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Stress reduction interventions: A scoping review to explore progress toward use of haptic feedback in virtual reality

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With the objective of providing scientific guidance for the development of a multisensory virtual reality (VR) relaxation device using haptic stimulation, the present review focuses on analysis of existing traditional and VR-based stress reduction interventions as well as their relevant measures. Two primary methods of stress reduction are explored: relaxation techniques and meditation techniques. Relaxation techniques enable the practitioner to achieve a tension-free state through control of and reduction in physiological activity. Meditation techniques also induce a relaxation response, but can additionally increase sustained attention to the present moment, to one's own bodily sensations, emotions, tensions, thoughts, *etc.*, or to an object, without judgement or adherence to a particular perspective. The limitations of traditional techniques are also noted, including the time required for training or mastery and the need for visualization efforts, and the benefits of VR-based relaxation techniques for the user are explored: these include the reduction of negative emotions, stress, anxiety, depression, and pain, as well as improved relaxation and positive affect. Particular attention is paid to the multisensorial approach made possible by VR. However, while it has been known for decades that tactile stimulation is very efficient to relax users, reduce stress, and induce positive emotions, tactile stimuli are currently under-exploited in VR-based stress reduction interventions. This review focuses specifically on touch and its beneficial effects on stress and affect. Finally, we discuss and provide forward-looking perspectives on the present and future use of tactile stimulation as a component of VR tools designed to reduce stress.

KEYWORDS

stress reduction, relaxation techniques, meditation techniques, virtual reality, tactile stimulation, multisensorial approach

Introduction

Many people experience stress during their lives including health professionals (Kushal et al., 2018), parents (Leitch et al., 2019), athletes (Mcloughlin et al., 2021), students (Reddy et al., 2018; Pascoe et al., 2020), and general population during the COVID-19 pandemic (Salari et al., 2020). Stress consists of a range of physical responses that an individual experiences when interacting with an environment appraised as delicate, constraining, or disruptive to his or her well-being (McGowan et al., 2006; Shahsavarani et al., 2015). Stress can be acute or chronic: that is, it may be related to a single spontaneous event (e.g., a public speaking event, a layoff, or a near-miss traffic incident) or to an ongoing set of circumstances or recurring event (e.g., marital problems, work-related strain, or persistent financial adversity). Stress has a high prevalence worldwide, but its exact prevalence and causes in a given society depend on various factors. For example, in a Canadian survey conducted in 2018 and 2019, approximately 22% of adults reported perceiving most days of their lives as somewhat or extremely stressful (Statistics Canada, 2020). In the same vein, in a United Kingdom online study by the Mental Health Foundation conducted in 2018, 74% of the 4,619 respondents reported feeling so much stress in the past year that they felt overwhelmed or unable to cope (Mental Health Foundation, 2021). Finally, a 2019 online survey of 3,617 adult US residents conducted by the American Psychological Association found that the most commonly-reported sources of stress were health care (71%), mass shootings (69%), and the political climate (62%; American Psychological Association, 2019); this is without considering the global pandemic that began in 2019. Indeed, since the onset of the COVID-19 pandemic, studies have been unanimous: stress has significantly increased among the general population. In a study by Turna et al. (2021), for example, 62.5% of North American participants reported experiencing significant stress, which is much higher than the 2018–2019 prevalence reported by Statistics Canada (2020). While a few studies have indicated that stress-related changes can generate positive outcomes for individuals (e.g., Aschbacher et al., 2013; Dierolf et al., 2018; Yaribeygi et al., 2017), most existing studies have conversely indicated that these changes can be triggering or aggravating factors for many diseases. Indeed, stress can lead to cognitive, psychological, and physical damage, with outcomes such as poor memory (Sandi, 2013), post-traumatic stress disorder (Shahsavarani et al., 2015; Turner et al., 2020), depression (Garfin et al., 2018; Shahsavarani et al., 2015; Turner et al., 2020), anxiety (Garfin et al., 2018; Turner et al., 2020), cardiovascular diseases (Shahsavarani et al., 2015; Slavich, 2016; Steptoe and Kivimäki, 2013; Turner et al., 2020; Yaribeygi et al., 2017), inflammation (Slavich, 2016; Yaribeygi et al., 2017), obesity (Steptoe and Kivimäki, 2013; Turner et al., 2020; Yaribeygi et al., 2017), gastrointestinal problems (Shahsavarani et al., 2015; Yaribeygi et al., 2017), respiratory problems (Shahsavarani et al., 2015), and sexual problems (Ilacqua et al., 2018; Shahsavarani et al., 2015). Naturally, these outcomes are dependent on the intensity and timing of the relevant stress, as well as individual differences (e.g., in age, gender, or genetic heritage; Sandi, 2013), but the fact remains that stress can occur in a wide range of situations and may have broad negative consequences for the population: for instance, anxiety disorder is the most prevalent psychiatric disorder, with an estimated 284 million people suffering from this in 2017 (Bandelow and Michaelis, 2015; Ritchie and Roser, 2018).

All these epidemiological data and the aforementioned evidence of the adverse effects of stress on health demonstrate the importance of investigating ways to reduce stress. In the literature, *relaxation* is defined as a state of absence of tension in the body and mind that is often accompanied by reduced neurological arousal, a decrease in sympathetic activity (e.g., normal blood pressure, reduced heart rate, and reduced muscle tension), and positive emotions, such as feelings of calm, tranquility, joy, *etc.* (Kwekkeboom and Gretarsdottir, 2006; Klainin-Yobas et al., 2015; Montero-Marin et al., 2019). This definition suggests that achieving relaxation could be an effective way to reduce stress. However, relaxation techniques tend to rely on the acquisition of skills in focus, concentration, and imagination. This prevents their use in scenarios involving short-term hospitalization and could also have a demotivating effect on potential regular users. Virtual reality (VR) could offer a solution to these limitations of traditional relaxation techniques, in the form of access to customized and immersive virtual worlds. Previous work has highlighted the potential of relaxing virtual environments to exert a calming effect on users; however, existing proposals for VR solutions mostly rely only on the use of visual and auditory cues. This represents a limitation, as tactile stimulation is very efficient as a way to induce positive affective states, while also reducing anxiety (e.g., Henricson et al., 2008). An approach providing multisensory feedback, including haptic feedback, might greatly improve the effectiveness of relaxation applications using VR. Haptic feedback is usually designed to stimulate the somatosensory system *via* sensations such as vibration or pressure.

