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ORIGINAL ARTICLE

Virtual reality environments for stress reduction and management: a scoping review

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Abstract

Virtual reality, a cutting-edge innovation in the realm of digital experiences, though more frequently employed for entertainment and education, can also serve as a tool for immersing users in therapeutic settings that promote relaxation and mindfulness. An increasing number of research attempts investigate its usability and impact on stress evaluation, management and reduction. This scoping review aims to depict the current role of virtual reality in stress reduction and identify common methods and practice, technology patterns as well as gaps. Results depict the emerging research interest in the domain of VR-based stress reduction systems. The developed systems included in this review were basically addressed to the general public (59%) for daily life stress reduction utilizing a commercial VR headset often combined with supportive sensors. Guided imagery emerged as the most implemented method, but it is also noteworthy that almost all studies implicitly used this method. According to the analysis, most studies performed evaluation of the proposed VR system including both subjective and objective measurements to provide evidence on its efficiency and its actual impact on stress levels. Finally, validation methodologies attempt to point out the potential of VR technology in the direction of providing an efficient solution for the alleviation of stress burdens. Even though numerous studies report the usefulness and efficiency of VR technology regarding stress reduction, several challenges still need to be addressed, mainly because of the difficult definition, detection and evaluation of stress. An approach integrating the existing knowledge regarding signals that can act as biomarkers of stress and qualitative measurements could open new pathways toward the development of more impactful VR-based stress reduction systems.

Keywords Virtual reality · VR · Virtual environments · Stress reduction

Abbreviations

ART	Attentional restoration theory
BIO	Biopac
BL	Bitalino
BPI	BioGraph ProComp Infiniti
BVP	Blood volume pulse
DASS	Depression, anxiety and stress scale
E-B	ECG belt
ECG	Electrocardiogram
EDA	Electrodermal activity
EEG	Electroencephalogram
EMG	Electromyography
EMO	Emotiv
EMP	Empatica
ER	Emotional recovery
EV	Equivital
FB	Fitbit
GSR	Galvanic skin response
HR	Heart rate
HRV	Heart rate variability
LF	Low frequency
LF/HF	Low frequency/high frequency
LM	Leap motion
MAAS	Mindful attention awareness scale
MeS	Mental stress
MM	Moodmetric
MoS	Momentary stress
MOV	Movisens
NM	Not mentioned
NN50	Percentage of differences between adjacent NN intervals > 50 ms

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NS	No sensor
OS	Occupational stress
PANAS	Positive and negative affect schedule
PNS	Peripheral nervous system
Po	Polar
POMS	Profile of mood states
PPG	Photoplethysmography
PS	Psychological stress
PSQI	Pittsburgh sleep quality index
PSS	Perceived stress scale
PTSD	Post-traumatic stress disorder
RAB	RABio
SCL	Skin conductance level
SH	Shimmer
SRT	Stress reduction theory
SS	SuperSpec
STAI	State-trait-anxiety-inventory
SUS	System Usability Scale
SWLS	Satisfaction with life scale
UEQ	User experience questionnaire
VAS	Visual analogue scale
VR	Virtual reality

1 Introduction

1.1 Virtual reality for stress reduction

The potential created by the rapid development of technology in its use for research or therapeutic purposes is becoming increasingly acceptable in the scientific community (Pourmand et al. 2017). Virtual reality (VR), a cutting-edge innovation in the realm of digital experiences, incorporates the use of computer modeling and simulation that enables a person to interact with an artificial three-dimensional (3D) visual or other sensory environment.[1] VR technology transports users to immersive, computer-generated worlds, redefining the way they interact with and perceive the digital environment. While this technology is frequently employed for entertainment and education, it can also serve as a tool for immersing users in therapeutic settings that promote relaxation and mindfulness. In recent years, VR is increasingly gaining the attention of healthcare professionals and the research community as a potentially utilizable alternative solution, supplementing the established clinical practice and providing a supportive tool against the possibly harmful impact of accumulated stress for maintaining an individual's quality of life.

Stress, as documented in official sources, encompasses the physiological and psychological reactions triggered by internal or external stressors.[2] It exerts its influence across virtually every system within the body, ultimately shaping a person's thoughts and behaviors. Causing physiological and behavioral changes, stress affects psychological and physiological functioning, possibly reducing living standards. Identified as a phenomenon of the modern world, directly linked with the rapid rhythms and the fierce competitiveness of the open market, stress increasingly draws the attention of the research community as it greatly affects the life of the average individual in many ways (Wadhwa 2017). In terms of this research interest, VR-based relieving systems are gradually introduced attempting to provide an efficient solution. In this scoping review paper, we are focusing on VR systems developed to address stress. Various techniques and methods can be found in the literature regarding stress reduction (Mason 2013). Some of them are biofeedback, guided imagery, deep breathing, mindfulness and meditation. The implementation of a stress reduction technique usually requires short sessions during which the individual follows certain instructions depending on the context of the technique. The aforementioned methods are established by several theoretical approaches like attentional restoration theory (ART), stress reduction theory (STR), art therapy, nature therapy, etc. (Ulrich et al. 1991; Song et al. 2016; Ohly et al. 2016; Rajoo et al. 2020;).

