this dissertation was to assess whether it was feasible and effective to add a wearable biocueing intervention to aggression regulation therapy among forensic psychiatric outpatients. Since this field of research only recently emerged, moving along with the increases in self-tracking and health monitoring (Gimpel, Nißen, & Görlitz, 2013), we first performed a systematic review of the existing literature in order to provide an overview of ambulatory biofeedback and biocueing interventions aimed at enhancing emotion regulation. Meanwhile, we started to collaborate with other researchers who developed a precursor version of the Sense-IT biocueing app using a user-centered design (Derks et al., 2017). We briefly assessed therapists' and other forensic professionals' perspectives on the use of a biocueing intervention and piloted the precursor version of the Sense-app in 10 forensic outpatients with aggressive behavior. With their information, a new version of the Sense-IT app was developed. Subsequently, we explored the effects of this biocueing intervention as an addition to aggression regulation therapy (ART) in 25 forensic outpatients. We used a quasi-experimental pretest-posttest group design, multiple single-case experimental designs, and qualitative information to assess changes related to interoceptive awareness, emotion regulation, and aggressive behavior. Furthermore, since successful uptake of mHealth interventions heavily depends on fit with the needs and preferences of both patients and therapists (Kip et al., 2018), we qualitatively assessed the perspectives of 21 forensic outpatients and 15 therapists on use and implementation of the Sense-IT app in order to identify guideposts for the future. Additionally, we investigated neurobiological correlates of aggressive behavior in 118 delinquent young adults and 25 controls, aiming to contribute to the so far inconclusive findings of research aimed at unraveling the neurobiological underpinnings of aggression and broader antisocial behavior (Fanti et al., 2019).

MAIN FINDINGS

First, we performed a systematic review of the literature investigating the use of biofeedback applications to enhance emotion regulation in non-psychiatric and psychiatric populations. In **chapter 2**, we explain the difference between ambulatory biofeedback applications, supporting users to perform biofeedback training at home, and applications enabling real-time feedback and just-in-time behavioral support in everyday life stressful situations. For the latter category, we introduced the term biocueing. Most studies were performed among non-psychiatric populations, and only a few biocueing studies were found. In most of the studies, significant positive effects were found on self-reported (stress-related) psychological measures. Significant improvements in physiological measures were

also reported, though these measures were used less frequently. Feasibility of the applications was often reported as sufficient, though not adequately assessed in most studies. We concluded that, despite the rapid developments in mHealth technology and the increasing number of wearable devices available for everyday stress regulation, biocueing applications had only sparsely found their way into clinical research and practice up to March 2020. Cautiously, given the small sample sizes and the limited quality of the majority of the studies, we noted that these first studies on biocueing and ambulatory biofeedback interventions showed promising results, supporting the potential effect of these interventions to enhance emotion regulation by delivering personalized feedback. The results of our review emphasized the need for more biocueing research, using more rigorous as well as individually tailored research designs and valid feasibility and effectivity assessment

In **chapter 3** we described the process of user-centered design and evaluation of a wearable biocueing intervention, the Sense-IT app. The design study, amongst others assessing therapists' and other forensic professionals' perspectives, revealed a cautiously positive attitude toward the use of biocueing as an addition to ART. The evaluation study among forensic outpatients demonstrated moderate acceptability and adequate usability for the new version of the Sense-IT app. Exploratory analysis demonstrated a significant decrease in trait aggression post-intervention, although no significant changes were found in other anger-related clinical outcomes. Important recommendations to increase acceptability and usability included enhanced stability of the app, design improvements, self-adjustment of settings, the use of smartwatches with longer battery life, and the use of the app on patients' smartphones. A new version of the Sense-IT app was developed using these recommendations.

Next, in **chapter 4** we explored the effects of this biocueing intervention, using the new version of the Sense-IT app, as an addition to ART. We used a combination of designs, including a pretest-posttest group design, multiple single-case experimental designs, and a qualitative design to assess changes related to interoceptive awareness, emotion regulation, and aggressive behavior. During the combination of this new intervention and regular ART, a significant decrease in self-reported aggressive behavior was found in the pretest-posttest design. Furthermore, many participants qualitatively reported increased interoceptive awareness associated with the use of the Sense-IT biocueing app. However, the results of the repeated ambulatory measurements of the single-case experimental designs did not indicate a clear effect favoring the addition of a biocueing intervention. On group level, no significant effects were found. On the individual level effects varied, with effects favoring the intervention condition only found for two participants. Overall, effect sizes of the addition of the biocueing intervention were small. We concluded that biocueing could be considered a helpful addition to

increase interoceptive awareness, but also stressed that the current intervention may not be of added value for all forensic outpatients with anger regulation difficulties. For the future, we recommended increasing usability, tailoring the intervention to individual needs, and integration into therapy. Furthermore, we emphasized that future research should further investigate the individual characteristics (i.e. aggression type, feedback receptivity) associated with effective behavioral support by the Sense-IT app, as the use of personalized treatment interventions in clinical practice, including new technological interventions, is only expected to increase in the coming years.

In **chapter 5**, we used qualitative information of forensic outpatients and therapists to inform the future implementation process. For this purpose, we evaluated the use of the Sense-IT biocueing app by forensic outpatients using a semi-structured interview and conducted two focus groups with forensic therapists to gain a more in-depth understanding of their perspective on facilitators and barriers of implementation. Both forensic outpatients and therapists showed a primarily positive attitude toward the addition of a biocueing intervention in therapy, with increased interoceptive and emotional awareness as most frequently mentioned advantage in both groups. Patients mainly reported technical or innovation-related barriers (i.e. connection and notification issues, perceived inaccuracy of the feedback, and limitations in the ability to personalize settings). Therapists reported facilitators and barriers on both the technical, individual, and organizational level, with most codes related to the individual therapist and patient level. Predominant barriers were limitations in usability of the app, patients' motivation, and both therapists' and patients' knowledge and skills. Integration into therapy, expertise within the therapists' team, and the provision of time and materials were identified as facilitators. We concluded that the chances of successful implementation and continued use of new mHealth interventions, such as the Sense-IT app, can be increased by careful consideration of these barriers and facilitators. We suggested that technical or innovation-related barriers such as usability issues should be addressed first, followed by increasing integration of the new intervention in daily routines and enhancing affinity with the intervention among therapists.

Lastly, we investigated neurobiological responses toward aggressive interactions. In **chapter 6**, we examined differences in psychophysiological (i.e., heart rate, respiratory sinus arrhythmia, skin conductance level) and electrophysiological responses (i.e., P3, late positive potential, mu suppression) to aggressive versus neutral scenes among delinquent young adults and controls. As hypothesized, we found significantly higher SCL reactivity during the task in the delinquent group compared to controls. However, this effect was irrespective of condition, in response to both aggressive and neutral interactions. This might suggest that in a (mild) delinquent young adult population arousal is elevated in general, but not

specifically during aggressive situations. Furthermore, we found no associations between the neurobiological measures and reactive and proactive aggression within the delinquent group. We, therefore, concluded that, although we found some indication of emotional dysregulation in these delinquent young adults, future studies should further elucidate the neurobiological mechanisms underlying emotion regulation difficulties associated with different types of aggression, considering samples with more severe aggression levels and other types of paradigms and parameters.

GENERAL DISCUSSION

New technologies in mental healthcare

When this research project was initiated, the use of wearable sensor-based mHealth apps in mental healthcare was still in its infancy. Moreover, almost all neurobiological research has been conducted in lab settings and, up to that point, the few studies that used neurobiological markers to predict aggressive incidents were performed in clinical settings. The fact that our systematic review, described in chapter 2, revealed only a handful of studies investigating the use of biocueing interventions to enhance emotion regulation in everyday life, further emphasized the pioneering nature of the studies in this dissertation. Today, knowledge about the use of mHealth in psychiatry has increased. However, although the potential of mHealth apps in improving monitoring and management of mental health symptoms has been clearly demonstrated, the majority of apps lack clinically validated evidence of their efficacy (Wang et al., 2018). This applies even more strongly to the newer category of wearable mHealth apps, using physiological measures (Behar, Oster, De Vos, & Clifford, 2019; Seppälä et al., 2019). Recently a few other biocueing studies have been performed, though most in non-psychiatric samples (e.g., Lentferink et al., 2021; Van Doorn et al., 2022) or in clinical psychiatric settings (e.g., Bosch et al., 2022). Furthermore, as development of mHealth apps usually involves cyclic iterations until the technology reaches satisfaction, mHealth research is also recommended to apply iterative designs with multiple rounds of qualitative and quantitative data collection (Alwashmi, Hawboldt, Davis, & Fetters, 2019; Jacobs & Graham, 2016).

Other reasons for the suboptimal fit between new technological interventions and traditional research designs, such as randomized controlled trials (RCTs), are the rapid pace of change in technology and limitations in availability of devices. For example, technology may get obsolete and devices may become unavailable during long trials (Dallery, Riley, & Nahum-Shani, 2015). In line with these recommendations and better fitting personalized treatment interventions, we included more qualitative measures for feasibility and usability assessment and changed the

research design evaluating the clinical effects from an RCT to multiple single-case experimental designs (SCEDs). As such, this dissertation is a pioneering example of the translational, iterative approach in which fundamental neurobiological research is dynamically transferred both toward and back from clinical practice in order to develop, adapt, and evaluate personalized treatment interventions, as recently advocated (Jansen, 2022).

Usability, feasibility, and acceptability

As stressed in a recent review reporting insufficient acceptance of sensor-based mHealth apps by patients (Seppälä et al., 2019), we assessed usability, feasibility, and acceptability throughout the research process.

Regarding usability, which is a key factor in the adoption of mHealth apps in general (Zapata, Fernández-Alemán, Idri, & Toval, 2015) and associated with intended continuous use of wearable biosensors among forensic inpatients (De Looff et al., 2021b), patients provided us with valuable information. Important to note is that the participating patients, although they estimated themselves as quite to very proficient in using new technologies, quickly stopped using the app when it did not fit their needs or did not meet their expectations. Although this is consistent with previous literature (Torous et al., 2019), it may also reflect characteristics of this specific population (i.e. motivational difficulties and limitations in frustration tolerance). Main recommendations to enhance usability, described in chapter 3, were enhanced stability of the app, design improvements, use of smartwatches with longer battery life, ability to personalize settings, and use of the app on patients' smartphones. As patient engagement is a characteristic of high efficacy mental health apps (Chandrashekar, 2018), which may be even more important among forensic samples with motivational difficulties, it is unfortunate that implementation of the last two recommendations in the new version of the app was complicated by research constraints. Therefore, it was hardly surprising that similar topics re-emerged in chapter 4. Furthermore, a substantial part of the barriers to implementation consisted of technological, innovation-related issues and limitations in both patients' and therapists' knowledge and skills. This stressed the relevance of a simple user interface and experience, another important characteristic of efficacious mental health apps (Chandrashekar, 2018). Our study therefore once again emphasized the importance of involving both patients and therapists throughout the developmental process in order to fit new interventions to their needs (Kip et al., 2018).

Regarding the feasibility of implementing sensor-based mHealth apps, some major issues emerged during the research process. First, specifically applicable to forensic outpatient populations, the studies in this dissertation demonstrated that almost all devices were returned by the participating patients. Therefore, pre-existing

concerns about the feasibility of borrowing smartwatches and mobile phones among this group of patients were not confirmed. Second, processing patients' feedback, resolving technical bugs and adjusting the app to periodic software updates required lasting engagement of an app developer. Given the extended duration of our study and financial and time constraints, it was challenging to create conditions for sufficient maintenance of the app, which is associated with higher app quality and more positive user ratings (Wisniewski et al., 2019). New versions of the app also required replacement of earlier used smartphones and -watches with new, compatible devices. Outside a research context, implementation of a sensor-based mHealth app would therefore require ongoing investments on the organizational level. Third, requirements associated with the use of medical devices in clinical research, for instance, the necessity of local data storage and the difficulty to distribute a research-based app in the Play Store without an expensive CE mark, may hamper future implementation.

Regarding acceptability, the results of chapters 3, 4, and 5 indicated that patients and most therapists had a positive attitude toward the use of new technological interventions. The perceived proficiency in using these new technologies was rated highest by patients. This difference is similar to the earlier reported higher scores on acceptance of wearable biosensors found in forensic inpatients compared to staff members (De Looff et al., 2021b). Since the e- and mHealth adoption level of the majority of the therapists could be considered as minimal or passive use, and successful implementation of these interventions largely depends on their providers (Whitten & Mackert, 2005), most gains are expected in enhancing acceptability among therapists. In line with recent literature recommending to align implementation with the individual and team differences in adoption readiness (Feijt et al., 2018), therapists mentioned integration in treatment and familiarity with the intervention as important factors for successful implementation. Furthermore, the suggested appointment of experts within the therapist teams aligns well with the recommendation to give active users a central role in supporting their colleagues to explore the possibilities of new interventions (Feijt et al., 2018).

Overall, the results of our studies support the main themes that were identified in a recent study assessing the use of eHealth in forensic mental healthcare (Kip, Oberschmidt, & Bierbooms, 2020), namely the importance of development, implementation, and evaluation in clinical practice, the need for guidelines and standards, facilitation of working with technology, and constant improvement of technology.

Effectivity

Interoceptive awareness

Increased awareness was mentioned by both therapists and patients as a main advantage of use and implementation of the Sense-IT app in regular therapy. However, the main study showed mixed results regarding the effects of the combination of a biocueing intervention and ART on interoceptive awareness. The majority of patients qualitatively reported increased interoceptive awareness by using the biocueing intervention. As interoceptive awareness has been identified as a necessary though not sufficient prerequisite for emotional awareness (Koelen & Derks, 2022) and thereby as an essential building block for behavioral adaptation (Craig, 2014) and emotion regulation (Füstös et al., 2013), these qualitative findings are encouraging. The reported increases indicate that forensic outpatients, who often have difficulty detecting increased inner tension, felt supported by the biocueing intervention to become aware of sensations from inside the body. However, no quantitative changes in insight into anger-related bodily sensations, associated with the use of the biocueing intervention, were found in the studies of this dissertation. We would like to address two important considerations regarding these findings. First, in retrospect, interoceptive awareness may not have been operationalized optimally. Whereas we operationalized this concept as awareness of physiological signals of tension in the qualitative design of our main study, we focused on insight in bodily signals specifically associated with anger in the pretest-posttest design of both pilot and main study. While the first concept primarily concerns perception, anger related interoceptive awareness also entails some interpretation of bodily signals (Bellemans et al., 2018) and should therefore be considered a more demanding skill. Furthermore, recent research states that interoceptive awareness should be considered a metacognitive process, integrating both interoceptive sensibility (i.e. self-evaluated assessment of subjective interoception) and interoceptive accuracy (i.e. performance on objective tests of heartbeat detection) (Forkmann et al., 2016; Garfinkel et al., 2015). According to this model of interoception, we focused on the facet of interoceptive sensibility and thereby lacked information regarding interoceptive accuracy and interoceptive awareness as a metacognitive process. Since the feedback of the Sense-IT app was perceived as inaccurate by a substantial part of the patients, which may be partly related to technical issues (see future directions) but may also be explained by limited interoceptive capabilities, understanding the role of interoception in using biocueing among forensic outpatients could have been enhanced if we had included an interoceptive accuracy measure and had used a clearer definition of interoceptive terms (Khoury et al., 2018). Second, some patients had difficulty differentiating between components of the Sense-IT biocueing app and the integrated daily EMA questions that were used for research purposes in the main study. The qualitative measure of interoceptive awareness may therefore have been

somewhat diluted by perceived increases in emotional awareness by responding to the EMA questions.

Emotion regulation

Regarding emotion regulation our main study demonstrated mixed results as well. Half of the participants qualitatively reported that they felt supported by the app to use coping strategies in order to reduce stress. On visual inspection emotion regulation difficulties decreased in this sample, however, no significant effects were found in the pretest-posttest design. Furthermore, no group or individual increases in behavioral control favoring the biocueing intervention were found in the single-case experimental designs. Several factors might have contributed to these findings. First, motivation to change and feedback receptivity varied among the participants. Although these factors may not be required to take advantage of the component of the Sense-IT app aimed at increasing interoceptive awareness, feedback receptivity is quite essential to benefit from the behavioral support component of the Sense-IT app, even among non-psychiatric samples without motivational difficulties (Lentferink et al., 2021). Therefore, it seems important to assess whether patients are open to receiving feedback and willing to try out different emotion regulation strategies. Related to this, some patients had (very) high expectations of what the app should deliver, which might have led to disappointment when subjectively experienced tension was not accompanied by high heart rates or when they received behavioral support messages while they did not notice tension. That this discrepancy can potentially cause distress, has been reported before (Nelson et al., 2020). Important to note is that, although biocueing interventions can identify substantial increases in arousal by measuring heart rate, they are unable to provide an unique and specific recognition of subjectively experienced stress and cannot determine valence in order to specify emotion categories (Siegel et al., 2018). As suggested in recent research in which patients' reported similar feedback (Bosch et al., 2022), a more detailed explanation of biocueing might help to let patients realize that additional appraisal has to be exerted by themselves as well. Furthermore, as some patients seemed to have expected decreases in anger or reported that they wanted to stay angry in specific situations, additional psycho-education, problematizing aggressive behavior but normalizing feelings of anger, should also be considered. Second, the just-in-time behavioral support component of the Sense-IT app was not prepared by the patient and therapist during a therapy session and was restricted to a short text message, which more implicitly referred to an adequate emotion regulation strategy. Since some patients reported less adaptive coping behaviors in response to the behavioral support messages, discussing and drafting the personalized message should be integrated into therapy and given more attention. Furthermore, some patients might benefit more from integrated relaxation exercises or gamified interventions instead of a text message (Bakker & Kazantzis, 2016). This all emphasizes the need to integrate

new interventions into regular treatment and to tailor these interventions to patient-specific needs (Kip et al., 2018) and to moments when they are most likely to be effective (Bidargaddi et al., 2020).

Aggressive behavior

Considering aggression, the pretest-posttest results of the pilot study indicated a significant decrease in trait aggression and the main study demonstrated a significant decrease in total aggression associated with the combination of biocueing intervention and ART. A significant decline in aggressive behavior favoring the biocueing intervention, reported using Ecological Momentary Assessment (EMA), was found in one participant in the single-case experimental design. However, no group effects were found over the multiple single-case experimental designs, and findings were not supported by therapist-reported aggression level and the qualitative reports of most participants. Several factors are worth noting. First, the EMA responses showed low prevalence of aggressive behavior in most patients. This created a floor effect in some patients. Whether this is related to social desirability, a lack of concept clarity, or an actual low incidence rate of aggressive behavior, remains unclear. Furthermore, the added value of therapist-reported aggression levels should be considered limited as these scores were not based on actually observed aggressive incidents but on patients' reports thereof. As some social desirability might have been at play in both therapist- and patient-reported aggression (Barry et al., 2017), patients' reports may have rendered even more accurate information on aggressive behavior in this study given the perceived anonymity of these reports (Lobbestael, 2015). The need for guidelines and indication criteria describing the characteristics of patients who are most likely to benefit from a biocueing intervention, as expressed by the therapists during the focus groups, resonates with recommendations in other literature to further evaluate these new interventions (Kip et al., 2020). More specifically, therapists hypothesized that one of these characteristics might be reactive aggression. This is in line with the mixed findings of psychophysiological studies (Blankenstein et al., 2021; De Looff et al., 2021a; Fanti et al., 2019), suggesting that reactive aggression is associated with increased reactivity to emotional stressors, whereas proactive aggression is associated with a low resting heart rate and decreased reactivity. Biocueing interventions provide information on physiological fluctuations that might be indicative of increased anger, based on a baseline measurement in rest, and therefore are expected to be particularly beneficial for patients with predominant reactive aggression. As reactive aggression and proactive aggression are often strongly intertwined (Smeets et al., 2017) and we did not want to exclude any participants in this early phase of evaluation of a new intervention, we did not use aggression type as an in- or exclusion criterion. Eventually, most participants showed more reactive than proactive aggression. However, as the findings of the case studies provide insufficient support for the idea that biocueing interventions

might be particularly beneficial for patients with predominant reactive aggression, this topic needs further investigation.