Our overall objective is to provide guidance for the creation of a new type of multisensory VR device which will use haptic stimulation to relax users in a clinical environment. Thus, the current survey of the literature focuses on research in the fields of both psychology and VR. We consider it important not only to design a device, but also to ensure that its efficiency in inducing relaxation can be validated and quantified: initially *via* laboratory studies and subsequently in more ecologically valid settings. A secondary, more general objective is to raise awareness of the importance of considering the use of haptic feedback in VR-based relaxation applications. Not only does this kind of feedback increase the user's sense of spacial presence in a virtual environment, but it is also linked to the somatosensory and affective systems, meaning that it represents a more effective way to immerse and relax users in the virtual environment. Therefore, to present an overview of scientifically validated relaxation and mediation techniques, as well as validated measures employed to evaluate their effectiveness, the following sections of this review introduce classic stress reduction interventions and their benefits, as well as the most commonly-used measures of relaxation. Subsequently, we present a discussion of VR-based stress reduction interventions, focusing specifically on the multisensory approach and the benefits of this in order to highlight the importance of VR development in this field. A third section presents evidence on the positive impact of touch on relaxation to demonstrate the benefits of adding haptic feedback to VR relaxation devices. Finally, we present a discussion of this evidence and the prospects for future work. It should be noted that, since there is a large amount of work on both classical and VR-based relaxation and meditation techniques, in order to synthesize as much information as possible in our presentation of the existing state of knowledge in this domain, we have chosen to rely primarily on recent systematic reviews and meta-analyses, which themselves draw their conclusions based on multiple studies on the topic. Concerning haptic feedback, given that the aim of this scoping review is to provide guidance for the development of a future VR-based relaxation device involving haptic stimulation, we deemed it relevant to examine the details of studies using haptic feedback whether this was provided *via* a VR environment or not. Thus, in the corresponding sections, we focus primarily on experimental studies involving both haptic feedback and stress. We selected mainly references with the following criteria: a date of publication greater than 2000, published in English and not focused on children. Exceptions made if we thought an article was important for a more overall comprehension of the topic (Seay et al., 1964)). We mainly conducted the survey using keywords such as: relaxation, meditation, stress, anxiety, virtual reality, haptic feedback, tactile stimulation, and touch. We specifically focused on works on immersion, sense of presence and their objective or subjective evaluation through user studies. The scientific publications reported on in this scoping review were extracted from the following databases: Google Scholar, PsycInfo, ScienceDirect, and ResearchGate. A table summarizing the main characteristics of the studies (authors, date and journal of publication, country in which the experiments or reviews were conducted, number of participants, location of study protocol, *etc.*) is provided in the Supplementary Material.

Stress reduction interventions

Relaxation and meditation techniques

Over the course of a number of years, pharmacological treatments have been developed to reduce stress and enable patients to reach a state of relaxation more quickly (Smith et al., 2020). Non-pharmacological interventions have also emerged, especially as an alternative to drugs that can enable the patient to avoid dependency and side effects, which may include nausea, insomnia, headaches, diarrhea, sexual dysfunction, *etc.* (Quagliato et al., 2019). These include relaxation and meditation techniques (see Table 1).

- **Relaxation techniques** are defined as interventions that focus on achieving a state of absence of tension in the body and mind, which counteracts stress and anxiety. The essential basis of the approach is to foster and develop the individual's ability to control and reduce physiological activity (Montero-Marin et al., 2019). The most commonly-used techniques are:
- **Progressive muscular relaxation (PMR) or Jacobson Relaxation:** a deep relaxation of the body induced by alternating voluntary and conscious contraction and relaxation of different muscle groups. It encourages the practitioner to focus on the contrast between the unpleasantness of the tension and the pleasantness of the relaxation (Kaminska et al., 2020).
- **Autogenic training or Schultz Relaxation:** muscular relaxation that leads the practitioner to imagine and focus on physical sensations of heaviness, warmth, or coolness in different parts of his or her body (e.g., arms, solar plexus, cranial region; Ernst and Kanji, 2000).
- **Applied Relaxation:** a method of self-control, used specifically as a treatment for anxiety and phobias. It consists of practicing different exercises (e.g., long PMR, short PMR, or cue-controlled relaxation); the practitioner thereby learns to relax very quickly in stressful situations that arise naturally (Huhtela et al., 2020).
- **Respiration-based relaxation:** a technique in which the practitioner focuses on their abdominal or diaphragmatic breathing. Relaxation is achieved through slow, deep inhalations and exhalations (Klainin-Yobas et al., 2015; Montero-Marin et al., 2019).
- **Yoga:** a way to achieve wellness and mind–body balance. There are many forms of yoga, but most share several elements: body movements, physical postures, controlled breathing, and meditation techniques (Pascoe and Bauer, 2015).
- **Musical relaxation:** a category that includes all musical activities aiming to promote relaxation (singing, listening, writing, or composing), as offered by healthcare professionals or trained music therapists (de Witte et al., 2020).
- **Aromatherapy:** a technique that uses essential oils, administered *via* inhalation or massage, to reduce anxiety (Gong et al., 2020).
- **Massage therapy:** a form of therapy involving various types of massage, i.e., manipulation of the skin and muscles, to remove tension and allow muscular and nervous relaxation (Klainin-Yobas et al., 2015).
- **Meditation techniques** are defined as interventions that not only create a relaxation response but also focus on exploring one's own thoughts, feelings, and perceptions, and on becoming aware of one's adaptive and maladaptive functioning processes in order to reinforce or abandon them, respectively (Montero-Marin et al., 2019). The most commonly-used techniques are:
- **Transcendental Meditation:** a form of meditation in which the practitioner aims to attain mental relaxation by focusing their attention on quieter levels of thought thanks to the effortless mental repetition of a sound without meaning (i.e., a mantra; Orme-Johnson and Barnes, 2014).