The interest in leveraging VR technology for stress reduction emerged from the broader research community's fascination with the appealing features of VR. In this initial article found in terms of this scoping review, Valtchanov et al. (2010) conducted an experiment to demonstrate the effectiveness of VR immersive natural environments. Their findings indicated that VR environments could yield similar positive effects as exposure to simulated nature. In the course of time, the studies that emerged demonstrate a growing research interest in proving the efficacy and potential of VR technology, as well as exploring innovative strategies for mitigating the stress experienced by modern individuals. The overwhelmingly increased research interest and the emergence of new solutions or approaches for stress mitigation justify the need to glean the accumulated knowledge in order to clarify the present goals and the future directions.

1.2 Significance of this scoping review

Over the years, there has been an increasing interest in the potential of VR technology to efficiently promote mental health via reducing and coping with stress. Various reviews have been published investigating specific methods of stress reduction translated into VR environments like nature therapy and mindfulness (Syed et al. 2021; Paolis et al. 2021),

[1] https://www.britannica.com/technology/virtual-reality.

[2] https://dictionary.apa.org/stress.

factors that should be considered during the design of such a VR system that aim at modulating a design framework or delineating the issues and challenges and proposing possible design solutions (Zaharuddin et al. 2019a, b), and target group-specific VR environments that usually aim at mapping systems that were developed for relieving stress on specific professions where highly stressful conditions are common experience among the employees (Michael et al. 2019; Hill et al. 2021; Meese et al. 2021). However important, the existing literature lacks a holistic exploration into VR systems specifically designed to alleviate the common experience of stress in modern individuals, investigating both the implemented/translated methods and techniques and their eventual/potential efficiency via the presentation of experimental results. In this scoping review, we aim at overcoming this gap via the exploration of studies that translated stress reduction methods and techniques into VR environments, exposing their reasoning, the systems' development methodology (including the selection of game elements, the incorporation of interactive aspects and the overall scenario) and evaluation experimental results that act as evidence of the potentiality of VR systems as a stress relieve solution for general public. The scoping review has the ambition to provide a comprehensive roadmap of the research efforts so far, underlining limitations and challenges that should be taken into consideration for the development of such a system. The research questions that we aim to address in this review are:

- Which methods/techniques (and supporting theories) for stress reduction are currently translated into VR environments?
- Which are the translation methodologies, i.e., the development methodologies followed during the creation of the virtual environments, and the utilized technologies/tools?
- Which characteristics do these systems incorporate in terms of the virtual environments' functionalities?
- Which are the evaluation methodologies and tools that are utilized for the provision of evidence for the efficiency of the systems? On which populations were experiments applied and which were the outcomes of the experiments?

Addressing these research questions is vital for the comprehensive examination of VR stress reduction solutions addressed to the general public. Identifying the methods and techniques for stress reduction that are currently selected for translation into VR worlds and understanding the reasoning of these selections are crucial knowledge for establishing the scientific basis and rationale behind VR stress reduction applications. The exploration of design and development strategies is essential to assess the practical aspects of creating such environments. This information is vital for identifying best practices and innovative approaches in designing VR systems, ultimately aiding in the development of more effective and user-friendly stress reduction applications. In this context, the examination of the characteristics of these systems could designate specific functionalities and features that enhance their efficacy. Finally, the investigation of the employed evaluation methodologies, as well as the experimental results, contributes to the assessment of the credibility and efficiency of the existing interventions, revealing the real-world impact, benefits and/or current limitations of these VR applications.

The rest of the paper is organized as follows: The section Methods depicts the procedure that was followed regarding the literature search, the eligibility criteria of this review, the data management and the synthesis of the results. The section Results presents the statistical results, using figures and centralized tables, after reviewing the included studies. Finally, the section Discussion comments on the results and delineates possible limitations of this study, while the section Conclusion highlights the importance of this paper for this research area.