Ethical considerations

The substantial expansion of digital technologies over the last years, including mHealth apps, also raised concerns, which are worth noting in this dissertation. First, the majority of mHealth-related apps available in the Play Store are not evidence-based or well tested and often do not follow current clinical standards or guidelines (Torous et al., 2018). This stresses the need for convergence between academia and industry in creating and evaluating apps (Sezgin, 2021), for which we accounted in our project by establishing a collaboration between clinicians, researchers, and app developers. However, it is known that academically produced and developed apps are often not (freely) available to patients and therefore remain underutilized (Donker et al., 2013). As the Sense-IT app was considered a medical device (without a CE mark), which can only be used in clinical trials and cannot be easily distributed, we experienced this disparity between the proliferation of commercial and academic apps firsthand in our project. Important to note is that over the last years several initiatives have been established to create frameworks for evaluation of mHealth apps (Chan, Torous, Hinton, & Yellowlees, 2015; Neary et al., 2021). Second, many mHealth apps are not well equipped to protect patient privacy and to ensure safety (Torous et al., 2018). Commercial apps often collect personal health data and own the right to share and sell this information (Glenn & Monteith, 2014). In our study, a medical ethical committee thoroughly assessed and approved the Investigational Medical Device Dossier (IMDD) of the Sense-IT app. To ensure optimal data safety, we chose not to transfer data but to store it in the app, on the mobile phone itself (i.e. local data storage). Furthermore, patients determined during the weekly therapy sessions whether they would reflect on their data with a therapist in order to identify and discuss interesting patterns. As the therapists stressed the importance of integration of the new intervention in their therapy sessions, facilitation of secure and convenient data-sharing between patients and therapists needs to be reconsidered in the future to prevent fragmentation (Torous et al., 2018). Third, as these new technologies are continuously monitoring health-related outcomes, they have a strong impact on users' everyday life. Whereas dedicated followers of the quantified self movement may enjoy tracking their health habits and receiving regular messages promoting health-improving behaviors, others might be less open to health-related suggestions, perceiving them as patronizing or as an invasion of personal space (Lupton, 2012). Furthermore, a mHealth app can become an additional stressor when users can or do not convert the suggestions into actions (Lupton, 2012). As we did in our studies, the voluntary nature of using a biocueing intervention should therefore be stressed, especially toward patients who have concerns to become an object of surveillance.

Strengths and limitations

As our systematic review revealed only a few studies investigating the use of biocueing interventions to enhance emotion regulation, both in psychiatric and non-psychiatric populations, the main strength of this thesis is the novelty of the intervention studied. Furthermore, almost all studies investigating neurobiological correlates of aggression have been conducted in lab or clinical settings. To our knowledge, this is the first dissertation investigating the feasibility and effectivity of a biocueing intervention, using physiological information, as an addition to aggression regulation therapy in a forensic outpatient population.

Another strength of this dissertation is that the studies were well embedded in daily clinical practice, thereby enhancing ecological validity and translation of these research results into real-world situations. Furthermore, as the studies were conducted by a scientist-practitioner, the development of the biocueing intervention could be well aligned to the treatment intervention.

The close collaboration with therapists, patients, researchers, and developers could be considered another strength of this research project. Throughout the studies in this dissertation, we used an iterative approach, integrating the qualitative feedback of patients and therapists in several developmental cycles. At the end of this research project, therapists were again involved to identify barriers and facilitators of future implementation of the Sense-IT app.

Finally, as traditional research designs do not optimally fit with new technological interventions, we used multiple single-case experimental designs to assess effectivity. Although this also posed challenges (see limitations) it might also inspire other scientist-practitioners who want to evaluate new, personalized interventions in clinical situations.

However, several limitations should be addressed as well. First of all, in chapter 2 we suggested that, to further validate the effectivity of biocueing interventions, self-reported psychological measures should preferably be combined with observed behavioral measures and physiological measures. Although we included therapist-reported aggression levels in our main study, the added value of these measures was limited as these scores were not based on actually observed aggressive incidents but on patients' reports thereof. Furthermore, we had to let go of the physiological measurements and neuropsychological tasks at pretest and posttest due to the COVID-19 social distancing measures.

Second, understanding the role of interoception in using biocueing could have been enhanced if we had included an interoceptive accuracy measure (Forkmann et al., 2016; Garfinkel et al., 2015) and had used a clearer definition of interoceptive

terms (Khoury et al., 2018) across the studies in this dissertation, as explained above.

Third, we encountered a low response to EMA and HR measures in the single-case experimental designs. Although we tried to enhance compliance by sending reminders and contingency management, as suggested in experience sampling literature (Myin-Germeys & Kuppens, 2021), the number of responses in the follow-up phase was so low that it did not meet the criteria for inclusion in the analyses. Therefore, analyses were only performed for the baseline and intervention phases. The compliance rates in the different phases might also suggest that the willingness to use the intervention (especially when the biocueing component was taken away) declined over time.

Fourth, dropout occurred as well, mainly in the main study. Although the dropout rate is comparable to other studies among forensic outpatients with aggressive behavior (Smeijers, Bulten, Buitelaar, & Verkes, 2018), the reasons for dropout indicate that the combination of a biocueing intervention and an intensive study design, in addition to everyday life stressful situations, may have been too demanding for some patients. To be able to receive and process their feedback, we encouraged patients who reported that they wanted to or already had stopped using the app to participate in the post-measurement. Although we thereby reduced the risk of bias in the quantitative and qualitative group results, some patients with negative experiences did still just return their devices and reported that they did not want to participate anymore.

Fifth, as the EMA questions were integrated into the Sense-IT app in the main study, some patients had difficulty differentiating between components of the biocueing intervention and the research design. Furthermore, the fact that forensic outpatients who often have difficulty reflecting on their emotions and behaviors were facilitated by the daily questions to do so, may have increased awareness of emotions, which may have had therapeutic effects as well. This might be further supported by the positive changes in the baseline phase found for several individuals in the single-case experimental designs. The interpretation of the effects of the biocueing intervention may therefore have been complicated by the use of experienced sampling in this study.

Sixth, as mentioned, we were not able to implement all the suggested improvements between pilot and main study. Although the ability to personalize settings was slightly ameliorated in the main study, patients were still not able to use the app on their own smartphones. We made this choice to prevent unwarranted changes in the app settings, and because of obstacles in app distribution and data storage restrictions. It is reasonable that these research-related usability issues have had an

impact on the results. Therefore, we suggest further usability evaluation outside a strict research setting but integrated into therapy, in which patients can customize the settings themselves and can use the Sense-IT app on their own smartphones.

FUTURE DIRECTIONS

As the studies in this dissertation are amongst the first to investigate the feasibility and effectivity of a biocueing intervention as an addition to aggression regulation therapy among forensic outpatients, we have multiple recommendations for further development and research, clinical practice, and policy. Thereby, our results support the idea of implementation as a multifaceted approach, in which technological development, professionals and patients' perspectives, and organizational support should be integrated (Kip et al., 2020).

Development and research

Technological or innovation-related suggestions

First of all, we fully agree with the expressed need for academic involvement in development and evaluation of mHealth apps (Sezgin, 2021; Torous et al., 2018). Although challenging, we recommend future researchers to use an iterative approach, co-creating and evaluating new versions of these apps by involving patients and therapists. Specific attention should be paid to accessibility for patients with mild intellectual disorders (De Looff et al., 2021b; Korczak & Zwierzchowska, 2020). Regarding this specific biocueing intervention, it is important to further improve usability and to create more realistic expectations by providing patients with a more detailed explanation of biocueing. As a substantial amount of patients' recommendations have already been implemented in a new version of the Sense-IT app, we hereby only stress the importance of further refinement of the baseline measurement procedure. Technological advances beyond the control of Sense-IT app developers, such as releases of smartwatches with extended battery life and improvements in activity recognition algorithms, may also enhance usability. Developmental changes associated with new advances should be carefully beta-tested by developers and researchers, before they are introduced to patients to prevent irritation and frustration associated with the use of the app.

Psychophysiological monitoring and support in everyday life

This dissertation stressed both the relevance of and the challenges associated with physiological measurement, monitoring and intervention in everyday life. As reported in other recent biocueing studies (Bosch et al., 2022; Van Doorn et al., 2022), the feedback provided by the Sense-IT was not always coherent with the subjective experience of the participants. Although this might be partly resolved by improving usability and creating more realistic expectations of what the

app delivers, it also demonstrates the importance of further investigating how physiological tension and subjectively experienced stress can most reliably be measured in everyday life (Vaessen et al., 2021), and how real-time monitoring and constant feedback of physiological data influence self-perception (Fairclough, 2009). Furthermore, our studies raise the question of how behavioral support can be provided in the most effective way to support patients to adequately regulate both their perceived stress levels and emotions. With this in mind, it is encouraging that recently a long-term grant has been assigned to a broad consortium of researchers to develop and evaluate novel monitoring and intervention strategies to track and reduce daily-life stress and its health impact (Stress in Action, https://stress-in-action.nl).

Studying personalized treatment interventions

As the studies in this dissertation indicate, using a biocueing intervention might not be of added value for all forensic outpatients with anger regulation difficulties. Moreover, for some patients, the component of the biocueing app aimed at enhancing interoceptive awareness may be helpful, while the behavioral support component might be associated with increased frustration. Furthermore, as the app was perceived as most helpful in difficult situations, selection of moments of use might also be important. For future research, it would therefore be highly relevant to further investigate which patients benefit from which component of a biocueing intervention, and when and for how long the intervention should be used. This is in line with the shift toward developing and delivering personalized interventions at precisely those moments when they are most likely to be effective for an individual (Berrouiguet et al., 2018; Bidargaddi et al., 2020). For this purpose, we recommend the earlier described iterative approach, (multiple baseline) single-case experimental designs and case series designs, particularly in complex patient groups in which studying technological interventions using more traditional research designs is not feasible. When using a biocueing on/off (AB) design, we advise having this change automatized by the app, especially among outpatients who might be hard to reach. Furthermore, we recommend selecting measures that are less sensitive to floor or ceiling effects and including measures related to different facets of interoception. When EMA is used, this research component should be clearly distinguished from the studied intervention. Opportunities to increase compliance to experience sampling should be carefully considered (Myin-Germeys & Kuppens, 2021). Finally, in order to predict what works for whom, precision psychiatry provides another promising venue for future research. This emerging approach depends on machine learning and is aimed at ameliorating treatment by basing medical decisions on individual patient characteristics, such as behavioral biomarkers (Fernandes et al., 2017; Fröhlich et al., 2018). Aligning with this approach, a research consortium has recently been granted to identify individual biopsychosocial profiles in order to adjust interventions to the needs of juveniles in forensic practice (SCIN, https://

neurolab.nl). For future research, it might be interesting to investigate whether biocueing interventions, collecting physiological biomarkers, could be used as decision support tools, in forensic psychiatry and beyond.

Clinical practice

As the results of the studies in this dissertation indicate, integration of the biocueing intervention in therapy, and increasing familiarity and affinity with the intervention are the next steps that should be taken to enhance adoption in clinical practice (Feijt et al., 2018). With the recommendations of the therapists, we drafted an implementation plan which is currently being executed. This implementation plan includes development of a website, infographics, videos and a short training module. Furthermore, the suggested appointment of experts within the therapists' teams will be used to let therapists explore the possibilities of this new intervention. According to the majority of the therapists, the Sense-IT biocueing app would be most useful in the first phases of treatment, in order to increase interoceptive awareness. This component of the Sense-IT app might suit most patients, probably also the ones with motivational difficulties. When a patient displays a certain amount of motivation to change and feedback receptivity, they might also benefit from the just-in-time behavioral support delivered by the Sense-IT app. Since this involves a reminder to use coping strategies to reduce stress, it is necessary that the therapist has already discussed different emotion regulation strategies with the patient and that the supportive message is prepared in collaboration during a therapy session. Before patients start using the biocueing intervention, a detailed explanation of biocueing is necessary to let patients realize that additional appraisal has to be exerted by themselves as well. Additional psycho-education problematizing aggressive behavior but normalizing feelings of anger may also be necessary. Furthermore, it is important to discuss in which situations the app would be most useful for a particular patient. Finally, in line with the feedback of the forensic outpatients indicating a need for more personalized use (i.e. on their own smartphones, only in specific circumstances, for longer or shorter periods, with the ability to customize the settings themselves), we encourage therapists and patients to use and evaluate the Sense-IT biocueing app in everyday practice. Important to note is that biocueing at present should not be used as an isolated tool in (forensic) psychiatric populations. Rather, biocueing elucidates specific situations or interactions as well as inadequate emotion regulation strategies that need to be reflected on and discussed in therapy sessions, or integrated in comprehensive internet interventions. Furthermore, as reactive aggression is associated with traumatic experiences (Kerig, 2020), use of biocueing interventions might also shed light on dysregulated stress responses indicating a need for trauma therapy. Therefore, biocueing interventions should be considered as additions to regular treatment, complementing more cognitive approaches and aligning with other body-oriented approaches such as psychomotor therapy (PMT) and mindfulness-

based therapy (Bellemans et al., 2019; Röhricht, 2009). Biocueing interventions, offering an accessible and basic opportunity for interoceptive awareness in everyday life, thereby align well with the recent pleas to increase engagement of the body in psychotherapy (Koelen & Derks, 2022; Luyten, 2022).

Policy

On policy level, it is important to facilitate further research into m-health apps. If this is not done sustainably, there is a good chance that an app will no longer be useful due to rapid developments (e.g., disappearance of particular wearable hardware from one manufacturer). In this research project, we therefore deliberately made the choice to work with an app which builds on smartwatch hardware which is widely available from several different manufacturers (e.g., TicWatch, Samsung) and an associated operating system (i.e., Android Wear OS) with already available and convenient state of the art software tools (e.g., the Google activity recognition algorithm). In addition, therapists indicate that positive, well-founded research results increase their willingness to implement and use the app. On the level of the specific mental healthcare organization, therapists need to be facilitated in terms of time (to become familiar with a new intervention) and sufficient equipment and clear agreements regarding the use of the equipment by patients (liability, data storage) need to be provided. On the national policy level, facilitating and contributing to careful ethical reflection and drafting guidelines around privacy and data safety when using m-health in vulnerable patient populations are essential.

Conclusions

In this dissertation, we studied the feasibility, usability and clinical effects of the Sense-IT biocueing app as an addition to aggression regulation therapy (ART) among forensic outpatients with anger regulation difficulties. The results in this dissertation suggest that biocueing is a feasible addition to regular treatment in forensic psychiatry. The integration of the Sense-IT app within existing treatment, in which patients and therapists integrate personalized use in therapy, may further increase feasibility and usability. Regarding effectivity, some indications of positive changes associated with the combination of the biocueing intervention and ART on interoceptive awareness and aggressive behavior were found. However, these results were not supported by the results of the single-case experimental designs, in which effects favoring the intervention condition were only significant in two participants. Therefore, these first results are insufficient to draw firm conclusions regarding the effectivity of this new intervention. For future research, we first recommend implementation and integration of the app within therapy programs, followed by (multiple baseline) single-case experimental designs and case series designs, which could be iteratively used to further evaluate, adapt, and personalize the biocueing intervention. If technological stability can be assured over a longer period of time, more traditional designs may be considered in less complex patients

groups. In addition, future research should further investigate for which patients the component of the app aimed at increasing interoceptive awareness is of added value, and which patients are supported by the behavioral support component of the Sense-IT biocueing app to use adequate emotion regulation strategies in order to prevent aggressive behavior. Since development and use of personalized treatment interventions are only expected to grow in the coming years, improving usability, tailoring the intervention to individual needs, and enhancing integration in therapy, in continuous co-creating efforts with patients and therapists, are highly recommended for future-proof forensic care.

REFERENCES

REFERENCES

Adams, Z. W., McClure, E. A., Gray, K. M., Danielson, C. K., Treiber, F. A., & Ruggiero, K. J. (2017). Mobile devices for the remote acquisition of physiological and behavioral biomarkers in psychiatric clinical research. *Journal of psychiatric research, 85*, 1-14.

Alwashmi, M. F., Hawboldt, J., Davis, E., & Fetters, M. D. (2019). The iterative convergent design for mobile health usability testing: mixed methods approach. *JMIR mHealth and uHealth, 7*(4), e11656.

Andersson, G., Cuijpers, P., Carlbring, P., Riper, H., & Hedman, E. (2014). Guided Internet-based vs. face-to-face cognitive behavior therapy for psychiatric and somatic disorders: a systematic review and meta-analysis. *World Psychiatry, 13*(3), 288-295.

Armstrong, T., Wells, J., Boisvert, D. L., Lewis, R., Cooke, E. M., Woeckener, M., & Kavish, N. (2019). Skin conductance, heart rate and aggressive behavior type. *Biological psychology, 141*, 44-51.

Bakker, D., & Kazantzis, N. (2016). Debra Rickwood ja Nikki Rickard. 2016.". *Mental health smartphone apps: review and evidence-based recommendations for future developments". JMIR mental health, 3*(1), e7.

Balapour, A., Reychav, I., Sabherwal, R., & Azuri, J. (2019). Mobile technology identity and self-efficacy: Implications for the adoption of clinically supported mobile health apps. *International Journal of Information Management, 49*, 58-68.

Balconi, M., & Mazza, G. (2009). Brain oscillations and BIS/BAS (behavioral inhibition/activation system) effects on processing masked emotional cues.: ERS/ERD and coherence measures of alpha band. *International Journal of Psychophysiology, 74*(2), 158-165.

Bandura, A. (1978). Social learning theory of aggression. *Journal of communication, 28*(3), 12-29.

Bangor, A., Kortum, P. T., & Miller, J. T. (2008). An empirical evaluation of the system usability scale. *Intl. Journal of Human–Computer Interaction, 24*(6), 574-594.

Barratt, E. S., Stanford, M. S., Kent, T. A., & Alan, F. (1997). Neuropsychological and cognitive psychophysiological substrates of impulsive aggression. *Biological psychiatry, 41*(10), 1045-1061.

Barry, C. T., Lui, J. H., & Anderson, A. C. (2017). Adolescent narcissism, aggression, and prosocial behavior: The relevance of socially desirable responding. *Journal of personality assessment, 99*(1), 46-55.

Bath, E., Tolou-Shams, M., & Farabee, D. (2018). Mobile health (mHealth): building the case for adapting emerging technologies for justice-involved youth. *Journal of the American Academy of Child and Adolescent Psychiatry, 57*(12), 903.

Beauchaine, T. P., Gatzke-Kopp, L., & Mead, H. K. (2007). Polyvagal theory and developmental psychopathology: Emotion dysregulation and conduct problems from preschool to adolescence. *Biological psychology, 74*(2), 174-184.

Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International Journal of Psychophysiology, 98*(2), 338-350.

Behar, J. A., Oster, J., De Vos, M., & Clifford, G. D. (2019). Wearables and mHealth in mental health and neurological disorders. *Physiol Meas, 40*(7), 070401.

Bellemans, T., Didden, R., Korzilius, H. P., & van Busschbach, J. T. (2020). Psychometric properties of the ABSI-id, an adapted measure for anger-related interoceptive awareness in individuals with mild intellectual disabilities or borderline intellectual functioning. *Journal of Intellectual & Developmental Disability*, 1-10.

Bellemans, T., Didden, R., van Busschbach, J. T., Hoek, P. T., Scheffers, M. W., Lang, R. B., & Lindsay, W. R. (2019). Psychomotor therapy targeting anger and aggressive behaviour in individuals with mild or borderline intellectual disabilities: A systematic review. *Journal of Intellectual & Developmental Disability, 44*(1), 121-130.

Bellemans, T., Didden, R., Visser, R., Schaafsma, D., Totsika, V., & van Busschbach, J. T. (2018). Psychomotor therapy for anger and aggression in mild intellectual disability or borderline intellectual functioning: An intervention mapping approach. *Body, Movement and Dance in Psychotherapy, 13*(4), 234-250.