TABLE 1 Summary of classical and VR-based stress reduction interventions and relevant measures.

Classical stress reduction interventions	Virtual reality (VR)-based stress reduction interventions
Techniques	*Techniques*
• *Relaxation:* progressive muscle relaxation; autogenic training, or Schultz Relaxation; Applied Relaxation; respiration-based relaxation; yoga; musical relaxation; aromatherapy; massage therapy • *Meditation:* Transcendental Meditation; Mindfulness-Based Stress Reduction; Mindfulness-Based Cognitive Therapy	Adaptations of classical relaxation and meditation interventions, with the addition of VR devices or environments, such as a VR headset or a VR multisensory room containing (for instance) projectors, speakers, olfactory stimulants, and tactile objects
Measures	*Measures*
• *Questionnaires:* Perceived Stress Scale; Derogatis Stress Profile; stress subscale of the Brief Symptom Inventory; State–Trait Anxiety Inventory; Beck Anxiety Inventory; Hamilton Rating Scale for Anxiety; Depression, Anxiety, and Stress Scale; Hospital Anxiety and Depression Scale; Five Facet Mindfulness Questionnaire; Mindful Attention Awareness Scale; Smith Relaxation State Inventory 3	• Questionnaires and physiological and physical measures as used to assess conventional interventions
• *Physiological:* electroencephalography; electrocardiography; electrodermal activity; photoplethysmography; respiratory inductance plethysmography; electromyography; skin temperature; cortisol levels	• *Sense of presence:* Igroup Presence Questionnaire; Immersive Virtual Environments Questionnaire
• *Physical:* eye-related features; facial expressions; voice characteristics; body language	
Results	*Results*
• Reduction in physiological and psychological stress symptoms	• The same benefits as observed with classical techniques
• Reduction in anxiety	• Additional VR-specific benefits: improvement in relaxation self-efficacy; improvement in focus on the present moment; improvement in preservation of attentional resources; reduction in mind-wandering; improvement in decentralization; improvement in positive emotions; reduction in negative emotions
• Improvement in stress reactivity	
• Improvement in positive affect	
• Improvement in depression symptoms and pain	

- **Mindfulness-Based Stress Reduction (MBSR):** an approach that develops mindfulness, namely a state of consciousness characterized by sustained attention to what the practitioner is doing or experiencing at a given moment (e.g., physical sensations, emotional states, and thoughts) without judgment or evaluation of these immediate internal and external experiences (Chiesa & Serretti, 2009).
- **Mindfulness-Based Cognitive Therapy (MBCT):** based on MBSR, this technique is used to treat relapses in depression. It involves a cognitive component, offering psychoeducation on the nature of thoughts and the link between thought and mood. The objective is to help the patient to develop a decentered attitude toward his or her own thoughts and not to perceive them as facts (Janssen et al., 2018).

Measures of stress, relaxation, and meditation

In designing a new stress reduction intervention, it is important to obtain an overview of scientifically accepted relaxation and meditation techniques, but it is also necessary to identify the scientifically validated measures that can be used to assess its effectiveness. An individual's levels of stress, relaxation, or meditation-related variables are usually measured before, during, and after the practice of relaxation or meditation techniques. The measurement tools employed in this process may be subjective and/or objective. Both are important in the validation of relaxation techniques, as the goal is that the user should both feel more relaxed, and also be more relaxed. Subjective measures collect self-reports in the form of questionnaire responses. The most widely used measure to assess stress is the Perceived Stress Scale (Cohen et al., 1983; used, for example, by Chiesa and Serretti, 2009; de Witte et al., 2020; Janssen et al., 2018; Pascoe and Bauer, 2015)), but others, such as the Derogatis Stress Profile (Derogatis, 1987) and the stress subscale of the Brief Symptom Inventory (Derogatis, 1993), are employed to a lesser extent (e.g., Chiesa and Serretti, 2009; Mahalil et al., 2015; Janssen et al., 2018). Anxiety is most commonly measured using the State–Trait Anxiety Inventory (Spielberger, 1983; used, for example, by Blum et al., 2019; Ernst and Kanji, 2000; Orme-Johnson and Barnes, 2014), followed by the Beck Anxiety Inventory (Beck et al., 1988; used, for example, by Gorini et al., 2010; Kim and Kim, 2018). The Hamilton Rating Scale for Anxiety (Hamilton, 1959) is used less frequently (e.g., Gorini et al., 2010; Kim and Kim, 2018). In addition, some studies have administered cross-dimensional questionnaires. Among these, the most frequently reported on in the literature are the Depression, Anxiety and Stress Scale (Lovibond and Lovibond, 1995; used, for example, by Gorska et al., 2020; Janssen et al., 2018; Pascoe and Bauer, 2015) and the Hospital Anxiety and Depression Scale (Zigmond and Snaith, 1983; used, for example, by Gu and Frasson, 2017; Klainin-Yobas et al., 2015). Regarding meditation-related variables, the most widely used questionnaires are the Five Facet Mindfulness Questionnaire (Baer et al., 2006, 2008; used, for example, by Janssen et al., 2018) and the Mindful Attention Awareness Scale (Brown and Ryan, 2003; used, for example, by Chiesa and Serretti, 2009; Janssen et al., 2018), both of which assess the participant's level of mindfulness. Concerning relaxation, recent meta-analyses (i.e., Janssen et al., 2018; Pascoe and Bauer, 2015) have mentioned only the Smith Relaxation State Inventory 3 (Smith et al., 2000).