2 Methods

For the writing of this manuscript, the literature search, the study selection and the extracted information, we followed the PRISMA-ScR (Tricco et al. 2018) guidelines for conducting scoping reviews. Studies like Arksey and O'Malley (2005) and Peters et al. (2015) for the conduction of a scoping review were useful sources of valuable information regarding the whole writing procedure.

2.1 Literature search

This review research included articles published from October 2010 to January 2022, while for the literature search, the PubMed and Scopus databases were used. The keywords utilized in the literature search were virtual reality and stress, and they were investigated in the titles and abstracts of the articles. For the search in the databases, the articles had to be in the English language. The following search query was used: *stress AND Virtual Reality*. Subsequently, the duplicated articles were removed, and the remaining studies were screened for eligibility.

2.2 Inclusion and exclusion criteria

The eligibility criteria were: (i) to include virtual reality environments aiming to reduce stress, (ii) to be a study published in a peer-reviewed journal or conference, (iii) to introduce a VR system, (iv) to be a study in English, (v) to not be a review, meta-analysis, editorial or commentary.

Table 1 Review analysis dimensions

Dimensions	Extracted information	Description
Applications	Target Group	The group of people the life conditions of whom were mainly considered during the design of the system
	System Goal	The main target of the developed VR system. It varies from stress reduction, relief or relaxation to stress management
	System Scenario	The VR environment scenario and the interactive game elements (if existed)
	System Context	The characterization of the system. GAME if game elements and characteristics applied, APP if not
Employed methods	Stress Reduction Method	The validated method implemented by the system. Guided meditation, guided imagery and biofeedback are some example values of this feature
	Theory	The supporting theory behind the utilized method
	Biofeedback	The use or not of biofeedback
	User's Participation—Interaction	Characterization of the user's participation distinguished as active and passive
Technologies adopted	VR Technology	The technology utilized as the main component of the system
	Development Software	The software used to develop the VR environment
	Sensors	The sensors (if any) utilized by the system
Evaluation	Evaluation Methodology and Metrics	The methodology used for the evaluation of the system. This feature contains information about the utilized questionnaires, the measured biosignals and their processing
	Validation	The results of the evaluation procedure and their credibility
	Usability Evaluation	The evaluation methods of system's usability (if any)

Inclusion criteria for the eligibility of the selected articles were: (i) to be virtual reality environment aiming to reduce stress (virtual reality-based environments with main target stress evaluation and reduction or management), (ii) to be a study published in a peer-reviewed or conference journal.

Exclusion criteria for this review were: (i) not to include a VR system as main component, (ii) to introduce a protocol/framework/methodology without system description or with no VR system inclusion, (iii) to introduce methods of stress detection or evaluation (without having as goal stress reduction or management), (iv) to be irrelevant with stress or to be relevant with various psychiatric disorders (such as PTSD, etc.), (v) to be a study not in English and (vi) to be a review, meta-analysis, editorial or commentary.

2.3 Data management

Two individual researchers, IL and DF, conducted the literature search and the removal of the duplicates, while the author IL screened the titles and abstracts for eligibility advised by the author IC. The remaining studies were reviewed by IL and DF guided by a set of inclusion and exclusion criteria in order to extract information from the selected articles. The extracted information follows a structure defined by IC, IL and DF, listed as follows: (i) publication type, (ii) year of publication, (iii) country/ies, (iv) journal/conference, (v) scientific field, (vi) paper purpose, (vii) system target, (viii) system scenario, (ix) system context (game or application), (x) utilized technology, (xi) development software, (xii) integrated/used sensors, (xiii) method applied for stress reduction, (xiv) target group, (xv) pilot conduction (yes or no), (xvi) if so, number of participants, (xvii) study duration, (xviii) evaluation, (xix) validation, (xx) immersion evaluation, (xxi) usability evaluation, (xxii) if tested on experiments or real life, (xxiii) if included biofeedback and finally (xxiv) if it was an interactive system.

The features extracted during the conduction of this scoping review were chosen to provide clean, straightforward information about the research directions in this field. There was a consistent and cautious approach regarding the detection and the classification of the extracted features. Table 1 presents the extracted features that were used to draw conclusions.

2.4 Literature search flow and results

The literature search was conducted in February 2022 with the requirements described above and 1370 studies were identified, 487 from PubMed database and 883 from Scopus database. After the removal of duplicates, 1037 studies were screened with 148 remaining. Finally, 51 studies were excluded during the reviewing for meeting one or more exclusion criteria, and 97studies were included in the present scoping review. The most common reasons for a study to be excluded were not being relevant with the main objective of the study and providing a theoretical framework or study protocols without VR system description. Figure 1 shows the flow diagram of the exclusion stages for this review study.