Berenbaum, H., Bredemeier, K., Thompson, R. J., & Boden, M. T. (2012). Worry, anhedonic depression, and emotional styles. *Cognitive Therapy and Research, 36*(1), 72-80.

Berkowitz, L. (1993). *Aggression: Its causes, consequences, and control*: Mcgraw-Hill Book Company.

Bernat, E. M., Hall, J. R., Steffen, B. V., & Patrick, C. J. (2007). Violent offending predicts P300 amplitude. *International Journal of Psychophysiology, 66*(2), 161-167.

Berrouiguet, S., Perez-Rodriguez, M. M., Larsen, M., Baca-García, E., Courtet, P., & Oquendo, M. (2018). From eHealth to iHealth: transition to participatory and personalized medicine in mental health. *Journal of medical Internet research, 20*(1), e7412.

Bidargaddi, N., Schrader, G., Klasnja, P., Licinio, J., & Murphy, S. (2020). Designing m-Health interventions for precision mental health support. *Translational psychiatry, 10*(1), 1-8.

Bindler, A., Ketel, N., & Hjalmarsson, R. (2020). Costs of victimization. *Handbook of Labor, Human Resources and Population Economics*, 1-31.

Blankenstein, N. E., de Rooij, M., van Ginkel, J., Wilderjans, T. F., de Ruigh, E. L., Oldenhof, H. C., . . . de Vries-Bouw, M. (2021). Neurobiological correlates of antisociality across adolescence and young adulthood: a multi-sample, multi-method study. *Psychological medicine*, 1-16.

Boden, M. T., & Thompson, R. J. (2015). Facets of emotional awareness and associations with emotion regulation and depression. *Emotion, 15*(3), 399.

Bolger, N., & Laurenceau, J.-P. (2013). *Intensive longitudinal methods: An introduction to diary and experience sampling research*: Guilford press.

Bosch, R., Chakhssi, F., & Noordzij, M. L. (2022). Acceptance and Potential Clinical Added Value of Biocueing in Forensic Psychiatric Patients with Autism Spectrum Disorder and/or Intellectual Disability. *Psychiatry Research*, 114645.

Bouffard, L. A., & Koeppel, M. D. (2014). Understanding the potential long-term physical and mental health consequences of early experiences of victimization. *Justice Quarterly, 31*(3), 568-587.

Boyce, W. T., Quas, J., Alkon, A., Smider, N. A., Essex, M. J., & Kupfer, D. J. (2001). Autonomic reactivity and psychopathology in middle childhood. *The British Journal of Psychiatry, 179*(2), 144-150.

Branje, S., & Koot, H. M. (2018). Psychophysiology of aggression. *Handbook of child and adolescent aggression*, 84-106.

Brännström, L., Kaunitz, C., Andershed, A.-K., South, S., & Smedslund, G. (2016). Aggression replacement training (ART) for reducing antisocial behavior in adolescents and adults: A systematic review. *Aggression and violent behavior, 27*, 30-41.

Brooke, J. (1996). Sus: a "quick and dirty'usability. *Usability evaluation in industry, 189*(3).

Brugman, S., Lobbestael, J., Arntz, A., Cima, M., Schuhmann, T., Dambacher, F., & Sack, A. T. (2015). Identifying cognitive predictors of reactive and proactive aggression. *Aggressive behavior, 41*(1), 51-64.

Buss, A. H., & Perry, M. (1992). The aggression questionnaire. *Journal of personality and social psychology, 63*(3), 452.

Calì, G., Ambrosini, E., Picconi, L., Mehling, W., & Committeri, G. (2015). Investigating the relationship between interoceptive accuracy, interoceptive awareness, and emotional susceptibility. *Frontiers in psychology, 6*, 1202.

Calzada-Reyes, A., Alvarez-Amador, A., Galán-García, L., & Valdés-Sosa, M. (2013). EEG abnormalities in psychopath and non-psychopath violent offenders. *Journal of forensic and legal medicine, 20*(1), 19-26.

Cassiello-Robbins, C., & Barlow, D. H. (2016). Anger: The unrecognized emotion in emotional disorders. *Clinical Psychology: Science and Practice, 23*(1), 66.

Cavanagh, J. F., & Frank, M. J. (2014). Frontal theta as a mechanism for cognitive control. *Trends in cognitive sciences, 18*(8), 414-421.

Centifanti, L. C. M., Kimonis, E. R., Frick, P. J., & Aucoin, K. J. (2013). Emotional reactivity and the association between psychopathy-linked narcissism and aggression in detained adolescent boys. *Development and Psychopathology, 25*(2), 473-485.

Chan, S., Torous, J., Hinton, L., & Yellowlees, P. (2015). Towards a framework for evaluating mobile mental health apps. *Telemedicine and e-Health, 21*(12), 1038-1041.

Chandrashekar, P. (2018). Do mental health mobile apps work: evidence and recommendations for designing high-efficacy mental health mobile apps. *Mhealth, 4*.

Cheng, Y., Hung, A.-Y., & Decety, J. (2012). Dissociation between affective sharing and emotion understanding in juvenile psychopaths. *Development and Psychopathology, 24*(2), 623-636.

Cima, M., & Raine, A. (2009). Distinct characteristics of psychopathy relate to different subtypes of aggression. *Personality and individual differences, 47*(8), 835-840.

Cima, M., Raine, A., Meesters, C., & Popma, A. (2013). Validation of the Dutch Reactive Proactive Questionnaire (RPQ): Differential correlates of reactive and proactive aggression from childhood to adulthood. *Aggressive behavior, 39*(2), 99-113.

Cohen, J. (1988). Statistical power analysis for the social sciences.

Cohen, M. A. (2020). *The costs of crime and justice*: Routledge.

Cornet, L., Bootsman, F., Alberda, D., & Kogel, C. d. (2016). Neurowetenschappelijke toepassingen in de jeugdstrafrechtketen: Den Haag: Boom criminologie. Onderzoek en beleid.

Cornet, L., Mandersloot, M., Pool, R., & De Kogel, C. (2017). De'zelfmetende'justitiabele: Een verkennend onderzoek naar technologische zelfmeetmethoden binnen justitiële context.

Craig, A. D. (2014). How do you feel? *How Do You Feel?* : Princeton University Press.

Crockett, J. E., Gill, D. L., Cashwell, T. H., & Myers, J. E. (2017). Integrating non-technological and technological peripheral biofeedback in counseling. *Journal of Mental Health Counseling, 39*(2), 163-179.

Crozier, J. C., Dodge, K. A., Fontaine, R. G., Lansford, J. E., Bates, J. E., Pettit, G. S., & Levenson, R. W. (2008). Social information processing and cardiac predictors of adolescent antisocial behavior. *Journal of abnormal psychology, 117*(2), 253.

Cui, Z., Zhong, S., Xu, P., Gong, G., & He, Y. (2013). PANDA: a pipeline toolbox for analyzing brain diffusion images. *Frontiers in human neuroscience, 7*, 42.

Cumpanasoiu, D., Mazefsky, C., Stedman, A., Peura, C., Tian, P., Guo, Y., . . . Goodwin, M. S. (2018). Physiological biomarkers for prediction of imminent aggression in minimally verbal children with autism spectrum disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 56*, S256-S257.

Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biological psychology, 52*(2), 95-111.

Dallery, J., Riley, W. T., & Nahum-Shani, I. (2015). Research designs to develop and evaluate technology-based health behavior interventions. *Behavioral healthcare and technology: Using science-based innovations to transform practice*, 168-186.

De Bruin, E. I., Van der Zwan, J. E., & Bogels, S. M. (2016). A RCT Comparing Daily Mindfulness Meditations, Biofeedback Exercises, and Daily Physical Exercise on Attention Control, Executive Functioning, Mindful Awareness, Self-Compassion, and Worrying in Stressed Young Adults. *Mindfulness, 7*(5), 1182-1192.

De Cesarei, A., & Codispoti, M. (2011). Affective modulation of the LPP and α-ERD during picture viewing. *Psychophysiology, 48*(10), 1397-1404.

De Looff, P., Nijman, H., Didden, R., & Noordzij, M. (2021). Usability and acceptance of wearable biosensors in forensic psychiatry: Cross-sectional questionnaire study. *JMIR formative research, 5*(5), e18096.

De Looff, P., Noordzij, M., Moerbeek, M., Nijman, H., Didden, R., & Embregts, P. (2019). Changes in heart rate and skin conductance in the 30 min preceding aggressive behavior. *Psychophysiology, 56*(10), e13420.

De Looff, P., Noordzij, M. L., Moerbeek, M., Nijman, H., Didden, R., & Embregts, P. (2019). Changes in heart rate and skin conductance in the 30 min preceding aggressive behavior. *Psychophysiology*, e13420.

De Looff, P. C., Cornet, L. J., De Kogel, C. H., Fernández-Castilla, B., Embregts, P. J., Didden, R., & Nijman, H. L. (2021). Heart Rate and Skin Conductance Associations with Physical Aggression, Psychopathy, Antisocial Personality Disorder and Conduct Disorder: An Updated Meta-Analysis. *Neuroscience & Biobehavioral Reviews*.

De Wied, M., Van Boxtel, A., Matthys, W., & Meeus, W. (2012). Verbal, facial and autonomic responses to empathy-eliciting film clips by disruptive male adolescents with high versus low callous-unemotional traits. *Journal of abnormal child psychology, 40*(2), 211-223.

Declercq, L., Cools, W., Beretvas, S. N., Moeyaert, M., Ferron, J. M., & Van den Noortgate, W. (2020). MultiSCED: A tool for (meta-) analyzing single-case experimental data with multilevel modeling. *Behavior Research Methods, 52*(1), 177-192.

Derks, Y. P., Klaassen, R., Westerhof, G. J., Bohlmeijer, E. T., & Noordzij, M. L. (2019). Development of an Ambulatory Biofeedback App to Enhance Emotional Awareness in Patients with Borderline Personality Disorder: Multicycle Usability Testing Study. *JMIR mHealth and uHealth, 7*(10), e13479.

Derks, Y. P., Visser, T. D., Bohlmeijer, E. T., & Noordzij, M. L. (2017). mHealth in mental health: how to efficiently and scientifically create an ambulatory biofeedback e-coaching app for patients with borderline personality disorder. *International Journal of Human Factors and Ergonomics, 5*(1), 61-92.

Dodge, K. A., & Coie, J. D. (1987). Social-information-processing factors in reactive and proactive aggression in children's peer groups. *Journal of personality and social psychology, 53*(6), 1146.

Donker, T., Petrie, K., Proudfoot, J., Clarke, J., Birch, M.-R., & Christensen, H. (2013). Smartphones for smarter delivery of mental health programs: a systematic review. *Journal of medical Internet research, 15*(11), e2791.

East, M. L., & Havard, B. C. (2015). Mental health mobile apps: from infusion to diffusion in the mental health social system. *JMIR mental health, 2*(1), e3954.

Eddie, D., Kim, C., Lehrer, P., Deneke, E., & Bates, M. E. (2015). A Pilot Study of Brief Heart Rate Variability Biofeedback to Reduce Craving in Young Adult Men Receiving Inpatient Treatment for Substance Use Disorders. *Applied psychophysiology and biofeedback, 39*(3), 181-192.

El-Sheikh, M., Kouros, C. D., Erath, S., Cummings, E. M., Keller, P., & Staton, L. (2009). Marital conflict and children's externalizing behavior: Pathways involving interactions between parasympathetic and sympathetic nervous system activity. *Monographs of the Society for research in Child Development, 74*(1), vii.

Eysenck, H. J. (1997). Personality and experimental psychology: the unification of psychology and the possibility of a paradigm. *Journal of personality and social psychology, 73*(6), 1224.

Fairburn, C. G., & Patel, V. (2017). The impact of digital technology on psychological treatments and their dissemination. *Behaviour research and therapy, 88*, 19-25.

Fairclough, S. H. (2009). Fundamentals of physiological computing. *Interacting with computers, 21*(1-2), 133-145.

Fanti, K. A., Eisenbarth, H., Goble, P., Demetriou, C., Kyranides, M. N., Goodwin, D., . . . Cortese, S. (2019). Psychophysiological activity and reactivity in children and adolescents with conduct problems: A systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews, 100*, 98-107.

Feijt, M. A., de Kort, Y. A., Bongers, I. M., & IJsselsteijn, W. A. (2018). Perceived drivers and barriers to the adoption of emental health by psychologists: the construction of the levels of adoption of emental health model. *Journal of medical Internet research, 20*(4), e153.

Feijt, M. A., De Kort, Y. A., Westerink, J. H., Bierbooms, J. J., Bongers, I. M., & IJsselsteijn, W. A. (2021). Assessing Professionals' Adoption Readiness for eMental Health: Development and Validation of the eMental Health Adoption Readiness Scale. *Journal of medical Internet research*, e28518.

Ferguson, B. J., Hamlin, T., Lantz, J., Villavicencio, T., Beversdorf, D. Q., & Coles, J. (2019). Examining the association between electrodermal activity and problem behavior in severe autism spectrum disorder: A feasibility study. *Frontiers in psychiatry, 10*, 654.

Fernandes, B. S., Williams, L. M., Steiner, J., Leboyer, M., Carvalho, A. F., & Berk, M. (2017). The new field of 'precision psychiatry'. *BMC medicine, 15*(1), 1-7.

Fisher, A. J., Medaglia, J. D., & Jeronimus, B. F. (2018). Lack of group-to-individual generalizability is a threat to human subjects research. *Proceedings of the National Academy of Sciences, 115*(27), E6106-E6115.

Fite, P. J., Raine, A., Stouthamer-Loeber, M., Loeber, R., & Pardini, D. A. (2010). Reactive and proactive aggression in adolescent males: Examining differential outcomes 10 years later in early adulthood. *Criminal Justice and Behavior, 37*(2), 141-157.

Fleming, T., Bavin, L., Lucassen, M., Stasiak, K., Hopkins, S., & Merry, S. (2018). Beyond the trial: systematic review of real-world uptake and engagement with digital self-help interventions for depression, low mood, or anxiety. *Journal of medical Internet research, 20*(6), e9275.

Fletcher, R. R., Tam, S., Omojola, O., Redemske, R., & Kwan, J. (2011). *Wearable sensor platform and mobile application for use in cognitive behavioral therapy for drug addiction and PTSD*. Paper presented at the 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society.

Forkmann, T., Scherer, A., Meessen, J., Michal, M., Schächinger, H., Vögele, C., & Schulz, A. (2016). Making sense of what you sense: Disentangling interoceptive awareness, sensibility and accuracy. *International Journal of Psychophysiology, 109*, 71-80.

Fröhlich, H., Balling, R., Beerenwinkel, N., Kohlbacher, O., Kumar, S., Lengauer, T., . . . Przytycka, T. M. (2018). From hype to reality: data science enabling personalized medicine. *BMC medicine, 16*(1), 1-15.

Furl, N., Lohse, M., & Pizzorni-Ferrarese, F. (2017). Low-frequency oscillations employ a general coding of the spatio-temporal similarity of dynamic faces. *Neuroimage, 157*, 486-499.

Füstös, J., Gramann, K., Herbert, B. M., & Pollatos, O. (2013). On the embodiment of emotion regulation: interoceptive awareness facilitates reappraisal. *Social cognitive and affective neuroscience, 8*(8), 911-917.

Gaggioli, A., Cipresso, P., Serino, S., Campanaro, D. M., Pallavicini, F., Wiederhold, B. K., & Riva, G. (2014). Positive Technology: A Free Mobile Platform for the Self-Management of Psychological Stress. *Annual Review of Cybertherapy and Telemedicine, 12*, 25-29.

Gagnon, J., Aubin, M., Emond, F. C., Derguy, S., Brochu, A. F., Bessette, M., & Jolicoeur, P. (2017). An ERP study on hostile attribution bias in aggressive and nonaggressive individuals. *Aggressive behavior, 43*(3), 217-229.

Gagnon, M.-P., Ngangue, P., Payne-Gagnon, J., & Desmartis, M. (2015). m-Health adoption by healthcare professionals: a systematic review. *Journal of the American Medical Informatics Association, 23*(1), 212-220. doi:10.1093/jamia/ocv052

Gao, Y., Raine, A., Venables, P. H., & Mednick, S. A. (2013). The association between P3 amplitude at age 11 and criminal offending at age 23. *Journal of Clinical Child & Adolescent Psychology, 42*(1), 120-130.

Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzuki, K., & Critchley, H. D. (2015). Knowing your own heart: distinguishing interoceptive accuracy from interoceptive awareness. *Biological psychology, 104*, 65-74.

Garofalo, C., Neumann, C. S., & Velotti, P. (2020). Psychopathy and aggression: The role of emotion dysregulation. *Journal of interpersonal violence*, 0886260519900946.

Gatzke-Kopp, L. M., Greenberg, M., & Bierman, K. (2015). Children's parasympathetic reactivity to specific emotions moderates response to intervention for early-onset aggression. *Journal of Clinical Child & Adolescent Psychology, 44*(2), 291-304.

Gerstle, J. E., Mathias, C. W., & Stanford, M. S. (1998). Auditory P300 and self-reported impulsive aggression. *Progress in neuro-psychopharmacology & biological psychiatry, 22*(4), 575-583.

Gimpel, H., Nißen, M., & Görlitz, R. (2013). Quantifying the quantified self: A study on the motivations of patients to track their own health.

Glenn, T., & Monteith, S. (2014). Privacy in the digital world: medical and health data outside of HIPAA protections. *Current psychiatry reports, 16*(11), 1-11.

Glick, B., & Gibbs, J. C. (2010). *Aggression replacement training: A comprehensive intervention for aggressive youth*: Research Press.

Godfrey, K. M. (2018). *Smartphones for smarter eating: Elucidating eating behaviors, stress, and heart rate variability.* (79), ProQuest Information & Learning, US DB - psyh DP - EBSCOhost. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=psyh&AN=2017-54454-085&site=ehost-live&scope=site&authtype=sso&custid=deakin

Goessl, V. C., Curtiss, J. E., & Hofmann, S. G. (2017). The effect of heart rate variability biofeedback training on stress and anxiety: a meta-analysis. *Psychological medicine, 47*(15), 2578.

Goldstein, A. P., Glick, B., & Gibbs, J. C. (1998). *Aggression replacement training: A comprehensive intervention for aggressive youth, Rev*: Research Press.

Goodkind, M., Eickhoff, S. B., Oathes, D. J., Jiang, Y., Chang, A., Jones-Hagata, L. B., . . . Korgaonkar, M. S. (2015). Identification of a common neurobiological substrate for mental illness. *JAMA psychiatry, 72*(4), 305-315.

Goodwin, M. S., Mazefsky, C. A., Ioannidis, S., Erdogmus, D., & Siegel, M. (2019). Predicting aggression to others in youth with autism using a wearable biosensor. *Autism research, 12*(8), 1286-1296.

Granja, C., Janssen, W., & Johansen, M. A. (2018). Factors determining the success and failure of eHealth interventions: systematic review of the literature. *Journal of medical Internet research, 20*(5), e10235.

Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and clinical neurophysiology, 55*(4), 468-484.

Gratz, K. L., & Roemer, L. (2004). Multidimensional assessment of emotion regulation and dysregulation: Development, factor structure, and initial validation of the difficulties in emotion regulation scale. *Journal of psychopathology and behavioral assessment, 26*(1), 41-54.

Gratz, K. L., & Tull, M. T. (2010). The relationship between emotion dysregulation and deliberate self-harm among inpatients with substance use disorders. *Cognitive Therapy and Research, 34*(6), 544-553.

Grol, R., & Wensing, M. (2004). What drives change? Barriers to and incentives for achieving evidence-based practice. *Medical Journal of Australia, 180*, S57-S60.

Gross, J. J., & Jazaieri, H. (2014). Emotion, emotion regulation, and psychopathology: An affective science perspective. *Clinical Psychological Science, 2*(4), 387-401.

Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: time-course of the late positive potential. *Clinical neurophysiology, 120*(3), 505-510.