There are two major limitations to the use of these subjective measures. First, the state reported by the participant may not correspond to their actual experience: instead, individuals may respond in a way that they consider to be socially desirable in the relevant situation (in accordance with social desirability bias; Crowne and Marlowe, 1960), or simply have difficulty identifying their own state (Moher et al., 2009). Second, the measurement of the participant's state is not instantaneous. To address these limitations, objective measurement instruments are also used in studies of stress, relaxation, or meditation. Objective measures enable the identification, evaluation, and monitoring of the immediate physical, chemical, and biological changes that are observed in the human body during stressful or relaxing experiences. Stress and relaxation exert an impact on the human brain, or more precisely on the activation of the autonomic nervous system. Specifically, stress activates the sympathetic nervous system (SNS), while relaxation activates the parasympathetic nervous system (PNS). SNS activation prepares the body for action and the exertion of energy, while PNS activation prepares the body for slowdown and energy conservation. Thus, the activation of these different systems involves different changes in the body in each case. Stress-induced activation of the SNS will produce an increase in heart rate, respiratory rate, blood pressure, cortisol levels, muscle tension, pupil dilation, *etc.*, while relaxation-induced activation of the PNS will produce a decrease in each of these variables (e.g., Pascoe and Bauer, 2015). Sensors can be placed at various locations around the body to detect such changes. Thus, studies often report the use of physiological measures, such as the following:

- **Electroencephalography (EEG)** is used to measure changes in electrical **brain activity**. A set of electrodes placed on the scalp captures the frequency of brainwaves, which can be divided into five categories on this basis: gamma, beta, alpha, theta, and delta. Gamma waves represent the highest level of excitement and delta the deepest sleep. Frequencies representing rapid beta waves correspond to a state of activation, such as stress, and alpha waves to a state of relaxation (e.g., Sharma and Gedeon, 2012; Perhakaran et al., 2016; Sethi et al., 2019).
- **Electrocardiography (ECG)** is used to measure a change in the electrical potential of **heart activity**, thereby detecting heart rate and changes in this. To accomplish this, electrodes are usually placed on the wrists, ankles, and specific points on the chest. Acute stress is usually associated with an acceleration in heart rate, while relaxation is associated with a lower heart rate (e.g., Sharma and Gedeon, 2012; Sethi et al., 2019; Kaminska et al., 2020).
- **Electrodermal activity (EDA) or galvanic skin response** is electrical activity on the skin surface. It can be measured by testing the extent to which the skin conducts electricity; this **skin conductance** depends on activity in the sweat glands. To collect this measurement, two sensors are placed on the participant's fingers. Tension produces an increase in skin conductance, and thus a decrease in skin resistance; conversely, relaxation induces a decrease in skin conductance, and thus an increase in skin resistance (e.g., Sharma and Gedeon, 2012; Greene et al., 2016; Giannakakis et al., 2017; Kaminska et al., 2020).
- **Photoplethysmography** is used to detect changes in **blood activity**, especially blood pressure and blood volume pulse. For this technique, an optical sensor is usually placed on the wrist to measure the reflection and absorption of light by the skin, which is modulated by changes in blood flow. Previous work has indicated that an increase in stress is associated with an increase in blood pressure and a decrease in blood volume pulse (e.g., Sharma and Gedeon, 2012; Greene et al., 2016).
- **Respiratory inductance plethysmography** is used to measure changes in **respiration**, including respiratory rate and volume. To accomplish this, the participant wears thoraco-abdominal straps. A state of arousal, such as stress, is associated with hyperventilation, while relaxation is associated with slower breathing (e.g., Greene et al., 2016; Kaminska et al., 2020).
- **Electromyography** is used to measure electrical activity in the **muscles and nerves**. To accomplish this, electrodes are placed on the skin over the muscles to be studied, such as those on the face. Stress is often associated with high muscle tension compared to that associated with a state of relaxation, with trapezoid muscle action potentials being particularly closely related to stress (e.g., Giannakakis et al., 2017; Kaminska et al., 2020).
- An **infrared thermopile** or **camera** can be used to measure **skin temperature**. A simple thermometer can also be used for this purpose. An increase in tension is associated with a decrease in skin temperature; conversely, a decrease in

stress is associated with an increase in skin temperature (e.g., Sharma and Gedeon, 2012; Kaminska et al., 2020).

- A **cortisol level test** can be used to measure the concentration of **cortisol hormone** in a participant's body. Tests are available for blood, urine, or saliva. High cortisol levels can indicate a state of stress (Pascoe and Bauer, 2015).

In addition to the physiological methods described above, physical measures are also used to detect stress. The most common of these involve measuring eye-related features, facial expressions, voice characteristics, and body language. The relevant eye-related features are pupil dilatation, pupil diameter, blink rate, eye aperture, eyelid response, and gaze distribution; these are mainly measured using eye-tracking systems. Previous work has demonstrated that the pupil tends to be dilated (i.e., larger) in situations involving greater alertness and concentration. Moreover, stress has been found to be associated with an increase in blink rate, eyelid closure, and gaze instability (e.g., Sharma and Gedeon, 2012; Greene et al., 2016; Giannakakis et al., 2017). Facial expressions are most commonly identified and measured using the Emotional Facial Action Coding System (Ekman et al., 2002). Head movement, facial blushing/paleness, and mouth activity are often examined; research has indicated that more head movements and lip deformations occur during exposure to stress (e.g., Sharma and Gedeon, 2012; Greene et al., 2016; Giannakakis et al., 2017). Measures relating to the voice include those indexing lexical, phonological, and prosodic features. For this purpose, intelligent speech recognition and speaker identification systems are used. For example, increasing levels of stress have been observed to be associated with a greater proportion of high-frequency components in the voice (e.g., Sharma and Gedeon, 2012; Giannakakis et al., 2017). Finally, behavioral patterns such as clenched jaws, trembling, crossed arms, or nail biting can be analyzed and coded by human experts. Research has focused in particular on the gestures, postures, and behaviors of car drivers and people with autism (e.g., Sharma and Gedeon, 2012; Greene et al., 2016).