Hastings, P. D., Nuselovici, J. N., Klimes-Dougan, B., Kendziora, K. T., Usher, B. A., Ho, M. h. R., & Zahn-Waxler, C. (2009). Dysregulated coherence of subjective and cardiac emotional activation in adolescents with internalizing and externalizing problems. *Journal of Child Psychology and Psychiatry, 50*(11), 1348-1356.

Hasuo, H., Kanbara, K., Sakuma, H., Yoshida, K., Uchitani, K., & Fukunaga, M. (2019). Self-Care System for Family Caregivers of Cancer Patients Using Resonant Breathing with a Portable Home Device: A Randomized Open-Label Study. *Journal of palliative medicine, 22*(1), 18-24.

Helfritz-Sinville, L. E., & Stanford, M. S. (2015). Looking for trouble? Processing of physical and social threat words in impulsive and premeditated aggression. *The Psychological Record, 65*(2), 301-314.

Henwood, K. S., Chou, S., & Browne, K. D. (2015). A systematic review and meta-analysis on the effectiveness of CBT informed anger management. *Aggression and violent behavior, 25*, 280-292.

Herrmann, C. S., Grigutsch, M., & Busch, N. A. (2005). 11 EEG oscillations and wavelet analysis. *Event-related potentials: A methods handbook*, 229.

Hornsveld, R. H., Muris, P., Kraaimaat, F. W., & Meesters, C. (2009). Psychometric properties of the aggression questionnaire in Dutch violent forensic psychiatric patients and secondary vocational students. *Assessment, 16*(2), 181-192.

Hovens, J., Lievaart, M., & Rodenburg, J. (2014). STAXI-2: Vragenlijst over boosheid. *Amsterdam: Hogrefe*.

Howell, N., Devendorf, L., Vega Gálvez, T. A., Tian, R., & Ryokai, K. (2018). *Tensions of data-driven reflection: A case study of real-time emotional biosensing.* Paper presented at the Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems.

Hubbard, J. A., McAuliffe, M. D., Morrow, M. T., & Romano, L. J. (2010). Reactive and proactive aggression in childhood and adolescence: Precursors, outcomes, processes, experiences, and measurement. *Journal of personality, 78*(1), 95-118.

Hubbard, J. A., Smithmyer, C. M., Ramsden, S. R., Parker, E. H., Flanagan, K. D., Dearing, K. F., . . . Simons, R. F. (2002). Observational, physiological, and self–report measures of children's anger: Relations to reactive versus proactive aggression. *Child development, 73*(4), 1101-1118.

Hulsbergen, M., Bohlmeijer, E., & Berking, M. (2014). Emotieregulatie. In B. Ten Ham, M. Hulsbergen, & E. Bohlmeyer (Eds.), *Transdiagnostische factoren. Theorie & praktijk.* (pp. 159-177). Amsterdam, the Netherlands: Uitgeverij Boom.

Jacobs, M. A., & Graham, A. L. (2016). Iterative development and evaluation methods of mHealth behavior change interventions. *Current Opinion in Psychology, 9*, 33-37.

Jansen, L. M. (2022). The neurobiology of antisocial behavior in adolescence current knowledge and relevance for youth forensic clinical practice. *Current Opinion in Psychology*, 101356.

Johanson, M., Vaurio, O., Tiihonen, J., & Lähteenvuo, M. (2020). A systematic literature review of neuroimaging of psychopathic traits. *Frontiers in psychiatry, 10*, 1027.

Kahneman, D. (2003). A perspective on judgment and choice: mapping bounded rationality. *American psychologist, 58*(9), 697.

Kazantzis, N., Whittington, C., Zelencich, L., Kyrios, M., Norton, P. J., & Hofmann, S. G. (2016). Quantity and quality of homework compliance: a meta-analysis of relations with outcome in cognitive behavior therapy. *Behavior Therapy, 47*(5), 755-772.

Kazdin, A. E. (2019). Single-case experimental designs. Evaluating interventions in research and clinical practice. *Behaviour research and therapy, 117*, 3-17.

Keeney, J. E. (2009). *Effects of heart rate variability biofeedback-assisted stress management training on pregnant women and fetal heart rate measures.* (70), ProQuest Information & Learning, US DB - psyh DP - EBSCOhost. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=psyh&AN=2009-99200-020&site=ehost-live&scope=site&authtype=sso&custid=deakin

Kerig, P. K. (2020). Emotion dysregulation and childhood trauma. *Oxford handbook of emotion dysregulation*, 265.

Khoury, N. M., Lutz, J., & Schuman-Olivier, Z. (2018). Interoception in Psychiatric Disorders: A Review of Randomized Controlled Trials with Interoception-based Interventions. *Harvard review of psychiatry, 26*(5), 250.

Kim, S., Zemon, V., Cavallo, M. M., Rath, J. F., McCraty, R., & Foley, F. W. (2012). Heart rate variability biofeedback, executive functioning and chronic brain injury. *Brain Injury, 27*(2), 209-222.

Kip, H., Bouman, Y. H., Kelders, S. M., & van Gemert-Pijnen, L. J. (2018). eHealth in treatment of offenders in forensic mental health: a review of the current state. *Frontiers in psychiatry, 9*, 42.

Kip, H., Oberschmidt, K., & Bierbooms, J. J. (2020). Ehealth technology in forensic mental healthcare: recommendations for achieving benefits and overcoming barriers. *International Journal of Forensic Mental Health, 20*(1), 31-47.

Kizakevich, P. N., Eckhoff, R. P., Lewis, G. F., Davila, M. I., Hourani, L. L., Watkins, R., . . . Morgan, T. (2019). Biofeedback-Assisted Resilience Training for Traumatic and Operational Stress: Preliminary Analysis of a Self-Delivered Digital Health Methodology. *JMIR mHealth and uHealth, 7*(9), e12590.

Klaver, C., De Geus, E., & De Vries, J. (1994). Ambulatory monitoring system. *Computers in psychology, 5*, 254-268.

Klee, D., Colgan, D. D., Hanes, D., & Oken, B. (2020). The effects of an internet-based mindfulness meditation intervention on electrophysiological markers of attention. *International Journal of Psychophysiology, 158*, 103-113.

Klein Tuente, S., Bogaerts, S., Bulten, E., Keulen-de Vos, M., Vos, M., Bokern, H., . . . Veling, W. (2020). Virtual reality aggression prevention therapy (VRAPT) versus waiting list control for forensic psychiatric inpatients: a multicenter randomized controlled trial. *Journal of clinical medicine, 9*(7), 2258.

Knoedler, D. W. (1989). The modified overt aggression scale. *The American journal of psychiatry, 146*(8), 1081-1082.

Knyazev, G. G., Bocharov, A. V., Levin, E. A., Savostyanov, A. N., & Slobodskoj-Plusnin, J. Y. (2008). Anxiety and oscillatory responses to emotional facial expressions. *Brain Research, 1227*, 174-188.

Koegl, C. J., & Farrington, D. P. (2021). Estimating the monetary cost of risk factors for crime in boys using the EARL-20B. *Psychological services, 18*(4), 441.

Koelen, J., & Derks, Y. (2022). Het lichaam als (gedempte) klankkast voor emotie *Het lichaam en psychisch functioneren* (pp. 73-101): Springer.

Koenig, J., Rinnewitz, L., Parzer, P., Resch, F., Thayer, J. F., & Kaess, M. (2017). Resting cardiac function in adolescent non-suicidal self-injury: the impact of borderline personality disorder symptoms and psychosocial functioning. *Psychiatry Research, 248*, 117-120.

Korczak, P., & Zwierzchowska, A. (2020). Using mobile applications in the process of enhancing and restoring abilities in individuals with intellectual disability and other disabilities–a literature review. *Advances in Rehabilitation, 34*(4), 36-41.

Kranzler, A., Young, J. F., Hankin, B. L., Abela, J. R., Elias, M. J., & Selby, E. A. (2016). Emotional awareness: A transdiagnostic predictor of depression and anxiety for children and adolescents. *Journal of Clinical Child & Adolescent Psychology, 45*(3), 262-269.

Krueger, R. A., & Casey, M. A. (2002). Designing and conducting focus group interviews: Citeseer.

Krug, E. G., Mercy, J. A., Dahlberg, L. L., & Zwi, A. B. (2002). The world report on violence and health. *The lancet, 360*(9339), 1083-1088.

Kudo, N., Shinohara, H., & Kodama, H. (2014). Heart rate variability biofeedback intervention for reduction of psychological stress during the early postpartum period. *Applied psychophysiology and biofeedback, 39*(3), 203-211.

Kuijpers, E., Nijman, H., Bongers, I. M. B., Lubberding, M., & Ouwerkerk, M. (2012). Can mobile skin conductance assessments be helpful in signalling imminent inpatient aggression? *Acta Neuropsychiatrica, 24*(1), 56-59.

Kunaharan, S., Halpin, S., Sitharthan, T., & Walla, P. (2019). Do EEG and startle reflex modulation vary with self-reported aggression in response to violent images? *Brain sciences, 9*(11), 298.

Landenberger, N. A., & Lipsey, M. W. (2005). The positive effects of cognitive–behavioral programs for offenders: A meta-analysis of factors associated with effective treatment. *Journal of Experimental Criminology, 1*(4), 451-476.

Lane, R. D., & Schwartz, G. E. (1987). Levels of emotional awareness: a cognitive-developmental theory and its application to psychopathology. *The American journal of psychiatry*.

Lang, P. J., & Bradley, M. M. (2010). Emotion and the motivational brain. *Biological psychology, 84*(3), 437-450.

Latzman, R. D., & Vaidya, J. G. (2013). Common and distinct associations between aggression and alcohol problems with trait disinhibition. *Journal of psychopathology and behavioral assessment, 35*(2), 186-196.

Lehrer, P. (2013). How does heart variability biofeedback work? Resonance, the baroreflex, and other mechanism. *Biofeedback, 41*, 26-31.

Lehrer, P., Kaur, K., Sharma, A., Shah, K., Huseby, R., Bhavsar, J., & Zhang, Y. (2020). Heart Rate Variability Biofeedback Improves Emotional and Physical Health and Performance: A Systematic Review and Meta Analysis. *Applied psychophysiology and biofeedback*.

Leigh, S., & Flatt, S. (2015). App-based psychological interventions: friend or foe? *Evidence-based mental health, 18*(4), 97-99.

Lemaire, J. B., Wallace, J. E., Lewin, A. M., de Grood, J., & Schaefer, J. P. (2011). The effect of a biofeedback-based stress management tool on physician stress: A randomized controlled clinical trial. *Open Medicine, 5*(4), 154-165.

Lentferink, A., Noordzij, M. L., Burgler, A., Klaassen, R., Derks, Y., Oldenhuis, H., . . . van Gemert-Pijnen, L. (2021). On the receptivity of employees to just-in-time self-tracking and eCoaching for stress management: a mixed-methods approach. *Behaviour & Information Technology*, 1-27.

Levenson, R. W. (2014). The autonomic nervous system and emotion. *Emotion Review, 6*(2), 100-112.

Lipsey, M. W., Landenberger, N. A., & Wilson, S. J. (2007). Effects of cognitive-behavioral programs for criminal offenders. *Campbell systematic reviews, 3*(1), 1-27.

Lisetti, C. L., & Nasoz, F. (2004). Using noninvasive wearable computers to recognize human emotions from physiological signals. *EURASIP journal on applied signal processing, 2004*, 1672-1687.

Lobbestael, J. (2015). Challenges in aggression assessment: The gap between self-report and behavior, and a call for new valid behavioral paradigms. *Journal of Socialomics, 5*(01), 5-6.

Lobbestael, J., Cima, M., & Arntz, A. (2013). The relationship between adult reactive and proactive aggression, hostile interpretation bias, and antisocial personality disorder. *Journal of personality disorders, 27*(1), 53-66.

Lorber, M. F. (2004). Psychophysiology of aggression, psychopathy, and conduct problems: a meta-analysis. *Psychological bulletin, 130*(4), 531.

Luijks, M.-J. A., Bevaart, F., Zijlmans, J., Van Duin, L., Marhe, R., Doreleijers, T. A., . . . Popma, A. (2017). A multimodal day treatment program for multi-problem young adults: study protocol for a randomized controlled trial. *Trials, 18*(1), 1-15.

Lupton, D. (2012). M-health and health promotion: The digital cyborg and surveillance society. *Social Theory & Health, 10*(3), 229-244.

Luxton, D. D., McCann, R. A., Bush, N. E., Mishkind, M. C., & Reger, G. M. (2011). mHealth for mental health: Integrating smartphone technology in behavioral healthcare. *Professional Psychology: Research and Practice, 42*(6), 505.

Luyten, P. (2022). Werken met het lichaam in psychotherapie *Het lichaam en psychisch functioneren* (pp. 327-344): Springer.

Mackintosh, M. A., Niehaus, J., Taft, C. T., Marx, B. P., Grubbs, K., , M., & , L. A. (2017). Using a Mobile Application in the Treatment of Dysregulated Anger Among Veterans. *Military Medicine, 182*(11), E1941-E1949.

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical therapy, 83*(8), 713-721.

Mandel, D. M. (2003). Psychophysiological resilience: A theoretical construct based on threat perception and early programming of restorative and arousal based adaptive mechanisms. *Journal of Prenatal & Perinatal Psychology & Health, 17*(3), 235.

Maric, M., & van der Werff, V. (2020). Single-case experimental designs in clinical intervention research. *SMALL SAMPLE SIZE SOLUTIONS*, 102.

Massoudi, B., Holvast, F., Bockting, C. L., Burger, H., & Blanker, M. H. (2019). The effectiveness and cost-effectiveness of e-health interventions for depression and anxiety in primary care: A systematic review and meta-analysis. *Journal of affective disorders, 245*, 728-743.

Mather, M., & Thayer, J. F. (2018). How heart rate variability affects emotion regulation brain networks. *Current opinion in behavioral sciences, 19*, 98-104.

May, R. W., Seibert, G. S., Sanchez-Gonzalez, M. A., & Fincham, F. D. (2019). Self-regulatory biofeedback training: an intervention to reduce school burnout and improve cardiac functioning in college students. *Stress, 22*(1), 1-8.

McCraty, R., & Atkinson, M. (2012). Resilience Training Program Reduces Physiological and Psychological Stress in Police Officers. *Glob Adv Health Med, 1*(5), 44-66.

McCraty, R., Atkinson, M., Lipsenthal, L., & Arguelles, L. (2009). New Hope for Correctional Officers: An Innovative Program for Reducing Stress and Health Risks. *Applied psychophysiology and biofeedback, 34*(4), 251-272.

McCraty, R., & Zayas, M. (2014). Cardiac coherence, self-regulation, autonomic stability, and psychosocial well-being. *Frontiers in psychology, 5*, 1090.

McCurdie, T., Taneva, S., Casselman, M., Yeung, M., McDaniel, C., Ho, W., & Cafazzo, J. (2012). mHealth consumer apps: the case for user-centered design. *Biomedical instrumentation & technology, 46*(s2), 49-56.

McDonnell, A., McCreadie, M., Mills, R., Deveau, R., Anker, R., & Hayden, J. (2015). The role of physiological arousal in the management of challenging behaviours in individuals with autistic spectrum disorders. *Research in Developmental Disabilities, 36*, 311-322.

McEwan, T. E., Davis, M. R., MacKenzie, R., & Mullen, P. E. (2009). The effects of social desirability response bias on STAXI-2 profiles in a clinical forensic sample. *British Journal of Clinical Psychology, 48*(4), 431-436.

McGarry, P., & Portnoy, J. (2022). Cardiovascular Psychophysiology and Antisocial Behavior *Clinical Forensic Psychology* (pp. 49-66): Springer.

McHugh, B., Dawson, N., Scrafton, A., & Asen, E. (2010). 'Hearts on their sleeves': the use of systemic biofeedback in school settings. *Journal of Family Therapy, 32*(1), 58-72.

McIntosh, L. G., Janes, S., O'Rourke, S., & Thomson, L. D. (2021). Effectiveness of psychological and psychosocial interventions for forensic mental health inpatients: A meta-analysis. *Aggression and violent behavior*, 101551.

McKee, M. G. (2008). Biofeedback: an overview in the context of heart-brain medicine. *Cleveland Clinic Journal of Medicine, 75*, S31.

McLay, R. N., & Spira, J. L. (2009). Use of a portable biofeedback device to improve insomnia in a combat zone, a case report. *Applied psychophysiology and biofeedback, 34*(4), 319-321.

McRae, K., & Gross, J. J. (2020). Emotion regulation. *Emotion, 20*(1), 1.

Mennella, R., Patron, E., & Palomba, D. (2017). Frontal alpha asymmetry neurofeedback for the reduction of negative affect and anxiety. *Behaviour research and therapy, 92*, 32-40.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., . . . Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic reviews, 4*(1), 1.

Moore, C. C., Hubbard, J., Morrow, M. T., Barhight, L. R., Lines, M. M., Sallee, M., & Hyde, C. T. (2018). The simultaneous assessment of and relations between children's sympathetic and parasympathetic psychophysiology and their reactive and proactive aggression. *Aggressive behavior, 44*(6), 614-623.

Murray-Close, D., Holterman, L. A., Breslend, N. L., & Sullivan, A. (2017). Psychophysiology of proactive and reactive relational aggression. *Biological psychology, 130*, 77-85.

Myers, R. H., & Myers, R. H. (1990). *Classical and modern regression with applications* (Vol. 2): Duxbury press Belmont, CA.

Myin-Germeys, I., & Kuppens, P. (2021). *The Open Handbook of Experience Sampling Methodology: A step-by-step guide to designing, conducting, and analyzing ESM studies*: Center for Research on Experience Sampling and Ambulatory Methods Leuven (REAL).

Nahum-Shani, I., Smith, S. N., Spring, B. J., Collins, L. M., Witkiewitz, K., Tewari, A., & Murphy, S. A. (2018). Just-in-time adaptive interventions (JITAIs) in mobile health: key components and design principles for ongoing health behavior support. *Annals of Behavioral Medicine, 52*(6), 446-462.

Narita, Y., Shinohara, H., & Kodama, H. (2018). Resting heart rate variability and the effects of biofeedback intervention in women with low-risk pregnancy and prenatal childbirth fear. *Applied psychophysiology and biofeedback*.

Naslund, J. A., Marsch, L. A., McHugo, G. J., & Bartels, S. J. (2015). Emerging mHealth and eHealth interventions for serious mental illness: a review of the literature. *Journal of mental health, 24*(5), 321-332.

Neary, M., Bunyi, J., Palomares, K., Mohr, D. C., Powell, A., Ruzek, J., . . . Schueller, S. M. (2021). A process for reviewing mental health apps: Using the One Mind PsyberGuide Credibility Rating System. *Digital Health, 7*, 20552076211053690.

Nelson, E. C., Sools, A. M., Vollenbroek-Hutten, M. M., Verhagen, T., & Noordzij, M. L. (2020). Embodiment of wearable technology: qualitative longitudinal study. *JMIR mHealth and uHealth, 8*(11), e16973.

Nicholas, J., Huckvale, K., Larsen, M. E., Basu, A., Batterham, P. J., Shaw, F., & Sendi, S. (2017). Issues for eHealth in psychiatry: results of an expert survey. *Journal of medical Internet research, 19*(2), e6957.

Novaco, R. W. (2007). Anger dysregulation.

Nuske, H. J., Finkel, E., Hedley, D., Parma, V., Tomczuk, L., Pellecchia, M., . . . Dissanayake, C. (2019). Heart rate increase predicts challenging behavior episodes in preschoolers with autism. *Stress, 22*(3), 303-311.

O'Neill, B., & Findlay, G. (2014). Single case methodology in neurobehavioural rehabilitation: Preliminary findings on biofeedback in the treatment of challenging behaviour. *Neuropsychological rehabilitation, 24*(3-4), 365-381.

Ogloff, J. R., Talevski, D., Lemphers, A., Wood, M., & Simmons, M. (2015). Co-occurring mental illness, substance use disorders, and antisocial personality disorder among clients of forensic mental health services. *Psychiatric Rehabilitation Journal, 38*(1), 16.