Benefits of relaxation and meditation techniques

Previous reviews and meta-analyses of studies using the measures of stress described above have demonstrated that relaxation and meditation techniques can have a positive impact on stress. For example, de Witte et al. (2020) have observed that musical interventions reduce physiological and psychological symptoms of stress. Similarly, Chiesa and Serretti (2009) have found that MBSR decreases stress in healthy individuals compared to an inactive control group. Conversely, certain techniques have been found to increase positive affect (see Orme-Johnson and Barnes, 2014, for a review on transcendental meditation, and Pascoe and Bauer, 2015, for a review on yoga) but also to enhance stress reactivity (Orme-Johnson and Barnes, 2014). In addition, anxiety-reducing effects have been observed in research on multiple relaxation techniques (Klainin-Yobas et al., 2015; Patel and Krishnamurthy, 2019) as well as in studies examining a specific relaxation or meditation technique, such as yoga (Pascoe & Bauer, 2015), aromatherapy (Gong et al., 2020), Applied Relaxation and MBSR (Kim and Kim, 2018), and Transcendental Meditation (Orme-Johnson and Barnes, 2014). According to Montero-Marin et al. (2019), meditation may be slightly more effective than relaxation. These techniques have also been found to be effective in alleviating symptoms of depression (Orme-Johnson and Barnes, 2014; Klainin-Yobas et al., 2015; Pascoe & Bauer, 2015; Patel and Krishnamurthy, 2019). Other studies have demonstrated a positive effect of relaxation on pain (Kwekkeboom and Gretarsdottir, 2006). Finally, slow breathing has also been reported to be associated with a reduction in pain (Jafari et al., 2017), and autogenic training has shown potential to reduce headaches (Seo et al., 2018), although the overall evidence base is unclear.

Reduction-stress interventions in virtual reality

Multisensorial approaches

The effectiveness of stress reduction interventions has been observed not only in relation to traditional techniques, but also in relation to VR-based approaches. (see Table 1). Over the past 50 years, the digital evolution has enabled the transposition of the conventional methods described above to the VR realm. For example, this may mean that, in addition to hearing instructions relating to a relaxation technique, a VR headset user is immersed in a virtual environment designed to promote relaxation (e.g., a forest, waterfall, or beach).

Even prior to the availability of VR and immersive virtual environments, scientists had begun to investigate the benefits of multisensory therapy to relieve stress and anxiety. Slevin and McClelland (1999) developed a multisensory therapy room aiming to relax users by stimulating multiple senses; such rooms may make use of projectors, speakers, olfactory stimulants, and tactile objects, for example. They conducted an experiment over a 12-week period involving a single participant with severe learning disabilities and autism. They collected both subjective and objective measures of relaxation (e.g., a behavioral relaxation rating scale and pulse rate). The results indicated significant differences in relaxation levels between pre-therapy and post-therapy time points. In particular, they observed a decrease in pulse rate of 19.6% after therapy. While this experiment was limited by its focus on a single participant, its result suggests the potential of multisensory environments to promote relaxation. However, this kind of room requires a large amount of space, and only one person can use it at any given time. Furthermore, such rooms are limited to real-world stimuli, while VR offers the possibility of simulating inaccessible or imaginary places and environments.

One of the first domain in which VR began to be used for the purposes of anxiety and stress management was the military. As observed by Pallavicini et al. (2016), working in the military, e.g. as a warfighter or pilot, can be extremely stressful. These authors have highlighted VR as a useful method for psychologically preparing soldiers for warzones, and as a way to provide a relaxing environment to help users with muscle relaxation and control of their breathing. Stetz et al. (2011) created a virtual environment called "Dream Island", which is presented using a VR system and aims to induce relaxation in members of forward surgical military teams. TThey observed lower levels of anxiety in participants, as measured using questionnaires, after they had practiced this VR-based relaxation technique.

VR for relaxation purposes is currently a strong focus of interest among researchers. A review of 285 empirical studies on VR indicated that the main disorder that this research focuses on is anxiety ($n = 192$), well ahead of schizophrenia ($n = 44$) and eating disorders ($n = 18$; Freeman et al., 2017). However, while researchers seem to exhibit increasing interest in this field, there is still a gap between studies and real-world applications. Indeed, VR-based relaxation applications are not yet widespread. Lindner et al. (2019) investigated the use of the "Happy Place" application developed by Mimerse in 2016 (see Figure 1). This application immerses users in a relaxing natural environment, including scripted animal behaviors and spatialized sounds. The environment is stylized in appearance, using a low-polygon approach, in order to be visually appealing while minimizing computational expense. The application recorded a total of 40,000 unique users over the course of 2 years; however, the average session duration was shorter than expected, at around 5 minutes, and the proportion of recurrent users was also rather low. This suggests both that there is a substantial amount of interest in VR-based relaxation applications, but also that potential users may experience disappointment in this particular application. Lindner et al. (2019) concluded that the design of relaxation applications must be guided by psychological science, and that more research on the relevant topics is required.

This section has highlighted numerous advantages of the use of VR for relaxation. Among the most important of these is the fact that VR enables users to be immersed in a life-sized alternate environment, surrounding them with a computer-generated world (Slater & Sanchez-Vives, 2016). Thus, this technology enables the creation of immersive and relaxing environments and provides a strong sense of spatial presence. While this could be achieved through traditional relaxation and meditation techniques, these require extensive training. Such training might not be available, for instance, during a short-term hospitalization or in an industrial context. Providing a greater sense of immersion and presence in a relaxing environment enhances the relaxation process by causing the user to forget about the clinical context to a greater extent. This explains why specialists in psychology are increasingly tending to turn to multisensorial VR for the purpose of inducing relaxation. Furthermore, as previously mentioned, VR can be deployed at large scales and in various contexts.