Olver, M. E., Stockdale, K. C., & Wormith, J. S. (2011). A meta-analysis of predictors of offender treatment attrition and its relationship to recidivism. *Journal of consulting and clinical psychology, 79*(1), 6.

Ortiz, J., & Raine, A. (2004). Heart rate level and antisocial behavior in children and adolescents: A meta-analysis. *Journal of the American Academy of Child & Adolescent Psychiatry, 43*(2), 154-162.

Otten, M., & Jonas, K. J. (2014). Humiliation as an intense emotional experience: Evidence from the electro-encephalogram. *Social neuroscience, 9*(1), 23-35.

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan—a web and mobile app for systematic reviews. *Systematic reviews, 5*(1), 210.

Owens, J., & Cribb, A. (2019). 'My Fitbit Thinks I Can Do Better!'do health promoting wearable technologies support personal autonomy? *Philosophy & Technology, 32*(1), 23-38.

Palix, J., Akselrod, M., Cungi, C., Giuliani, F., & Favrod, J. (2017). Changes in Heart Rate Variability Recorded in Natural Situation with T-Shirt Integrated Sensors and Level of Observed Behavioral Excitation: A Pilot Study of Patients with Intellectual Disabilities and Psychiatric Disorders. *Frontiers in psychiatry, 8*(4). doi:10.3389/fpsyt.2017.00004

Paradiso, R., Faetti, T., & Werner, S. (2011). *Wearable monitoring systems for psychological and physiological state assessment in a naturalistic environment.* Paper presented at the 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society.

Park, M. J., Kim, D. J., Lee, U., Na, E. J., & Jeon, H. J. (2019). A literature overview of virtual reality (VR) in treatment of psychiatric disorders: recent advances and limitations. *Frontiers in psychiatry, 10*, 505.

Parker, R. I., Vannest, K. J., & Brown, L. (2009). The improvement rate difference for single-case research. *Exceptional children, 75*(2), 135-150.

Patrick, C. J. (2014). Physiological correlates of psychopathy, antisocial personality disorder, habitual aggression, and violence. *Electrophysiology and Psychophysiology in Psychiatry and Psychopharmacology*, 197-227.

Patrick, K., Hekler, E., Estrin, D., Mohr, D., Riper, H., Crane, D., . . . Riley, W. (2016). The pace of technologic change: implications for digital health behavior intervention research (Vol. 51, pp. 816-824): Elsevier.

Peira, N., Fredrikson, M., & Pourtois, G. (2013). EMOTION REGULATION WITH ONLINE HEART RATE-BASED BIOFEEDBACK. *Psychophysiology, 49*, S104-S104.

Pinheiro, J. C., & Bates, D. M. (2000). Linear mixed-effects models: basic concepts and examples. *Mixed-effects models in S and S-Plus*, 3-56.

Popma, A., & Raine, A. (2006). Will future forensic assessment be neurobiologic? *Child and Adolescent Psychiatric Clinics, 15*(2), 429-444.

Popov, T., Miller, G. A., Rockstroh, B., & Weisz, N. (2013). Modulation of α power and functional connectivity during facial affect recognition. *Journal of Neuroscience, 33*(14), 6018-6026.

Popov, T., Steffen, A., Weisz, N., Miller, G. A., & Rockstroh, B. (2012). Cross-frequency dynamics of neuromagnetic oscillatory activity: Two mechanisms of emotion regulation. *Psychophysiology, 49*(12), 1545-1557.

Portnoy, J., & Farrington, D. P. (2015). Resting heart rate and antisocial behavior: An updated systematic review and meta-analysis. *Aggression and violent behavior, 22*, 33-45.

Poston, P. D. (2018). Change of Heart: An Integral Inquiry into prenatal depression, heartmath, and transformation. *Dissertation Abstracts International: Section B: The Sciences and Engineering, 78*(11), No Pagination Specified.

Price, C. J., & Hooven, C. (2018). Interoceptive awareness skills for emotion regulation: Theory and approach of mindful awareness in body-oriented therapy (MABT). *Frontiers in psychology, 9*, 798.

Price, M., Yuen, E., Goetter, E., Herbert, J., Forman, E., Acierno, R., & Ruggiero, K. (2014). mHealth: a mechanism to deliver more accessible, more effective mental health care. *Clinical psychology & psychotherapy, 21*(5), 427-436.

Puhalla, A. A., & McCloskey, M. S. (2020). The relationship between physiological reactivity to provocation and emotion dysregulation with proactive and reactive aggression. *Biological psychology, 155*, 107931.

Pustejovsky, J., Chen, M., & Swan, D. (2021). Single-case effect size calculator (Version 0.5.2) Web application. *Retreived from https://jepusto.shinyapps.io/SCD-effect-sizes/*.

Raine, A. (2008). From genes to brain to antisocial behavior. *Current Directions in Psychological Science, 17*(5), 323-328.

Raine, A., Dodge, K., Loeber, R., Gatzke-Kopp, L., Lynam, D., Reynolds, C., . . . Liu, J. (2006). The reactive–proactive aggression questionnaire: Differential correlates of reactive and proactive aggression in adolescent boys. *Aggressive Behavior: Official Journal of the International Society for Research on Aggression, 32*(2), 159-171.

Raine, A., & Jones, F. (1987). Attention, autonomic arousal, and personality in behaviorally disordered children. *Journal of abnormal child psychology, 15*(4), 583-599.

Ramey, S. L., Perkhounkova, Y., Hein, M., Chung, S., Franke, W. D., & Anderson, A. A. (2016). Building Resilience in an Urban Police Department. *Journal of Occupational and Environmental Medicine, 58*(8), 796-804.

Reiner, R. (2008). Integrating a portable biofeedback device into clinical practice for patients with anxiety disorders: Results of a pilot study. *Applied psychophysiology and biofeedback, 33*(1), 55-61.

Riley, W. T., Serrano, K. J., Nilsen, W., & Atienza, A. A. (2015). Mobile and wireless technologies in health behavior and the potential for intensively adaptive interventions. *Current Opinion in Psychology, 5*, 67-71.

Roberton, T., Daffern, M., & Bucks, R. S. (2015). Beyond anger control: Difficulty attending to emotions also predicts aggression in offenders. *Psychology of Violence, 5*(1), 74.

Röhricht, F. (2009). Body oriented psychotherapy. The state of the art in empirical research and evidence-based practice: A clinical perspective. *Body, Movement and Dance in Psychotherapy, 4*(2), 135-156.

Ross, J., Stevenson, F., Lau, R., & Murray, E. (2016). Factors that influence the implementation of e-health: a systematic review of systematic reviews (an update). *Implementation science, 11*(1), 1-12.

R Core Team (2021). R: A language and environment for statistical computing. Retrieved from http://www.R-project.org/

Roushan, T., Adib, R., Johnson, N., George, O., Hossain, M. F., Franco, Z., . . . Ahamed, S. I. (2019). *Towards predicting risky behavior among veterans with PTSD by analyzing gesture patterns.* Paper presented at the 2019 IEEE 43rd Annual Computer Software and Applications Conference (COMPSAC).

Rubio-Valera, M., Luciano, J. V., Ortiz, J. M., Salvador-Carulla, L., Gracia, A., & Serrano-Blanco, A. (2015). Health service use and costs associated with aggressiveness or agitation and containment in adult psychiatric care: a systematic review of the evidence. *BMC psychiatry, 15*(1), 1-13.

Savard, J. S. (2017). Reducing Adolescent Anger and Aggression with Biofeedback: A Mixed-Methods Multiple Case Study. *Dissertations & Theses*(422).

Scheepers, P. L. H., Tobi, H., & Boeije, H. (2016). Onderzoeksmethoden (9e dr.).

Schlier, B., Krkovic, K., Clamor, A., & Lincoln, T. M. (2019). Autonomic arousal during psychosis spectrum experiences: Results from a high resolution ambulatory assessment study over the course of symptom on-and offset. *Schizophrenia research, 212*, 163-170.

Schmitt, J., Warner, K., & Gupta, S. (2010). The high budgetary cost of incarceration.

Schnall, R., Rojas, M., Bakken, S., Brown, W., Carballo-Dieguez, A., Carry, M., . . . Travers, J. (2016). A user-centered model for designing consumer mobile health (mHealth) applications (apps). *Journal of biomedical informatics, 60*, 243-251.

Schreiweis, B., Pobiruchin, M., Strotbaum, V., Suleder, J., Wiesner, M., & Bergh, B. (2019). Barriers and facilitators to the implementation of eHealth services: systematic literature analysis. *Journal of medical Internet research, 21*(11), e14197.

Schubring, D., & Schupp, H. T. (2019). Affective picture processing: Alpha-and lower beta-band desynchronization reflects emotional arousal. *Psychophysiology, 56*(8), e13386.

Schubring, D., & Schupp, H. T. (2021). Emotion and brain oscillations: high arousal is associated with decreases in alpha-and lower beta-band power. *Cerebral Cortex, 31*(3), 1597-1608.

Schueller, S. M., Glover, A. C., Rufa, A. K., Dowdle, C. L., Gross, G. D., Karnik, N. S., & Zalta, A. K. (2019). A mobile phone–based intervention to improve mental health among homeless young adults: Pilot feasibility trial. *JMIR mHealth and uHealth, 7*(7), e12347.

Schumann, A., Köhler, S., Brotte, L., & Bär, K.-J. (2019). Effect of an eight-week smartphone-guided HRV-biofeedback intervention on autonomic function and impulsivity in healthy controls. *Physiological measurement, 40*(6), 064001.

Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. *Progress in brain research, 156*, 31-51.

Sendzik, L., Schäfer, J. Ö., Samson, A. C., Naumann, E., & Tuschen-Caffier, B. (2017). Emotional awareness in depressive and anxiety symptoms in youth: A meta-analytic review. *Journal of youth and adolescence, 46*(4), 687-700.

Seppälä, J., De Vita, I., Jämsä, T., Miettunen, J., Isohanni, M., Rubinstein, K., . . . Berdun, J. (2019). Mobile phone and wearable sensor-based mHealth approaches for psychiatric disorders and symptoms: systematic review. *JMIR mental health, 6*(2), e9819.

Sergiou, C. S., Santarnecchi, E., Romanella, S. M., Wieser, M. J., Franken, I. H., Rassin, E. G., & van Dongen, J. D. (2021). tDCS targeting the Ventromedial Prefrontal Cortex reduces reactive aggression and modulates electrophysiological responses in a forensic population. *Biological psychiatry: cognitive neuroscience and neuroimaging*.

Serino, S., Cipresso, P., Gaggioli, A., Pallavicini, F., Cipresso, S., Campanaro, D., & Riva, G. (2014). Smartphone for self-management of psychological stress: A preliminary evaluation of positive technology app. *Revista de Psicopatología y Psicología Clínica, 19*(3), 253-260.

Sezgin, E. (2021). Can We Use Commercial Mobile Apps Instead of Research Mobile Apps in Healthcare Research? *Frontiers in Public Health, 9*.

Shamay-Tsoory, S. G., Tomer, R., Berger, B. D., & Aharon-Peretz, J. (2003). Characterization of empathy deficits following prefrontal brain damage: the role of the right ventromedial prefrontal cortex. *Journal of cognitive neuroscience, 15*(3), 324-337.

Sharon, T. (2017). Self-tracking for health and the quantified self: Re-articulating autonomy, solidarity, and authenticity in an age of personalized healthcare. *Philosophy & Technology, 30*(1), 93-121.

Sheppes, G., Suri, G., & Gross, J. J. (2015). Emotion regulation and psychopathology. *Annual review of clinical psychology, 11*, 379-405.

Siegel, E. H., Sands, M. K., Van den Noortgate, W., Condon, P., Chang, Y., Dy, J., . . . Barrett, L. F. (2018). Emotion fingerprints or emotion populations? A meta-analytic investigation of autonomic features of emotion categories. *Psychological bulletin, 144*(4), 343.

Singer, T., Kiebel, S. J., Winston, J. S., Dolan, R. J., & Frith, C. D. (2004). Brain responses to the acquired moral status of faces. *Neuron, 41*(4), 653-662.

Smeets, K., Oostermeijer, S., Lappenschaar, M., Cohn, M., Van der Meer, J., Popma, A., . . . Buitelaar, J. K. (2017). Are proactive and reactive aggression meaningful distinctions in adolescents? A variable-and person-based approach. *Journal of abnormal child psychology, 45*(1), 1-14.

Smeijers, D., Benbouriche, M., & Garofalo, C. (2020). The association between emotion, social information processing, and aggressive behavior: A systematic review. *European Psychologist*.

Smeijers, D., Bulten, E., Buitelaar, J., & Verkes, R.-J. (2018). Treatment responsivity of aggressive forensic psychiatric outpatients. *International journal of offender therapy and comparative criminology, 62*(12), 3834-3852.

Smeijers, D., & Koole, S. L. (2019). Testing the effects of a virtual reality game for aggressive impulse management (VR-GAIME): study protocol. *Frontiers in psychiatry, 10*, 83.

Smidt, K. E., & Suvak, M. K. (2015). A brief, but nuanced, review of emotional granularity and emotion differentiation research. *Current Opinion in Psychology, 3*, 48-51.

Smith, J. D. (2012). Single-case experimental designs: a systematic review of published research and current standards. *Psychological methods, 17*(4), 510.

Spielberger, C. D., Sydeman, S. J., Owen, A. E., & Marsh, B. J. (1999). *Measuring anxiety and anger with the State-Trait Anxiety Inventory (STAI) and the State-Trait Anger Expression Inventory (STAXI)*: Lawrence Erlbaum Associates Publishers.

Stanford, M. S., Houston, R. J., Villemarette-Pittman, N. R., & Greve, K. W. (2003). Premeditated aggression: Clinical assessment and cognitive psychophysiology. *Personality and individual differences, 34*(5), 773-781.

Steadman, H. J., Osher, F. C., Robbins, P. C., Case, B., & Samuels, S. (2009). Prevalence of serious mental illness among jail inmates. *Psychiatric services, 60*(6), 761-765.

Tanis, C. J. (2012). Performance enhancement and stress reduction using biofeedback with women collegiate volleyball players. *Athletic Insight: The Online Journal of Sport Psychology, 4*(2), 127-140.

Taylor, S. E. (2006). Tend and befriend: Biobehavioral bases of affiliation under stress. *Current directions in psychological science, 15*(6), 273-277.

Ten Ham, B. V. H., Hulsbergen, M., & Bohlmeyer, E. (2016). Transdiagnostische factoren. Theorie & praktijk. *Tijdschrift voor Psychiatrie, 58*(4), 336-336.

Ter Harmsel, J. F., Noordzij, M. L., Goudriaan, A. E., Dekker, J. J. M., Swinkels, L. T. A., van der Pol, T. M., & Popma, A. (2021). Biocueing and ambulatory biofeedback to enhance emotion regulation: A review of studies investigating non-psychiatric and psychiatric populations. *Int J Psychophysiol, 159*, 94-106. doi:10.1016/j.ijpsycho.2020.11.009

Ter Harmsel, J. F., Smulders, L. M., Noordzij, M. L., Swinkels, L. T. A., Goudriaan, A. E., Popma, A., & Van der Pol, T. M. (submitted). Forensic Psychiatric Outpatients' and Therapists' Perspectives on a Wearable Biocueing App (Sense-IT) as an Addition to Aggression Regulation Therapy: a Qualitative Study.

Ter Harmsel, J. F., Van der Pol, T. M., Swinkels, L. T. A., Goudriaan, A. E., Popma, A., & Noordzij, M. L. (2021). Development of a wearable biocueing app (Sense-IT) among forensic psychiatric outpatients with aggressive behavior: design and evaluation study. *JMIR formative research, 5*(11), e29267.

Ter Harmsel, J. F., Van Dongen, J. D. M., Zijlmans, J., Van der Pol, T. M., Marhe, R., & Popma, A. (2022). Neurobiological Responses towards Stimuli Depicting Aggressive Interactions in Delinquent Young Adults and Controls: No Relation to Reactive and Proactive Aggression. *Brain sciences, 12*(2), 124.

Thomson, N. D., Kevorkian, S., Blair, J., Farrell, A., West, S. J., & Bjork, J. M. (2021). Psychophysiological underpinnings of proactive and reactive aggression in young men and women. *Physiology & behavior, 242*, 113601.

Thurber, M. R. (2007). Effects of heart-rate variability biofeedback training and emotional regulation on music performance anxiety in university students. *Dissertation Abstracts International Section A: Humanities and Social Sciences, 68*(3), 889.

Titzler, I., Saruhanjan, K., Berking, M., Riper, H., & Ebert, D. D. (2018). Barriers and facilitators for the implementation of blended psychotherapy for depression: A qualitative pilot study of therapists' perspective. *Internet interventions, 12*, 150-164.

Tolin, D. F., McGrath, P. B., Hale, L. R., Weiner, D. N., & Gueorguieva, R. (2017). A multisite benchmarking trial of capnometry guided respiratory intervention for panic disorder in naturalistic treatment settings. *Applied psychophysiology and biofeedback, 42*(1), 51-58.

Torous, J., Andersson, G., Bertagnoli, A., Christensen, H., Cuijpers, P., Firth, J., . . . Lewis, S. (2019). Towards a consensus around standards for smartphone apps and digital mental health. *World Psychiatry, 18*(1), 97.

Torous, J., Firth, J., Huckvale, K., Larsen, M. E., Cosco, T. D., Carney, R., . . . Wykes, T. (2018). The emerging imperative for a consensus approach toward the rating and clinical recommendation of mental health apps. *The Journal of nervous and mental disease, 206*(8), 662-666.

Tugade, M. M., Fredrickson, B. L., & Feldman Barrett, L. (2004). Psychological resilience and positive emotional granularity: Examining the benefits of positive emotions on coping and health. *Journal of personality, 72*(6), 1161-1190.

Umetani, K., Singer, D. H., McCraty, R., & Atkinson, M. (1998). Twenty-four hour time domain heart rate variability and heart rate: relations to age and gender over nine decades. *Journal of the American College of Cardiology, 31*(3), 593-601.

Vaessen, T., Rintala, A., Otsabryk, N., Viechtbauer, W., Wampers, M., Claes, S., & Myin-Germeys, I. (2021). The association between self-reported stress and cardiovascular measures in daily life: A systematic review. *PloS one, 16*(11), e0259557.

van Baardewijk, Y., Andershed, H., Stegge, H., Nilsson, K. W., Scholte, E., & Vermeiren, R. (2010). Development and tests of short versions of the youth psychopathic traits inventory and the youth psychopathic traits inventory-child version. *European Journal of Psychological Assessment*.

Van Buuren, S., & Groothuis-Oudshoorn, K. (2011). mice: Multivariate imputation by chained equations in R. *Journal of statistical software, 45*, 1-67.

Van Dongen, J. D., Brazil, I. A., Van der Veen, F. M., & Franken, I. H. (2018). Electrophysiological correlates of empathic processing and its relation to psychopathic meanness. *Neuropsychology, 32*(8), 996.

Van Doorn, M., Nijhuis, L. A., Monsanto, A., Van Amelsvoort, T., Popma, A., Jaspers, M. W. M., . . . Nieman, D. H. (2022). Usability, Feasibility, and Effect of a Biocueing Intervention in Addition to a Moderated Digital Social Therapy-Platform in Young People With Emerging Mental Health Problems: A Mixed-Method Approach. *Frontiers in psychiatry, 13*. doi:10.3389/fpsyt.2022.871813

Van Goozen, S. H., Fairchild, G., Snoek, H., & Harold, G. T. (2007). The evidence for a neurobiological model of childhood antisocial behavior. *Psychological bulletin, 133*(1), 149.

Van Lier, H. G., Pieterse, M. E., Garde, A., Postel, M. G., de Haan, H. A., Vollenbroek-Hutten, M. M., . . . Noordzij, M. L. (2019). A standardized validity assessment protocol for physiological signals from wearable technology: Methodological underpinnings and an application to the E4 biosensor. *Behavior Research Methods*, 1-23.

Vázquez, A., Jenaro, C., Flores, N., Bagnato, M. J., Pérez, M. C., & Cruz, M. (2018). E-health interventions for adult and aging population with intellectual disability: a review. *Frontiers in psychology*, 2323.

Velotti, P., Garofalo, C., Callea, A., Bucks, R. S., Roberton, T., & Daffern, M. (2017). Exploring anger among offenders: The role of emotion dysregulation and alexithymia. *Psychiatry, psychology and law, 24*(1), 128-138.

Venables, N. C., Hall, J. R., Yancey, J. R., & Patrick, C. J. (2015). Factors of psychopathy and electrocortical response to emotional pictures: Further evidence for a two-process theory. *Journal of abnormal psychology, 124*(2), 319.

VERBI Software, 2021. MAXQDA 2022 [computer software]. Berlin, Germany: VERBI Software. Available from maxqda.com.

Wagels, L., Habel, U., Raine, A., & Clemens, B. (2022). Neuroimaging, hormonal and genetic biomarkers for pathological aggression—success or failure? *Current opinion in behavioral sciences, 43*, 101-110.

Wagner, C. R., & Abaied, J. L. (2015). Relational victimization and proactive versus reactive relational aggression: The moderating effects of respiratory sinus arrhythmia and skin conductance. *Aggressive behavior, 41*(6), 566-579.

Wagner, C. R., & Abaied, J. L. (2016). Skin conductance level reactivity moderates the association between parental psychological control and relational aggression in emerging adulthood. *Journal of youth and adolescence, 45*(4), 687-700.

Wang, H. T., Yang, C. M., Chen, K. R., & Chueh, K. H. (2019). Relationship between heart rate variability and aggressive behavior among patients with schizophrenia hospitalized in acute wards. *Perspectives in psychiatric care*.

Wang, K., Varma, D. S., & Prosperi, M. (2018). A systematic review of the effectiveness of mobile apps for monitoring and management of mental health symptoms or disorders. *Journal of psychiatric research, 107*, 73-78.

Wang, L., & Miller, L. C. (2019). Just-in-the-moment adaptive interventions (JITAI): a meta-analytical review. *Health Communication*, 1-14.

Wang, Y., Lin, Y., Fu, C., Huang, Z., Xiao, S., & Yu, R. (2021). Effortless retaliation: the neural dynamics of interpersonal intentions in the Chicken Game using brain–computer interface. *Social cognitive and affective neuroscience*.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of personality and social psychology, 54*(6), 1063.

Weltman, G., Lamon, J., & Freedy, E. (2014). Police department personnel stress resilience training: an institutional case study. *Glob Adv Health Med, 3*(2), 72-79.

White, I. R., Royston, P., & Wood, A. M. (2011). Multiple imputation using chained equations: issues and guidance for practice. *Statistics in medicine, 30*(4), 377-399.

Whited, A., Larkin, K. T., & Whited, M. (2014). Effectiveness of emWave Biofeedback in Improving Heart Rate Variability Reactivity to and Recovery from Stress. *Applied psychophysiology and biofeedback, 39*(2), 75-88.

Whitten, P. S., & Mackert, M. S. (2005). Addressing telehealth's foremost barrier: provider as initial gatekeeper. *International journal of technology assessment in health care, 21*(4), 517-521.

Wiederhold, B., & Riva, G. (2012). Inter-reality in the evaluation and treatment of psychological stress disorders: the INTERSTRESS project. *Annual Review of Cybertherapy and Telemedicine: Advanced Technologies in the Behavioral, Social and Neurosciences, 181*, 8-11.

Wing, J., Beevor, A., Curtis, R., Park, S., Hadden, J., & Burns, A. (1998). Health of the nation outcome scales (HoNOS). *The British Journal of Psychiatry, 172*(1), 11-18.

Wisniewski, H., Liu, G., Henson, P., Vaidyam, A., Hajratalli, N. K., Onnela, J.-P., & Torous, J. (2019). Understanding the quality, effectiveness and attributes of top-rated smartphone health apps. *Evidence-based mental health, 22*(1), 4-9.

Wu, W., Gil, Y., & Lee, J. (2012). Combination of Wearable Multi-Biosensor Platform and Resonance Frequency Training for Stress Management of the Unemployed Population. *Sensors, 12*(10), 13225-13248.

Yu, B., Funk, M., Hu, J., Wang, Q., & Feijs, L. (2018). Biofeedback for everyday stress management: A systematic review. *Frontiers in ICT, 5*, 23.

Yucha, C., & Montgomery, D. (2008). *Evidence-based practice in biofeedback and neurofeedback*: AAPB Wheat Ridge, CO.

Zapata, B. C., Fernández-Alemán, J. L., Idri, A., & Toval, A. (2015). Empirical studies on usability of mHealth apps: a systematic literature review. *Journal of medical systems, 39*(2), 1-19.

Zebarjadi, N., Adler, E., Kluge, A., Jääskeläinen, I. P., Sams, M., & Levy, J. (2021). Rhythmic neural patterns during empathy to vicarious pain: Beyond the affective-cognitive empathy dichotomy. *Frontiers in human neuroscience*, 380.

Zhang, W., & Gao, Y. (2015). Interactive effects of social adversity and respiratory sinus arrhythmia activity on reactive and proactive aggression. *Psychophysiology, 52*(10), 1343-1350.

Zhao, Y., Ni, Q., & Zhou, R. (2018). What factors influence the mobile health service adoption? A meta-analysis and the moderating role of age. *International Journal of Information Management, 43*, 342-350.

Zijlmans, J., Marhe, R., van Duin, L., Luijks, M.-J., Bevaart, F., & Popma, A. (2021). No association between autonomic functioning and psychopathy and aggression in multi-problem young adults. *Frontiers in psychology, 12*, 686.

Zijlmans, J., van Duin, L., Jorink, M., Marhe, R., Luijks, M.-J. A., Crone, M., . . . Bevaart, F. (2021). Disentangling multiproblem behavior in male young adults: a cluster analysis. *Development and Psychopathology, 33*(1), 149-159.

Zucker, T. L., Samuelson, K. W., Muench, F., Greenberg, M. A., & Gevirtz, R. N. (2009). The effects of respiratory sinus arrhythmia biofeedback on heart rate variability and posttraumatic stress disorder symptoms: A pilot study. *Applied psychophysiology and biofeedback, 34*(2), 135-143.

Zwets, A. J., Hornsveld, R., Kraaimaat, F. W., Kanters, T., Muris, P., & van Marle, H. (2014). The psychometric properties of the anger bodily sensations questionnaire (ABSQ). *The Journal of Forensic Psychiatry & Psychology, 25*(4), 432-450.

SUPPLEMENTARY MATERIAL

APPENDIX A

Search strategy

("Biofeedback, Psychology"[MeSH] OR "Feedback, Physiological"[MeSH] OR Biofeedback[tw] OR Biosensor*[tw] OR (Sensor*[tw] AND Integrat*[tw]) OR Feedback[tw] OR "Real time"[tw] OR Realtime[tw] OR Monitoring[tw] OR Monitored[tw] OR Wearable*[tw]) AND (("Heart Rate"[MeSH] OR "Heart Rate"[tw] OR "Heart Rates"[tw] OR "Heart Rating"[tw] OR "Heart Ratings"[tw] OR "Heart frequency"[tw] OR "Heart frequencies"[tw] OR "Heart beat"[tw] OR "Heart beats"[tw] OR "Heart beating"[tw] OR "Heart beatings"[tw] OR Heartbeat*[tw]OR "Cardiac frequency"[tw] OR "Cardiac frequencies"[tw] OR "Ventricle Rate"[tw] OR "Ventricle Rates"[tw] OR "Ventricle Ratings"[tw] OR "Pulse Rate"[tw] OR "Pulse Rates"[tw] OR "Pulse Rating"[tw] OR "Pulse Ratings"[tw] OR "Cardiac Chronotropy"[tw] OR "Cardiac Chronotropies"[tw] OR "Cardiac Chronotropism"[tw] OR "Cardiac rate"[tw] OR "Cardiac rates"[tw] OR "Cardiac rating"[tw] OR "Cardiac ratings"[tw] OR HRV[tw]) OR ("Galvanic Skin Response"[MeSH] OR Dermogalvanic*[tw] OR ((Skin[tw] OR Cutaneous[tw]) AND (Conduct*[tw] OR Resistan*[tw] OR Impedanc* [tw] OR Galvanic*[tw]))) OR ("Respiration"[MeSH] OR Breathing[tw] OR Respirati*[tw] OR Inhalat*[tw] OR Exhalat*[tw])) AND ("Aggression"[MeSH] OR "Psychomotor Agitation"[MeSH] OR "Inhibition (Psychology)"[MeSH] OR "Impulsive Behavior"[MeSH] OR Aggression*[tw] OR Aggressiv*[tw] OR Inhibition*[tw] OR Disinhibition*[tw] OR Emotionality[tw] OR "Emotion Regulation"[tw] OR "Emotion Regulations"[tw] OR "Emotion Regulating"[tw] OR "Emotion Regulatings"[tw] OR "Emotion Management"[tw] OR Impulsiv*[tw] OR "Impulse Control"[tw] OR "Self Regulation"[tw] OR "Self Regulating"[tw] OR "Self Control"[tw] OR "Self Controlling"[tw] OR Agitat*[tw]) AND ("2007"[PDAT] : "2019"[PDAT])

APPENDIX B

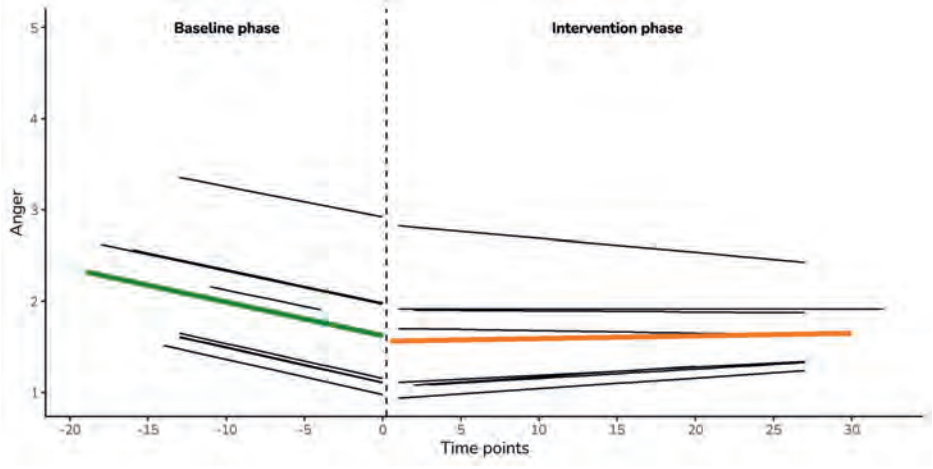
Establishment of the baseline procedure

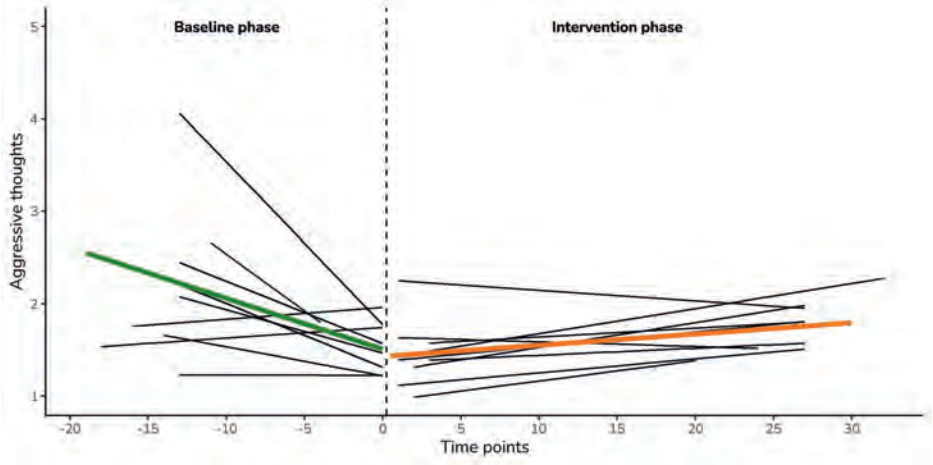
Group 1 (adults)	
Baseline procedure: - Started at end of baseline assessment (T0), in everyday life. Settings: - Sensitivity: normal - Notifications at: level 3,4,5 - Notifications during: all activity profiles, except car driving	"The mean heart rate should preferably be around 75; and SD should preferably be higher than 7. If heart rate is very different, consider a new baseline measurement. If SD is remarkably low (e.g., < 3), consider adjustment. Never forget to record adjustments."
⇩	
Group 2 (adults)	
Baseline procedure: - During baseline assessment (T0), with 1 min. of walking activity Settings: - Sensitivity: low - Notifications at: level 4,5 - Notifications during: all activity profiles, except car driving	"The mean heart rate is preferably around 85; the SD should preferably be higher than 7.5. If the heart rate is higher than 100, record the results and then start a new baseline measurement. If the SD is notably low (< 3) or high (> 20), again note the outcomes and then start a new baseline measurement."
⇩	
Group 3 (young adults)	
Baseline procedure: - During baseline assessment (T0), with 1 min. of walking activity Settings: - Sensitivity: normal - Notifications at: level 4,5 - Notifications during: all activity profiles, except car driving	"The mean heart rate is preferably around 85; the SD should preferably be higher than 7.5. If the heart rate is higher than 100, record the results and then start a new baseline measurement. If the SD is notably low (< 3) or high (> 20), again note the outcomes and then start a new baseline measurement."
⇩	
Group 4 (young adults)	
Baseline procedure: - During baseline assessment (T0), with 1 min. of walking activity Settings: - Sensitivity: low - Notifications at: level 4,5 - Notifications during: sitting still, walking	"The mean heart rate is preferably around 85; the SD should preferably be higher than 7.5. If the heart rate is higher than 100, record the results and then start a new baseline measurement. If the SD is notably low (< 3) or high (> 20), again note the outcomes and then start a new baseline measurement."

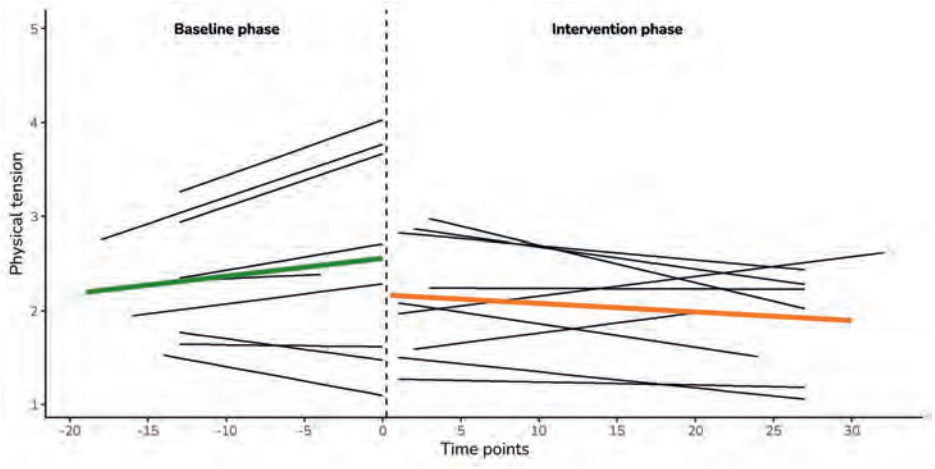
⇩	
Group 5 (adults)	
Baseline procedure: - During baseline assessment (T0), with 1 min. of walking activity Settings: - Sensitivity: low - Notifications at: level 4,5 - Notifications during: sitting still, walking	"The mean heart rate is preferably around 85; the SD should preferably be higher than 7.5. If the heart rate is higher than 100, record the results and start a new baseline measurement. If the SD is notably low (< 3) or high (> 20), again note the outcomes and then start a new baseline measurement."
⇩	
Group 6 (young adults)	
Baseline procedure: - During baseline assessment (T0), with 1 min. of walking activity Settings: - Sensitivity: low - Notifications at: level 4,5 - Notifications during: sitting still, walking	"The mean heart rate should preferably be around 80 (range: 60-90); the SD should preferably be higher than 7.5 (range: 5-12.5). If the heart rate or SD falls outside the range, note the results and start a new baseline measurement, paying close attention to the variation offered. Then choose the results of the baseline measurement that best matches the preferred settings; where the SD is of greater importance than the mean. "
⇩	
Group 7 (adults)	
Baseline procedure: - During baseline assessment (T0), with 1 min. of walking activity Settings: - Sensitivity: low - Notifications at: level 4,5 - Notifications during: sitting still, walking	"The mean heart rate should preferably be around 80 (range: 60-90); the SD should preferably be higher than 7.5 (range: 5-12.5). If the heart rate or SD falls outside the range, note the results and start a new baseline measurement, paying close attention to the variation offered. Then choose the results of the baseline measurement that best matches the preferred settings; where the SD is of greater importance than the mean."

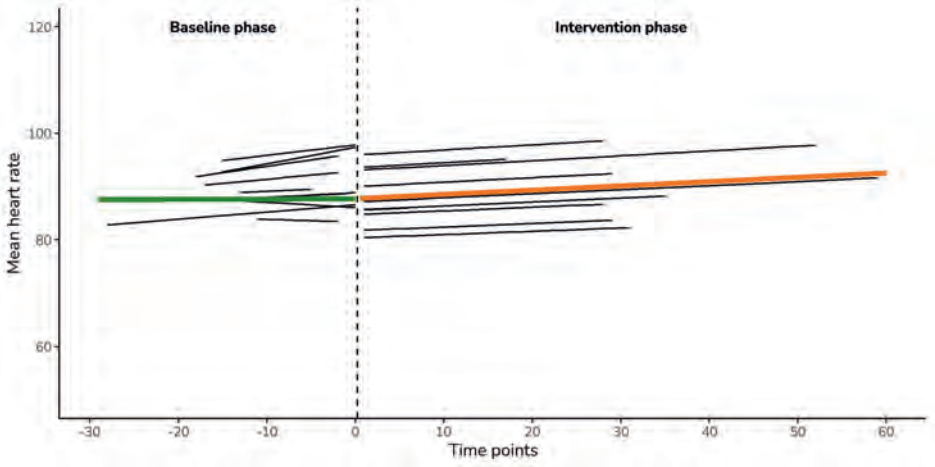
APPENDIX C

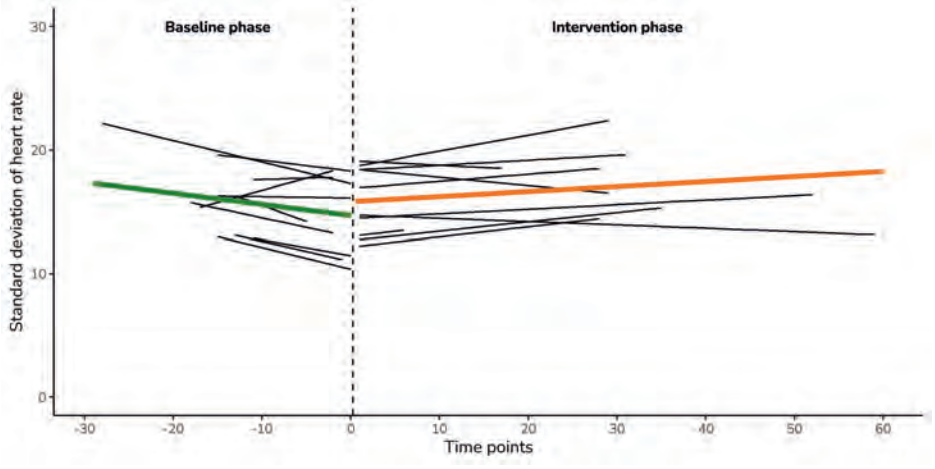
One- and two-level regression results for anger, aggressive thoughts, physical tension, mean heart rate and heart rate SD in baseline phase A_1 and intervention phase B.