Measures used in stress-reduction interventions involving VR

The measures used to measure anxiety and stress in studies of VR-based interventions are the sameas those used to evaluate traditional techniques. However, some additional instruments to measure participants' sense of presence and immersion have

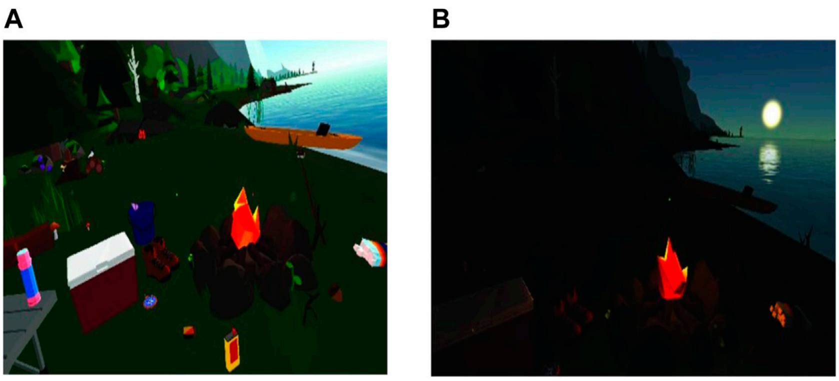

FIGURE 1
Screenshots of the Happy Place application **(A)** Day environment with interactive objects. **(B)** Night environment (reproduced from Lindner et al. (2019)).

been developed for use in VR research. These measures are important, since the objective is to help the user immerse themselves in a relaxing virtual environment. The experience of a sense of presence has a positive influence on emotions, and the ability of a VR environment to provide real-life experiences is relevant in the treatment of anxiety and stress-related symptoms (Villani et al., 2014). For these reasons, in addition to measures of mindfulness or relaxation, studies involving VR interventions also use measures to assess the participant's sense of presence during participation (i.e., their subjective perception of being present in the VR environment). To this end, most studies have used the Igroup Presence Questionnaire (Schubert, 2003; used, for example, by Da Costa et al., 2018; Vailland et al., 2020). For instance, (Vailland et al., 2020), observed a significant increment in sense of spatial presence when using haptic feedback in VR (7.62 vs. 6.62) thanks to the IVEQ questionnaire. As a recently-developed alternative, the Immersive Virtual Environments Questionnaire (Tcha-Tokey et al., 2016) has also shown promise as a tool for assessment of this and other VR-related variables, such as engagement, immersion, skills, and usability (e.g., Setiawan et al., 2019; Vailland et al., 2020).

Benefits of relaxation and meditation techniques involving VR

Studies have shown that relaxation and meditation techniques administered *via* VR enhance relaxation (Scates et al., 2020) and reduce stress (Kaminska et al., 2020). These techniques have also been found to improve positive affect (Kaminska et al., 2020) as well as sense of presence (Navarro-Haro et al., 2017), and to decrease negative emotions (Navarro-Haro et al., 2017; Kaminska et al., 2020). Overall, research has observed no significant difference in stress reduction between standard relaxation and meditation techniques and these same techniques administered *via* VR (Andersen et al., 2017; Blum et al., 2019; Chandrasiri et al., 2020). However, the latter type of intervention has also been found to have others benefits in comparison to standard methods (for non-significant results, see Gorska et al., 2020). For example, Blum et al. (2019) observed that participants who practiced a VR-based breathing technique (with cardiac biofeedback) reported higher levels of relaxation self-efficacy, stronger focus on the present moment, better preservation of their attentional resources, and less mind-wandering than participants who practiced this breathing technique without VR. Similarly, Chandrasiri et al. (2020) have noted that VR-based mindfulness practice improves participants' decentralization in comparison to standard mindfulness practice. Finally, Mahalil et al. (2015) have found that administration of a VR-based stress therapy increases participants' positive emotions and decreases their negative emotions to a greater extent than a standard mental imagery technique. Their results also highlight a reduction of perceived nervosity after the VR-based therapy (1.9 vs. 1.0 reported on a Likert scale).

Discussion: Enhancing relaxation through haptic feedback in VR

Stress and pain are a matter of health and well-being. Our review has highlighted the fact that various relaxation techniques that have been in use for decades or even centuries can help to reduce these negative experiences. Most techniques rely solely on the user's imagination and visualization abilities: "imagine a beach, imagine the sound of the waves, the Sun warming your skin." These traditional techniques have proved to be efficient in reducing anxiety and pain. However, it takes time to master them, which makes them difficult to access in acute situations, e.g. for a hospitalized patient, and for casual users. The adoption of VR and multisensory feedback provides the ability to immerse users in a positive and relaxing virtual environment, without the need for any prior knowledge or existing skills on their part. In contrast to traditional relaxation techniques, this approach requires no training, but is still effective in relaxing users and reducing pain.

Multisensory VR applications are effective as a method of relieving stress and anxiety. However, in most studies, the sensory input provided usually consists of visual and auditory stimuli; few studies have focused on VR applications using tactile stimuli. Touch was the first sense acquired by animals in the course of evolution, and it enables humans to perceive the world surrounding them with a high degree of precision. It is also a sense used for interacting with others, for instance when shaking hands or hugging in some cultures. Indeed, touch seems to have a strong impact on well-being, positive affect, and relaxation (Stańko-Kaczmarek and KaczmarekLukasz, 2015). In this section, we first discuss of the benefits of touch from a physiological point of view. The second subsection discusses the use of touch in relaxation techniques. Finally, we present a discussion of the majority of recent publications examining a combination of touch and VR for relaxation and stress-reduction purposes.

Effects of touch on emotion and anxiety

Many studies have reported that tactile stimulation seems to reduce anxiety in animals. For example, Seay et al. (1964) conducted an experiment in which baby monkeys had to choose between two environments, each of which included a decoy monkey. The first decoy was made of iron wire, but provided food; the second was made of cotton, but did not provide any food. The monkeys mainly chose the second environment, indicating that they preferred softness over food. This suggests the great importance of touch in animal behavior.

In the same way, Manseur et al. (2019) have recently compared the behavioral development of two populations of neonatal rats: one in which the rats were left without interaction, and one in which they were regularly handled by humans. The latter group displayed more positive behaviors: they tended to explore new environments more quickly and were more efficient in a forced swimming test. More interestingly, the handled rats exhibited greater resistance to depression and better adaptive responses to anxiety.

Animal biology appears to corroborate these behavioral observations. Van Oers et al. (1998) conducted an experiment on rats which had been removed from their mother for 24 hours. They separated the pups into two groups: a control group, in which the pups were left undisturbed, and an experimental group, in which they were stroked by humans. Subsequently, the researchers induced a mild stimulus, corresponding to a saline injection, in all pups. In response, they observed an increase in adrenocorticotropic hormone in pups that had not been stroked. This hormone is known to stimulate the adrenal gland, producing cortisol, which is normally released in response to stress. Conversely, pups that had been stroked exhibited normal cortisol levels. Similar results have also been observed in different species. For example, Soares et al. (2011) conducted an experiment comparing cortisol levels in surgeonfish that were exposed to an environment containing a model cleanerfish that was either stationary or mechanically moving. They observed that the surgeonfish immediately interacted with and touched the moving model and that cortisol levels decreased in these surgeonfish. These studies highlight the potential of touch to modulate cortisol levels in animals.

These results in various animal species suggest that the positive effects of touch cannot be explained by its social value or cultural factors alone. Current evidence suggests that the link between touch and anxiety reduction can largely be explained by tactile biology. Recent work has highlighted the existence of mechanoreceptive C tactile afferents in animal skin, including that of humans. Liljencrantz and Olausson (2014) conducted multiple experiments in humans involving physiological and psychophysiological measures. They concluded that the stimulation of these afferents is related to pleasant sensations: specifically, a stroking speed of between one and 10 cm per second induces the perception of pleasantness. Moreover, their Functional Magnetic Resonance Imaging (fMRI) study of human brain responses to touch stimuli indicated that tactile stimulation activates not only the somatosensory areas of the brain, which are related to touch perception, but also the insular cortex, which plays a major role in emotions. Along similar lines, Kelling et al. (2016) tested a proposed system combining real-time heart monitoring using a smartwatch with a haptic device placed on the arm of the user. They used two tactile actuators to simulate a stroking movement on the arm. To determine whether their system was effective, they conducted an experiment in which participants were engaged in a stressful task, during which the haptic system was automatically activated based on the participant's heart rate. At the end of the task, participants who had undergone tactile stimulation exhibited a heart rate on average 8.31% lower than those in a control group who did not receive tactile stimulation; although statistical analysis (specifically, a *t*-test) indicated that this was only a tendency ($p = 0.07$), this could probably be attributed to the small participant sample. Taken together, these results suggest that touch may be a promising avenue in interventions promoting well-being.

Benefits of touch for anxiety

The pattern of findings described above explains why the health industry has begun to investigate the potential of touch in reducing anxiety and pain. Henricson et al. (2008) investigated how touch could moderate stress among patients being treated in intensive care. In a preliminary study involving a total of 44 patients, they compared the effects of a tactile intervention (administered to an experimental group) to those of a standard rest-based treatment (administered to a control group) on stress indicators including blood pressure, heart rate, and noradrenalin requirement, which were measured before, during, and after the intervention. After a 5-day period of treatment, they observed that the tactile intervention was more effective in reducing anxiety than an hour of rest. More specifically, they observed a reduction in noradrenalin requirement, suggesting an increase in circulatory stability.

In addition to the evidence that tactile stimulation increases positive affect and decreases negative emotions such as anxiety, Björkhem-Bergman and Pedersen (2017) have conducted a pilot study on the effect of tactile stimulation on pain. Palliative care patients were offered an average of three tactile massages. Based on participants' self-reports, provided on a Likert scale before and after each massage, this treatment was associated with an increase in well-being as well as a decrease in anxiety and pain. Additionally, the number of rescue doses administered for anxiety and pain was monitored for 24 hours before and after the massage treatments. In the cases of both anxiety and pain, the number of doses halved during the period following a massage.

Beyond the capacity of touch to increase positive affect and reduce pain, Stańko-Kaczmarek and KaczmarekLukasz (2015) investigated its effects on attention in an experiment in which two groups of participants were instructed to paint a road using different tools: either a brush or their fingers. During the experiment, the researchers assessed the participants' state mindfulness using a continuous self-evaluation method involving a rating dial. After the painting task, they also measured each participant's scope of attention using a visual observation task. The results indicated that participants in the finger-painting group reported higher levels of state mindfulness than those in the brush-painting group, and that the former group also exhibited a wider scope of attention in the observation task. This could suggest that tactile stimulation has the potential for fruitful use during meditation, since one of the goals of meditation is to enhance attention and concentration.

Overall, tactile stimulation appears to be a promising way to improve patients' quality of life. Interventions involving touch have been found to be associated with multiple benefits in humans, including increase in positive affect, stress reduction, and increase in attention. While VR technologies are already well known for their provision of visual feedback, the development of haptic technologies is relatively recent and they are therefore less widely used.

VR for relaxation with haptic feedback

The abovementioned findings indicate that touch is a very efficient modality by which to provide stimulation that can relax the user. It is strongly linked to an individual's sense of presence, but also has associations with positive affect for both social and biological reasons. In particular, touch plays a major role in emotion regulation and stress management. This should make it suitable for use in a VR application for relaxation. However, it currently remains little-used in multisensory VR applications designed for this purpose. One potential explanation for this seemingly missed opportunity is that haptic feedback is a relatively recently-established technology, especially in the context of industry. Various kinds of tactile inputs have been used for relaxation purposes, including simulated heartbeat or breathing ((Ueoka and Almutawa, 2018), (Choi et al., 2021), (Ban et al., 2022)). As our ultimate goal is the conception and evaluation of a multisensorial VR system that can increase the user's sense of presence in a virtual environment in order to help patients forget about the clinical environment that they are in, this section presents several illustrations of the few recent and promising pieces of work that have combined immersive technologies and tactile feedback for the purposes of relaxation and stress reduction.

Dijk and Weffers (2013) have proposed the use of a multisensory room using visual, auditory, and tactile stimuli to immerse the user in a sea environment (see Figure 2). The sea is well known to be a relaxing environment, and is often used in meditation. The user is situated in the room, which uses a specific pattern of lighting. He or she wears headphones *via* which the auditory stimulation is administered. Finally, a device named the "Touch Blanket" provides haptic feedback designed to simulate waves moving over the body. All the multisensory room equipment is designed to immerse the user and allow him or her to experience the feeling of being by an ocean shore. The researchers' results suggest that this combination of multisensory haptic and audio stimulation is more effective in relaxing the user than only a single form of sensory feedback. Furthermore, they also highlight the importance of adapting the feedback to the user's breathing. The primary limitation of this study is that it only provides informal evaluations of the technique based on the experience of few participants.