Baseline phase
Intervention phase
Physical tension
Time points


Baseline phase
Intervention phase
Mean heart rate
Time points


Baseline phase
Intervention phase
Standard deviation of heart rate
Time points

APPENDIX D

Questioning route

Key questions and topics to be addressed:

1. What could be the main added value of implementing the Sense-IT app in treatment, in your opinion?
   [Topics to be addressed if they do not emerge]
   a. *For patients*
   b. *For therapists*
   c. *For (the efficacy of) treatment*
   [Optional topic, if sufficient time: For what type of patient, or in which phase in therapy do you expect that implementing the Sense-IT app would be most valuable?]

2. What do you see as the main barriers to implementing the Sense-IT app in treatment?
   [Topics to be addressed if they do not emerge]
   a. *Related to the Sense-IT app itself*
   b. *On the patient level*
   c. *On the therapist level*
   d. *On the organizational level*
   [Optionally, if they do not emerge: specifying subcategories of the organizational level]

3. What do you need to get started with the Sense-IT app in treatment? Name one to three facilitators.
   [Optionally, if this topic not emerged: Do you think that, as a therapist, you should have tried the Sense-IT app yourself first?]

4. Do you have any other recommendations that might promote the implementation of the Sense-IT app in treatment?

NEDERLANDSE SAMENVATTING

NEDERLANDSE SAMENVATTING

Agressie en gewelddadig delictgedrag hebben veel impact op slachtoffers, daders en de maatschappij als geheel. De forensische zorg, één van de partijen die belast is met het (al dan niet door justitie opgelegd) behandelen van grensoverschrijdend gedrag ter vermindering van recidive, staat daarmee voor een belangrijke taak. In de afgelopen jaren wordt steeds minder vaak voor klinische zorg gekozen en vaker ambulante interventies ingezet. Onderzoek binnen de ambulante forensische zorg is echter schaars, en de effectiviteit van de onderzochte behandelmethoden beperkt. Dit kan deels verklaard worden vanuit motivatieproblemen bij patiënten en de daarmee samenhangende beperkte *transfer* van dat wat in de therapie geleerd wordt naar de dagelijkse praktijk. Verder kan als mogelijke verklaring ook gedacht worden aan de beperkte aandacht binnen huidige interventies voor de moeite die veel patiënten hebben met het (tijdig) opmerken van lichamelijke spanningssignalen die samenhangen met boosheid. Dit onderzoeksproject richt zich dan ook op het ontwikkelen en onderzoeken van mogelijke aanvullingen op het huidige ambulante behandelaanbod.

Onze aandacht ging daarbij specifiek uit naar mogelijke interventies die voortborduren op de resultaten van psychofysiologisch onderzoek naar antisociaal en agressief gedrag. In dit type onderzoek staat de activiteit van het autonome zenuwstelsel (ANS) centraal, zowel in rust als in reactie op stressvolle stimuli. Uit meerdere studies is naar voren gekomen dat een verlaagde rusthartslag samenhangt met proactieve agressie en antisociaal gedrag. Reactieve agressie lijkt daarentegen juist geassocieerd met een verhoogde reactiviteit van de hartslag in reactie op stressvolle stimuli, zoals negatieve emoties of provocatie. Er zijn echter ook onderzoeken waaruit deze bevindingen niet naar voren komen, mogelijk door de grote variatie in de ernst van het agressieve gedrag binnen de verschillende groepen die zijn onderzocht. Daarnaast zijn in de afgelopen jaren verschillende onderzoeken gedaan waarbij agressief gedrag retrospectief werd voorspeld aan de hand van fysiologische gegevens. Uit deze studies kwam naar voren dat agressieve uitbarstingen vooraf worden gegaan door fysiologische veranderingen, zoals een toename in hartslag. Omdat er ook andere factoren zijn die voor een toename in hartslag kunnen zorgen, betekent dit niet dat agressie op een unieke en specifieke manier kan worden voorspeld uit hartslag. Wel geeft het aan dat hartslag een relevante – en door de recente ontwikkelingen in *wearable* technologie ook toegankelijke en bruikbare – variabele is om in het dagelijks leven te monitoren.

In onze zoektocht naar aanvullende interventies die gebruik maakten van psychofysiologische maten, stuitten we op biofeedback. Biofeedback wordt ingezet om patiënten te leren hun fysiologische reacties op emotionele situaties te reguleren door ze aan de hand van fysiologische feedback (zoals hartslag of

hartslagvariabiliteit) te laten trainen met verschillende reacties en deze al dan niet te bekrachtigen. In de loop der jaren werd het mogelijk om dit thuis, met draagbare apparatuur aangesloten op een eigen computer, te oefenen. Deze vorm wordt ook wel ambulante biofeedback genoemd. Door de snelle technologische ontwikkelingen werd het vervolgens ook mogelijk om met *wearable*, non-invasieve meetapparatuur (zoals borstbanden en polssensoren) fysiologische gegevens te registreren in het dagelijks leven van patiënten. Ook werd het mogelijk patiënten op specifieke momenten, bijvoorbeeld wanneer hun fysiologische waarden sterk oplopen, bewust te maken van hun fysiologische toestand en te voorzien van een bericht dat adequate coping ondersteunt – ook wel *just-in-time behavioral support* genoemd. Naar deze vorm van biofeedback verwijzen wij in dit proefschrift met de term *biocueing*. Waar bij ambulante biofeedback de focus ligt op het bevorderen van het buiten de sessies trainen van regulatievaardigheden, staan bij biocueing het vergroten van interoceptief bewustzijn door het *real-time* signaleren van fysiologische spanning in het dagelijks leven, en het adequaat reageren op toenemende spanning met behulp van *just-in-time* gedragsmatige ondersteuning centraal.

Het hoofddoel van de studies in dit proefschrift was dan ook om te onderzoeken of biocueing een haalbare en effectieve aanvulling is op de reguliere agressieregulatietherapie (ART) onder forensisch psychiatrische patiënten binnen de ambulante zorg.

Onderzoeksopzet

Omdat dit onderzoeksveld nog in de kinderschoenen stond, hebben we eerst de reeds bestaande literatuur nauwkeurig in kaart gebracht. We voerden een systematische review uit om een overzicht te geven van het onderzoek naar ambulante biofeedback en biocueing interventies ter bevordering van emotieregulatie. Ondertussen startten we een samenwerking met andere onderzoekers die met behulp van *user-centered design* een voorloper van de Sense-IT biocueing app hadden ontwikkeld. We verkenden allereerst de houding van therapeuten en andere forensische professionals ten aanzien van het gebruik van een *biocueing* interventie binnen de forensische psychiatrie. Vervolgens brachten we de haalbaarheid en bruikbaarheid in kaart door 10 forensische patiënten met agressief gedrag twee weken lang een eerste versie van de Sense-IT biocueing app te laten gebruiken. Met hun informatie werd een nieuwe versie van de Sense-IT app ontwikkeld. Vervolgens onderzochten we de eerste effecten van deze biocueing interventie als aanvulling op ART bij 25 forensische patiënten binnen de ambulante zorg. We gebruikten een quasi-experimenteel *pretest-posttest* groepsdesign, meerdere *single-case experimental designs* (SCEDs), en kwalitatieve informatie om veranderingen met betrekking tot interoceptief bewustzijn, emotieregulatie, en agressief gedrag in kaart te brengen. Omdat een succesvolle toepassing

van mHealth interventies sterk afhangt van de aansluiting bij de behoeften en voorkeuren van zowel patiënten als therapeuten, hebben we vervolgens de visies van 21 forensische patiënten en 15 therapeuten met betrekking tot het gebruik en de implementatie van de Sense-IT biocueing app nader geëvalueerd. Hiervoor namen we semi-gestructureerde interviews af bij de patiënten en organiseerden we twee focusgroepen met behandelaren. Tenslotte vergeleken we in een nevenproject de psycho- en elektrofysiologische reacties van 118 delinquente jongvolwassen op afbeeldingen met agressieve en neutrale interacties met de reacties van 25 controleproefpersonen, en onderzochten we onder de delinquente groep de relatie tussen deze maten en reactieve en proactieve agressie, met als doel een bijdrage te leveren aan het het neurobiologisch onderzoek naar agressie en breder antisociaal gedrag.

Bevindingen

In hoofdstuk 2 worden de resultaten van het systematisch literatuuronderzoek beschreven, waarmee we het onderzoek naar ambulante vormen van biofeedback ter verbetering van emotieregulatie in kaart brachten in zowel niet-psychiatrische als psychiatrische populaties. Ook leggen we in dit hoofdstuk het verschil uit tussen ambulante biofeedback interventies, waarbij patiënten thuis hun regulatievaardigheden kunnen trainen, en interventies die *real-time* feedback en *just-in-time* gedragsmatige ondersteuning in stressvolle situaties in het dagelijks leven mogelijk maken. Voor deze laatste categorie introduceren we in dit artikel de term *biocueing.* Na een uitgebreide literatuurstudie werd een selectie van 119 artikelen grondiger bestudeerd. Uiteindelijk bleken 30 studies aan de criteria voor opname in de review te voldoen. Ondanks de snelle vooruitgang op het gebied van *wearable* technologie werden, tot maart 2020, slechts vier biocueing studies gevonden. In het merendeel van de studies werden significante verbeteringen gevonden op zelfgerapporteerde stress-gerelateerde psychologische maten, zoals de *Perceived Stress Scale*. Ook werden er significante verbeteringen gerapporteerd op fysiologisch niveau, maar deze maten werden minder vaak gebruikt. Gelet op de haalbaarheid van het inzetten van deze nieuwe vormen van biofeedback geldt dat deze veelal als voldoende werd beoordeeld, maar dat deze in de meeste studies niet uitgebreid (zowel kwantitatief als kwalitatief) in kaart was gebracht. Met de nodige voorzichtigheid gezien de kleine steekproefgroottes en de beperkte kwaliteit van de meeste studies in dit nieuwe onderzoeksveld, concludeerden we dat, gezien de overwegend positieve resultaten, biocueing en ambulante biofeedback veelbelovende interventies leken die mogelijk als aanvulling op de reguliere behandeling kunnen worden ingezet. Gezien de aard en beperkte omvang van de beschikbare studies, werd het belang onderstreept van nader onderzoek naar de inzet van specifiek biocueing als interventie bij emotieregulatieproblematiek.

In hoofdstuk 3 beschrijven we het proces van design en evaluatie van de in onze studies gebruikte *wearable* interventie, de Sense-IT biocueing app. Uit de design-studie, waarin onder andere de houding van therapeuten en andere forensische professionals ten aanzien van *biocueing* binnen de forensische psychiatrie werd verkend, bleek een voorzichtig positieve houding ten aanzien van het gebruik van biocueing als aanvulling op ART. Het evaluatieonderzoek, waarin 10 forensisch ambulante patiënten met agressief gedrag een voorloper van Sense-IT app voor twee weken uittesten, toonde een gemiddelde mate van acceptatie en voldoende gebruiksvriendelijkheid aan. Daarnaast lieten exploratieve analyses een significante afname in dispositieboosheid zien na de interventie, hoewel er geen significante veranderingen werden gevonden in andere agressie-gerelateerde klinische uitkomsten. Belangrijke aanbevelingen om de acceptatie en bruikbaarheid van de Sense-IT app te vergroten waren onder andere verbeterde stabiliteit van de app, verbeteringen in het design, het zelf kunnen aanpassen van instellingen, het gebruik van smartwatches met een langere batterijduur, en het gebruik van de app op de eigen smartphones van patiënten.

Met behulp van de kwalitatieve feedback van de deelnemers werd een nieuwe versie van de Sense-IT app ontwikkeld.

Vervolgens onderzochten we in hoofdstuk 4 de effecten van deze biocueing interventie, met behulp van de nieuwe versie van de Sense-IT app, als aanvulling op ART. We gebruikten een quasi-experimenteel *pretest-posttest* groepsdesign, meerdere SCEDs, en kwalitatieve informatie om veranderingen met betrekking tot interoceptief bewustzijn, emotieregulatie, en agressief gedrag in kaart te brengen. Voor de periode waarin deze nieuwe interventie en ART gezamenlijk werden aangeboden, werd een significante afname in zelfgerapporteerd agressief gedrag gevonden in het *pretest-posttest* design. Daarnaast rapporteerde 76% van de deelnemers kwalitatief een verhoogd interoceptief bewustzijn geassocieerd met het gebruik van de Sense-IT biocueing app. De resultaten van de herhaalde ambulante metingen van de SCEDs wezen echter niet op een duidelijk effect ten gunste van de toevoeging van de biocueing interventie. Zo werden op groepsniveau geen significante effecten gevonden en liepen de effecten op individueel niveau uiteen, waarbij slechts bij twee deelnemers een effect ten gunste van de interventieconditie werd gevonden. Over het algemeen waren de effecten van de toevoeging van de biocueing interventie klein. We concludeerden dat biocueing beschouwd kan worden als een nuttige toevoeging om het interoceptieve bewustzijn te vergroten, maar benadrukten ook dat de huidige interventie – en meer specifiek de component van de app die gedragsmatige ondersteuning geeft – mogelijk niet van toegevoegde waarde is voor alle forensische patiënten met agressieregulatieproblematiek binnen de ambulante zorg.

In hoofdstuk 5 maakten we gebruik van de kwalitatieve informatie van forensische patiënten en therapeuten, verzameld middels semi-gestructureerde interviews en focusgroepen, om richtlijnen voor toekomstig gebruik en implementatie op te kunnen stellen. Zowel forensische patiënten als therapeuten toonden zich overwegend positief over de toevoeging van een biocueing interventie in de therapie, waarbij een toename in interoceptief en emotioneel bewustzijn door beiden het meest frequent als voordeel werd benoemd. Patiënten noemden daarnaast vooral technische of aan de innovatie gerelateerde belemmeringen (zoals verbindings- en meldingsproblemen, ervaren onnauwkeurigheid van de feedback, en beperkte mogelijkheden om de instellingen te personaliseren). Therapeuten rapporteerden zowel belemmeringen als faciliterende factoren op technisch, individueel, en organisatorisch niveau, waarbij de meeste uitspraken betrekking hadden op het individuele therapeut- en patiëntniveau. De meest genoemde belemmeringen waren beperkingen in de bruikbaarheid van de app, de motivatie van patiënten, en de kennis en vaardigheden van zowel therapeuten als patiënten. Integratie in de therapie, expertise binnen het therapeutenteam, en het beschikbaar stellen van tijd en materialen werden als faciliterende factoren geïdentificeerd. We concludeerden dat de kans op succesvolle implementatie en blijvend gebruik van nieuwe mHealth interventies, zoals de Sense-IT app, kan worden vergroot door zorgvuldig rekening te houden met deze belemmerende en faciliterende factoren.

Tenslotte brachten we in een nevenproject de neurobiologische reacties op agressieve interacties onder delinquente jongvolwassenen en controleproefpersonen in kaart. In hoofdstuk 6 onderzochten we verschillen in zowel psychofysiologische responsen (zoals hartslag en huidgeleiding) als elektrofysiologische responsen (zoals de P3 en LPP, specifieke responsen in het brein die worden gerelateerd aan emotieregulatie) op afbeeldingen met agressieve en neutrale interacties tussen beide groepen. We vonden een significant hogere huidgeleidingsreactiviteit tijdens de taak in de delinquente groep vergeleken met de controlegroep. In tegenstelling tot onze verwachtingen was dit effect echter onafhankelijk van de conditie, dus zowel in reactie op afbeeldingen met agressieve als neutrale interacties. Dit zou kunnen suggereren dat in een (mild) delinquente jongvolwassen populatie de *arousal* in het algemeen verhoogd is, maar niet specifiek tijdens agressieve situaties. Daarbij vonden we geen verschillen tussen groepen en condities voor al de andere maten. Ook vonden we geen associaties tussen de neurobiologische maten en reactieve en proactieve agressie binnen de delinquente groep. We concluderen daarom dat, hoewel we enige aanwijzingen vonden voor emotionele ontregeling bij deze delinquente jongvolwassenen, toekomstige studies de neurobiologische mechanismen die ten grondslag liggen aan emotieregulatieproblemen geassocieerd met verschillende typen van agressie verder moeten verhelderen.

Sterkten van het onderzoek

Zoals aangegeven toonde het literatuuronderzoek aan dat het gebruik van biocueing ter bevordering van emotieregulatie, zeker onder psychiatrische populaties, nog in de kinderschoenen stond bij aanvang van dit project. Daarnaast geldt dat er in de afgelopen jaren binnen klinische settingen wel meerdere studies zijn uitgevoerd naar het voorspellen van agressief gedrag aan de hand van fysiologische informatie, maar dat de daaruit opgedane kennis nog weinig wordt toegepast binnen de ambulante forensische zorg. Het huidige onderzoeksproject betreft dan ook één van de eerste studies naar de inzet van biocueing op basis van fysiologische informatie onder een forensisch ambulante patiëntenpopulatie, waarbij zowel op kwantitatief als kwalitatief niveau veel informatie is verzameld die relevant is voor toekomstig onderzoek naar de inzet en implementatie van nieuwe technologische interventies in de klinische praktijk.

Een andere kracht van het huidige onderzoek is dat de studies goed waren ingebed in de dagelijkse klinische praktijk, wat de ecologische validiteit en de vertaling van deze onderzoeksresultaten naar de praktijk ten goede komt. Omdat de studies werden uitgevoerd door een *scientist-practitioner*, kon het gebruik van de biocueing interventie goed worden afgestemd op de reguliere behandelmethode en de werkwijze binnen de instelling.

De nauwe samenwerking met therapeuten, patiënten, onderzoekers en ontwikkelaars kan als een andere sterkte van dit onderzoeksproject worden beschouwd. Gedurende dit project is een iteratieve aanpak gehanteerd, waarbij in verschillende ontwikkelingsronden de feedback van patiënten en de aandachtspunten van behandelaren en onderzoekers zijn verwerkt. Na de twee studies onder patiënten werden therapeuten opnieuw betrokken om belemmerende en faciliterende factoren voor toekomstige implementatie van de Sense-IT biocueing app te identificeren.

Tenslotte is, door gebruik te maken van meerdere SCEDs, veel informatie gegenereerd op het niveau van de individuele patiënt. Deze methode krijgt recent steeds meer aandacht wanneer onderzoek wordt gedaan naar de toepassing van nieuwe interventies in de klinische praktijk, met name ook onder complexe patiëntenpopulaties. Ook wordt deze methode veel gebruikt ter evaluatie van technologische interventies, waarvoor traditionele onderzoeksdesigns vaak onvoldoende flexibiliteit bieden. Hoewel deze methode ook uitdagingen met zich meebracht (zie beperkingen), sluit deze aanpak goed aan bij de toenemende aandacht voor meer gepersonaliseerde behandelvormen binnen de psychiatrie (*personalized medicine*), en kan dit project derhalve een inspiratie vormen voor andere onderzoekers die nieuwe, gepersonaliseerde interventies willen onderzoeken in de klinische praktijk.

Beperkingen van het onderzoek
Het doen van klinisch relevant onderzoek, in nauwe samenwerking met patiënten en therapeuten, ging ook gepaard met de nodige uitdagingen. Zo werd vanwege vertragingen in het toetsingsproces door de medische-ethische commissie, de beperkte instroom en de te geringe flexibiliteit voor het onderzoeken van een technologische interventie binnen een traditioneel onderzoeksdesign, het design gewijzigd naar meerdere SCEDs. Dit heeft veel informatie gegenereerd op het niveau van de individuele patiënt, maar maakt de uitkomsten moeilijker te generaliseren naar een groep. Met die reden hebben we besloten de SCED-resultaten niet alleen op individueel maar ook op groepsniveau te analyseren, zoals geadviseerd bij het bestuderen van nieuwe, gepersonaliseerde interventies binnen kleine steekproeven.

Een andere belangrijke beperking is dat, doordat de EMA-vragen in Deelproject II geïntegreerd waren in de Sense-IT app, het voor sommige patiënten lastig was om onderscheid te maken tussen de biocueing interventie en onderdelen van de onderzoeksopzet. Bovendien kan het feit dat ambulante forensische patiënten, die vaak moeite hebben met het reflecteren op hun emoties en gedrag, door de dagelijkse onderzoeksvragen werden gefaciliteerd om dit te doen, het bewustzijn van emoties hebben vergroot. Het is mogelijk dat het gebruik van dagelijkse EMA-vragen dus een therapeutisch effect heeft gehad, ook in de controlefase. De positieve veranderingen die voor enkele individuele patiënten al in de controlefase van de SCEDs werden gevonden, alsook de richting van het verband zoals geïndiceerd door de coëfficiënten op groepsniveau, zouden hierop kunnen wijzen. Deze factoren bemoeilijken derhalve een al te stellige interpretatie van de effecten van de biocueing interventie.