Serrano et al. (2016) have proposed a mood-induction procedure to induce relaxation and a sense of presence in a virtual environment. They compared four different conditions: VR only (i.e., visual and auditory input), VR plus smell, VR plus touch, and VR plus smell and touch.

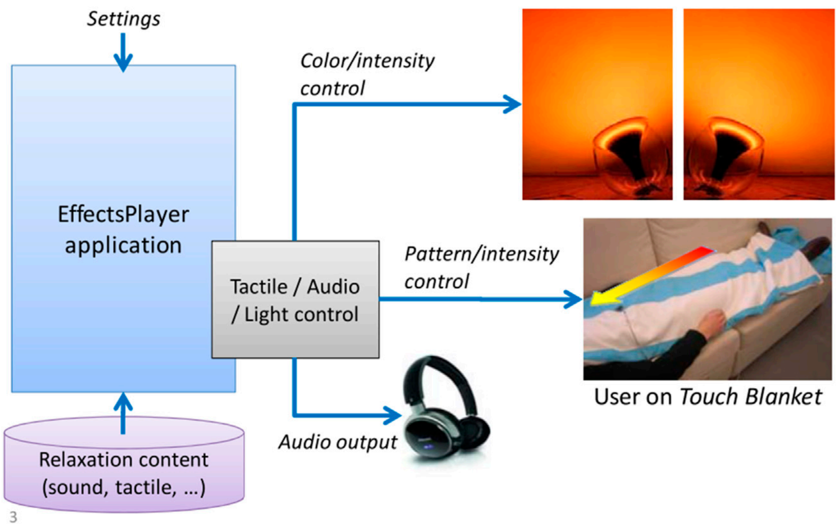

FIGURE 2
Simplified system diagram of open-loop audio–tactile breathing guide, providing tactile stimuli *via* the Touch Blanket and audio/light stimuli (reproduced from Dijk and Weffers (2013)).

Participants in the VR plus smell and touch condition reported feeling more relaxed, with a higher sense of presence, than those in the other conditions. However, this trend was not statistically significant, and the authors stated that further research is required. One possible explanation for this weak result might be that the tactile stimulus was static, as it consisted of grass made of plastic and synthetic materials.

Young Im et al. (2019) have proposed a VR system involving visuo-haptic feedback to provide an immersive experience for anxiety reduction. They used an Oculus device to present the VR environment and a Falcon device for haptic feedback. They conducted an experiment in which two virtual environments, a virtual party and the inside of an elevator, were presented to seven participants with diagnosed panic disorders, while real-time visuo-haptic feedback enabled them to see and feel their own heartbeat. Participants' depression and anxiety levels were evaluated before and after two VR sessions. The results indicated that this combination of inputs was effective in relieving subjective anxiety, but there was also an indication of a trend toward reduction of VR-induced cybersickness. However, this study did not investigate the role played by each individual sensory modality in the results.

These studies highlight the potential role that touch could play in relaxing users of VR environments. So far, research has relied on physiological data and/or questionnaires to evaluate the influence of touch on emotions and anxiety. In recent work, researchers have also attempted to couple tactile feedback with other VR components in order to immerse users in relaxing virtual environments. As touch increases an individual's sense of presence, it also reinforces the user's immersion in the VR environment. However, there is currently no haptic system enabling users to feel everything that occurs in VR, as the domain of haptics can so far provide only certain specific stimuli (Slater and Sanchez-Vives, 2016). Thus, it is important to consider what kind of haptic feedback is relevant to the specifical goal of increasing the user's sense of presence in a virtual environment as part of a relaxation app, This is all the more important in a clinical context where the cost and size of hardware are critical factors. Future research should further investigate the benefits of tactile stimulation as a promising form of support for VR-based methods of inducing relaxation and reducing stress.

Conclusion

Stress is widespread around the world and has many adverse physical and psychological effects on those who experience it. These observations have prompted the development of numerous stress-related interventions that can improve relaxation, well-being, and physical health. In the present review, we identified two main techniques to reduce stress. First, relaxation techniques aim to help individuals to develop skills to control and reduce their physiological activity; these methods are mainly based on muscular relaxation (e.g., PMR or autogenic training) and breathing (e.g., applied relaxation). Second, meditation techniques aim to help individuals to achieve a relaxation response as well as cultivating their ability to identify and act on their own functioning processes (i.e., thoughts, emotions, *etc.*). The most commonly-used meditation methods are based primarily on developing sustained attention to the present moment (e.g., Transcendental Meditation and MBSR). Both subjective measures (i.e., self-reported questionnaires) and objective measures (e.g., EEG, ECG, EDA) have demonstrated the effectiveness of both types of intervention. Indeed, relaxation and meditation techniques have been shown to reduce symptoms of stress, anxiety, pain, and depression, but they have also been found to increase positive affect. Nevertheless, using these techniques requires a considerable period of training and mastery, which is not possible in some contexts (e.g., during a short-term hospitalization). Thus, researchers and psychologists have developed a tendency to transfer these traditional relaxation and meditation techniques to the domain of VR technologies. This approach can directly provide an immersive and relaxing environment that does not require visualization efforts or imagination skills on the part of its users. VR-based stress reduction interventions take a multisensorial approach, meaning that they aim to stimulate multiple senses, for example through images, music, and smells. This approach has been shown to have benefits for the user's physiological and psychological condition. However, while these VR technologies offer multiple forms of stimulation (in the visual, auditory, and olfactory modalities), tactile stimulation remain underused. Despite this, the present review provides some evidence that touch is closely related to stress reduction, increased attention, and positive affect. For instance, our next work will be the creation of a haptic device designed to be light-weighted and used in combination with a VR headset to provide haptic sensations such as wind or rain. The system will be first evaluated with user studies, both in laboratory and in a clinical context with real patients. Hence, we hope that the information contained in this review will inspire future research aiming to evaluate the benefits of including a haptic modality in VR-based stress reduction interventions.

Author contributions

LB was the primary contributor to "Stress reduction interventions" section and YG was the primary contributor to "Discussion: enhancing relaxation through haptic feedback in

VR" section. Both authors contributed equally to the other sections.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2022.900970/full#supplementary-material

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