Een andere beperking is dat bij meerdere deelnemers na de interventiefase de motivatie voor het gebruik van de Sense-IT app in het kader van het onderzoek leek af te nemen. De *smartwatch* werd in de follow-up fase weinig gedragen en er werden weinig EMA-vragen ingevuld. De analyses werden hierop aangepast: enkel de controlefase en interventiefase van de deelnemers met voldoende metingen konden betrouwbaar met elkaar worden vergeleken. Door het ontbreken van de follow-up fase kon derhalve niet worden onderzocht of gevonden effecten aanhielden na het beëindigen van de interventie. Tevens geldt dat de EMA-vragen op een 5-punts Likert schaal werden beantwoord. Dit kan een nadelig effect hebben gehad op de variatie in de data, en daarmee op de resultaten.

Verder geldt dat er sprake was van uitval, met name in Deelproject II. Hoewel de uitval vergelijkbaar is met andere studies onder forensisch ambulante patiënten met agressief gedrag, is het mogelijk dat er meer patiënten met negatieve ervaringen zijn uitgevallen. Om dit te voorkomen, moedigden we patiënten die aangaven dat

ze de app niet langer wilden gebruiken of daar al mee gestopt waren, aan om alsnog deel te nemen aan de nameting. Hoewel we daarmee het risico op vertekening in de kwantitatieve en kwalitatieve groepsresultaten hebben verminderd, hebben we niet volledig kunnen voorkomen dat een aantal patiënten enkel de apparatuur inleverde zonder verder aan metingen mee te werken.

Daarnaast geldt dat, gelet op de redenen voor uitval, de combinatie van een biocueing-interventie met regelmatige meldingen en een studieopzet met dagelijkse metingen voor sommige patiënten te veeleisend is geweest en mogelijk tijdelijk voor meer spanning heeft gezorgd; een mogelijkheid die ook in de literatuur reeds werd benoemd. Voor een aantal patiënten lijkt de ervaren discrepantie tussen de subjectief ervaren spanning en de ontvangen feedback tot irritatie en frustratie te hebben geleid. Tevens gaven enkele patiënten aan de feedback als te confronterend te hebben ervaren. Anderzijds moet worden opgemerkt dat in de levens van deze patiënten vaak al meerdere stressoren aanwezig waren, en zich soms ook gedurende het onderzoek belangrijke levensveranderingen voordeden, waardoor het gebruik van de app en deelname aan het onderzoek een te grote extra belasting werd.

Op het niveau van de Sense-IT app geldt verder dat de *baseline* meting, waarop de niveaus worden gebaseerd, nog nadere aandacht vraagt. Gelet op de ambulante setting werd gekozen voor een korte baselinemeting, met beperkte variatie in beweging. Dit kan ervoor gezorgd hebben dat sommige deelnemers op een eerder moment, en naar hun mening te vaak, meldingen ontvingen. Een langere baselinemeting, met meer variatie, zou hier mogelijk aan bij kunnen dragen. Ook het gegeven dat de overgang naar een nieuwe fase door een onderzoeker handmatig moest worden aangezet, kan voor extra belasting van de deelnemers hebben gezorgd.

Tenslotte geldt dat de deelnemers binnen het onderzoeksdesign minder ruimte hadden om de Sense-IT app op een volledig gepersonaliseerde manier te gebruiken. Zo hadden deelnemers graag alle instellingen zelf willen kunnen aanpassen. Vanwege gegevensopslag en omdat enkele deelnemers geen eigen *smartphone* hadden, werd gekozen voor het gebruik van onderzoekstelefoons. Meerdere deelnemers gaven aan dat ze het vervelend vonden om twee telefoons bij zich te dragen en hadden liever de Sense-IT app op hun eigen telefoon gebruikt. Daarnaast geldt dat de *smartwatches* nog een enigszins beperkte batterijduur (+/- 8 uur) hadden. Al deze punten hebben vermoedelijk bijgedragen aan een suboptimale gebruiksvriendelijkheid van de Sense-IT app, wat invloed kan hebben gehad op zowel de uitval als de resultaten.

Conclusie

Concluderend laten de studies in dit proefschrift een overwegend positieve houding zien onder zowel patiënten als therapeuten ten opzichte van biocueing als een aanvullende interventie binnen de (ambulante) forensische psychiatrie. De resultaten toonden voldoende gebruiksvriendelijkheid aan voor gebruik van de onderzochte biocueing interventie in de praktijk. Verdere doorontwikkeling en verfijning van de app blijven echter noodzakelijk. Daarnaast zijn er enkele aanwijzingen gevonden voor positieve veranderingen op het gebied van agressief gedrag en interoceptief bewustzijn samenhangend met het gebruik van de Sense-IT app, maar geldt dat de huidige resultaten onvoldoende sterk zijn om definitieve uitspraken te kunnen doen over de effecten van biocueing als aanvullende interventie. De effectiviteit van biocueing dient daarom in de toekomst verder onderzocht te worden. Meer specifiek, en in lijn met de verschuiving naar het ontwikkelen van meer gepersonaliseerde behandelinterventies, zou toekomstig onderzoek erop gericht moeten zijn om vast te stellen welke patiënten ondersteund worden door (welke onderdelen van) een biocueing interventie, en, indien van toepassing, wanneer en hoe gedragsmatige ondersteuning op de meest effectieve manier kan worden ingezet. Aangezien verwacht wordt dat de ontwikkeling en het gebruik van gepersonaliseerde behandelinterventies de komende jaren verder zullen toenemen, is het voor een toekomstbestendige forensische zorg van belang om in te zetten op het verbeteren van de bruikbaarheid, nadere afstemming op individuele behoeften, integratie in de therapie en het vergroten van de affiniteit met dit type interventies, in voortdurende co-creatie met patiënten en therapeuten.

DANKWOORD

DANKWOORD

Ongelooflijk. Na al die jaren is het dan toch echt af! Zeker in de eerste helft van deze marathon, toen er vooral veel en lang gewacht moest worden, heb ik me afgevraagd waarom deze eindstreep nou zo nodig door mij behaald moest worden. Ik herinner me zelfs tranen van respect (gemengd met een vleugje jaloezie) wanneer mensen wel het verstandige besluit namen om eerder uit te stappen. Maar, wat ik uit het lopen van een echte marathon weet, bleek ook hier waar: over de helft bleek het vooral een kwestie van rustig doorlopen en volhouden. Toen ik de eindstreep eenmaal rook, wist ik er met de nodige discipline nog een behoorlijke eindsprint uit te persen, met dit proefschrift als resultaat. Het schrijfproces, dat ik als een vrij eenzame strijd heb beleefd, werd gelukkig verlicht door een hoop aanmoediging van vrienden en familie vanaf de zijlijn. Daarnaast was dit onderzoek, wat al met al toch een heel leerzame ervaring was, er niet geweest zonder de inzet en volharding van een heel aantal mensen. Tijd om jullie, zwart op wit, te bedanken!

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De eerste zaadjes voor dit onderzoeksproject werden – ergens in een zonnig oord, als ik me niet vergis – geplant door Thimo en Arne. Iets later sloten ook Matthijs en Anneke aan, waardoor ik mij rijk kon rekenen met een vierkoppig team van promotoren en co-promoteren, met een berg aan kennis en ervaring.

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Anneke, de 'female touch' in dit gezelschap! Zoals je opmerkte na de indiening van mijn proefschrift is de promovendus in het systeem van de VU nog altijd een man, terwijl de werkelijkheid toch leert dat het aantal vrouwen dat promoveert het aantal mannen inmiddels is voorbijgestreefd. Dank voor het delen van jouw kennis en ervaring met het doen van onderzoek in complexe patiëntenpopulaties. Wanneer we ergens tegenaan liepen, had jij vaak al een concrete oplossing paraat. Ook aan je feedback op mijn artikelen heb ik veel gehad. Dank voor je vooruitziende blik en

scherpte! Daarnaast heb je laten zien dat het mogelijk en van toegevoegde waarde is om wetenschap en praktijk te combineren. Ik kan me zo voorstellen dat dit ook geholpen heeft om het pad te effenen naar de kans die ik heb gekregen om binnen Arkin naast mijn promotietraject ook de GZ-opleiding te volgen!

Matthijs, zonder jouw hulp was dit proefschrift er zeker nooit gekomen. Vanzelfsprekend vanwege jouw kennis van de interactie tussen mens en technologie, waarvan ik voor ik dit traject begon nog maar weinig kaas gegeten had. Maar, nog veel meer vanwege jouw vaardigheid om aannames kritisch onder de loep te nemen, door te vragen en mij uit te dagen om alternatieve verklaringen te onderzoeken. Dank daarvoor! Daarnaast heb je mij ontzettend geholpen met alle statistische analyses en bleek je mijn redder in nood als R weer eens vastliep binnen de (nog niet optimaal op onderzoekers ingerichte) praktijkinstelling. Ik kijk met een glimlach terug op de neurotische blijdschap wanneer na veel gepuzzel alles dan toch echt werkte: ware wetenschappers aan het werk. Daarnaast ben ik je dankbaar voor je rust, je vriendelijkheid en betrouwbaarheid: zou dat nu versterkt worden door compassievolle technologie of het resultaat zijn van sporten en mediteren? Nieuwe onderzoeksvragen te over: die zwaartekrachtsubsidie voor het onderzoeken van stress in het dagelijks leven komt je meer dan toe, en belooft veel interessante bevindingen voor de toekomst!

Thimo, zoals gezegd sta jij aan de bron van dit promotietraject. Door jouw voorbereidende werk hebben we dit praktijkgerichte onderzoek op poten kunnen zetten. Hoewel we op een aantal dimensies niet verder uit elkaar zouden kunnen liggen en het ook regelmatig niet met elkaar eens waren, heb ik je betrokkenheid erg gewaardeerd. Een mooie kaart bij een mijlpaal, een belletje als er na eindeloze bureaucratie dan toch een 'go' kwam, een fles champagne bij het eerste artikel, de zoveelste onderzoeksborrel: vieren kan je als de beste! Daarnaast heb ik respect voor je lef om met je ideeën naar buiten te treden. Zelf houd ik het graag klein en met heel veel mitsen en maren omkleed, maar ik ben me gedurende dit traject steeds meer gaan beseffen hoe belangrijk ook de 'sales'-kant is binnen de wetenschap. Tenslotte realiseerde ik me op het IAFMHS congres in Berlijn nog weer hoe innovatief we bezig zijn bij Inforsa. Heel benieuwd naar wat jij de komende jaren met de toppers van de Academische Werkplaats, ofwel het 'CrimeLab', gaat bewerkstelligen!

Dank aan jullie voor de begeleiding gedurende dit traject, en zeker ook voor de steun en waardevolle feedback op mijn werk in de laatste maanden. Toen de reminders jullie om de oren vlogen hebben jullie vast de eerdere opmerking van Arne over de planning 'ambitieus, maar haalbaar' (waarvan bij mij alleen 'haalbaar' bleef hangen) betreurd. Glad we made it!

Leden van de leescommissie, prof. dr. Lydia Krabbendam, prof. dr. Wim Veling, prof. dr. Maaike Kempes, dr. Peter de Looff en dr. Lucres Nauta: heel hartelijk dank voor de aandacht en moeite die jullie hebben genomen om mijn proefschrift te lezen en te beoordelen. Extra fijn dat jullie hier rond de zomervakantie tijd voor wilden maken. Ik zie er naar uit om met jullie van gedachten te wisselen!

Natuurlijk wil ik ook Randy en Youri bedanken, die de eerste versie van de Sense-IT app ontwikkelden en daarmee een belangrijk deel van de weg voor mij hebben geëffend. Mooi dat na al die jaren hard werken het onderzoek naar het ondersteunen van emotioneel bewustzijn met behulp van de Sense-IT app steeds meer aandacht krijgt. Moniek, ook jou wil ik bedanken! Wat een uitdaging was het om alle vereisten voor de app vanuit de jeugdzorg en forensisch zorg bij elkaar te krijgen en vervolgens voldoende duidelijk over te brengen naar de 'technische jongens'. Zonde dat we niet langer samen op konden trekken! Daarnaast dank aan Karin voor het samen sparren en uitwerken van het plan in het kader van de Implementatie-impuls, met een prachtig resultaat! Tevens dank aan al de partijen die, binnen en buiten het Sense-IT consortium, hebben geholpen bij de doorontwikkeling van de app en website.

Mijn dank gaat ook uit naar alle behandelaren van Inforsa die mij geholpen hebben om in contact te komen met potentiële deelnemers aan de Sense-IT studies. Dat was niet altijd makkelijk, zeker als een cliënt in crisis raakte, tijdelijk niet bereikbaar was of gewoon geen zin had, maar vaak vonden we samen toch weer een ingang! Yolanda, van contracten en autorisaties tot etentjes en FAZ kerstevents, dank voor al jouw hulp bij de onophoudelijke stroom regelzaken! Dank ook aan Eline, die na haar stage nog een tijd bleef als onderzoeksassistent, en aan al de masterstudenten die hebben meegewerkt aan deze studie (of de voorbereidingen of naweeën ervan hebben meebeleefd): Merel, Martijn, Elise, Geeske, Tamara, Jessica, Rogier, Laura, Nine, Leonie, Bo, Christiaan, Annemiek, Lotte, Michelle, Nienke, Lisette, Wiesje, Lisa, Roos, Ashira, Vera, Esry, Christine, Cylia, Melanie, Joris, Margreet, Isabella en Lisa. Jullie hebben een hoop werk verzet: vragenlijsten en interviews afgenomen, niet-werkende smartwatches weer aan de praat gekregen, cliënten gemotiveerd, een hoop fietskilometers afgelegd en regelmatig voor dichte deuren gestaan, maar niet opgegeven! Het medicijn voor teleurstelling: een fikse dosis relativeringsvermogen, humor, drankjes en af een toe een mooie unboxing-session. In telkens wisselende samenstellingen hebben jullie voor een écht teamgevoel gezorgd, waarbij jullie ook elkaar weer verder konden helpen. Leuk dat sommigen van jullie elkaar nog steeds spreken! Ik denk dat jullie een goed beeld hebben gekregen van de uitdagingen en weerbarstigheid van het doen van wetenschappelijk onderzoek in de klinische praktijk, hoewel dat velen van jullie niet bepaald heeft aangemoedigd om een wetenschappelijke carrière te overwegen. Cylia, jij bent niet ontmoedigd geraakt: superleuk dat jij en Lisanne nu, met nieuwe energie, creativiteit en enthousiasme,

de innovatieve onderzoeksprojecten naar VR en biocueing verder gaan vormgeven. Het verschil tussen de oude en nieuwe generatie werd al mooi duidelijk in Berlijn, waar de oude garde van A naar B wandelde en jullie je op hippe steps verplaatsten. Ik heb alle vertrouwen in jullie! En weet dat je bij Jochem altijd in statistische nood aan kunt kloppen, nogmaals dank aan jou ook!

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Zelf had ik dit promotietraject nooit vol kunnen houden als dat mijn enige taak was geweest. Ik ben blij dat ik al die jaren zowel binnen als buiten Inforsa meer werkervaring kon opdoen als behandelaar. Mijn dank gaat uit naar alle oud-collega's van het forensisch ACT en later het FACT-team van Inforsa waar ik als groentje binnenkwam. Wat heb ik in die jaren een hoop geleerd van jullie, door de wol geverfde, collega's! To name a few: Pieter, Maarten, Lieke, Matijn, Rolf, Gijs, Michael, Ashanti, dank voor jullie kennis, humor en relaxtheid in toch regelmatig vrij pittige en bij lange na niet doorsnee casuïstiek. En voor de vele borrels, waarvan die in het raam en op het dak van de SAR absoluut in mijn geheugen staan gegrift. Hommo en Agnes, ook jullie laten je het hoofd niet gek maken en leken juist opvallend goed te gaan op de crisisachtige situaties waar ik stress van kreeg. Dank voor het gelijkwaardige intercollegiale overleg (nee, ik zal het écht nooit

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OTHER PUBLICATIONS

OTHER PUBLICATIONS

Swinkels, L. T. A., Hendriks, C. B. L., Van der Pol, T. M., Popma, A., Ter Harmsel, J. F., Reef, J., & Dekker, J. J. M. (2022). The impact of COVID-19 restrictions on social relationships of forensic psychiatric outpatients with preexisting social network-related problems: A mixed methods study. Journal of Forensic Psychology Research and Practice, 1-16.

Swinkels, L. T. A., Van der Pol, T. M., Popma, A., Ter Harmsel, J. F., & Dekker, J. J. M. (2020). Improving mental wellbeing of forensic psychiatric outpatients through the addition of an informal social network intervention to treatment as usual: A randomized controlled trial. BMC Psychiatry, 20(1), 1-15.

Ter Harmsel, J. F., Molendijk, T., van El, C. G., M'Charek, A., Kempes, M., Rinne, T., & Pieters, T. (2016). Rapportages Pro Justitia van het Nederlands Instituut voor Forensische Psychiatrie en Psychologie in retrospectief; toepassingen van genetische en neurowetenschappelijke inzichten, in 2000 en 2009. Tijdschrift voor Psychiatrie, 58(1), 20-29.

CURRICULUM VITAE

ABOUT THE AUTHOR

Annemieke ter Harmsel was born on the 16th of February 1989 in Rijssen, The Netherlands. Janna Frederiek ter Harmsel is her official name, which would later cause much confusion in the bureaucratic caverns of science. She completed her secondary education at the Jacobus Fruytier Scholengemeenschap in Apeldoorn, in 2007. After her graduation, she moved to Groningen to study Linguistics at the University of Groningen. In her second year, she also started to study Psychology. Over the years, she developed a specific interest in forensic (neuro)psychology. While completing her bachelors, she got the great idea to combine three masters, at the University of Groningen and the University of Tilburg. In 2012, she obtained her master degree in Neurolinguistics (cum laude), and in 2013 her master degrees in Neuropsychology (cum laude) and Forensic Psychology (with distinction). During her studies, she worked as a research assistant at the University Medical Center Groningen and, later, as a junior researcher for a project of the Vrije Universiteit Medical Center and psychiatric observation clinic Pieter Baan Centrum.

Annemieke entered clinical practice with her neuropsychology internship at the rehabilitation center Beatrixoord and, soon after, with a forensic internship assisting a psychologist reporting for the Netherlands Institute for Forensic Psychiatry and Psychology (NIFP). After graduation, she worked as a junior researcher and psychodiagnostician at forensic psychiatric center De Oostvaarderskliniek. In 2014, she started as a scientist-practitioner at the outpatient department (FACT team) of Inforsa, the forensic mental healthcare department of Arkin. Meanwhile, she extended her experience outside the forensic field, working as a psychologist at Fidea. After overcoming several barriers and a few breakdowns, she officially started her PhD-project in July 2016. This project was carried out at Inforsa (Arkin), in collaboration with researchers from the Amsterdam University Medical Center (Vrije Universiteit) and the University of Twente. In 2018, Annemieke started her training to become a licensed healthcare psychologist (GZ-psycholoog) at Arkin. While in training and running her PhD project, she worked for two years as a psychologist at the outpatient department of Inforsa. In 2020, she moved for two more years to trauma treatment center Sinai Centrum. Here, she developed a specific interest in treatment of veterans with PTSD and anger regulation difficulties. After completing her training in December 2021, she made the tough decision to solely focus on her PhD-project for six months.

While writing the current section, she is enjoying a mini-sabbatical. Besides starting a training to become a Pro Justitia reporting psychologist at the NIFP, she has no fixed plans yet. However, it is clear that she will leave the academic world, hoping to contribute more directly to patients' mental health and accessible mental healthcare by focusing on her clinical work.