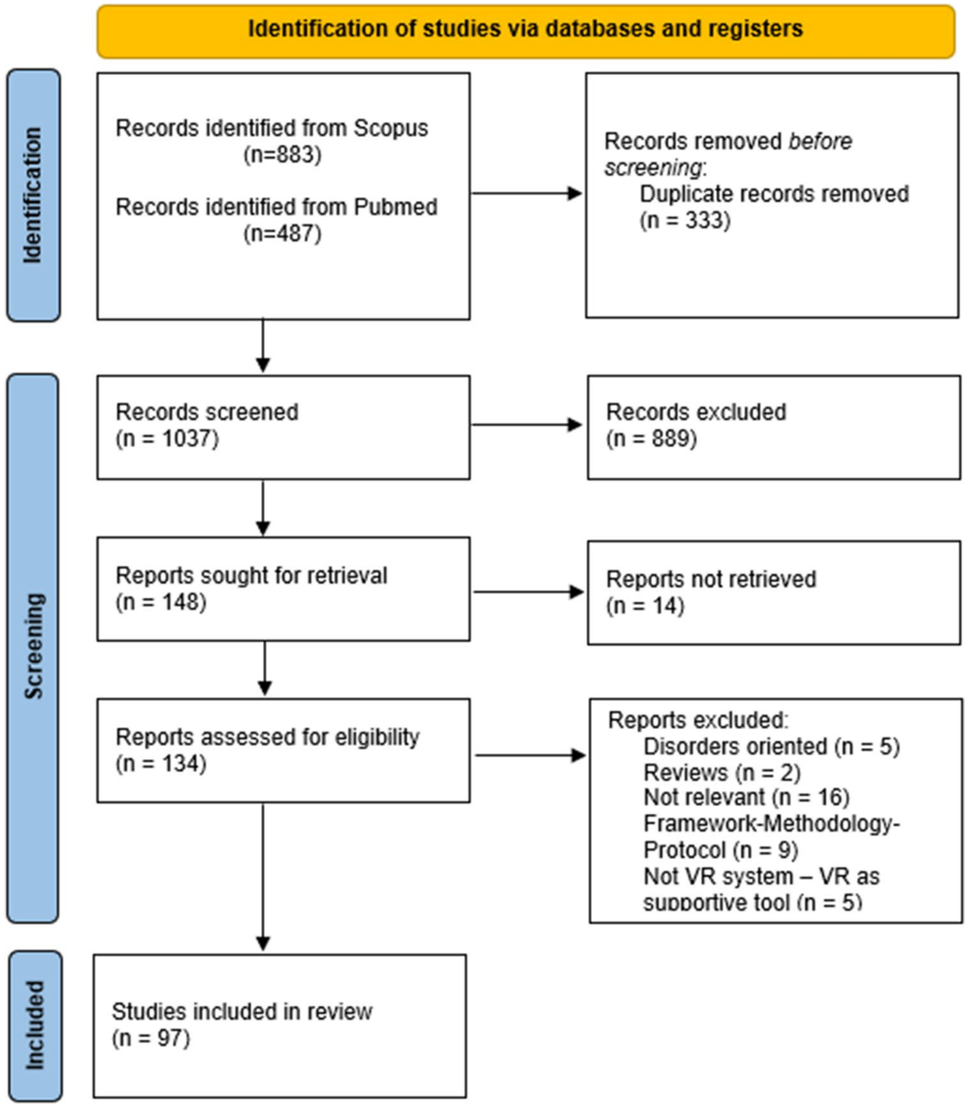

Fig. 1 PRISMA flow diagram

2.5 Synthesis of results

In this review paper, the results extracted from the monitored studies are presented with the following structure:

- Presentation of statistics depicted in charts or pies.
- Presentation of brief descriptive tables that assemble information regarding the tendencies of researching attempts.
- Synthesis of results and conclusions extracted not only from the statistics but also from the general picture modulated from the recitation/analysis of the studies.

3 Results

Our literature research focused on a period (i.e., after 2010) that VR technology gained more and more recognition regarding its potential in supporting standard clinical practice in the field of psychiatry and psychology. It is noteworthy that researchers seemed to have less interest in investigating stress until 2016, while after 2017 and especially during the COVID pandemic period (2020–2021) there is a remarkable increase in studies that introduce stress relieving systems and approaches. This could be justified by the psychological deficits that most of the people experienced because of the pandemic (Manchia et al. 2022). Figure 2 depicts the prementioned observations and the exponential increase of publications.

3.1 Applications

This section includes results and observations related to the applications, presenting information regarding the target group of the mapped systems, their goal, the scenario of the virtual environment and the system context.

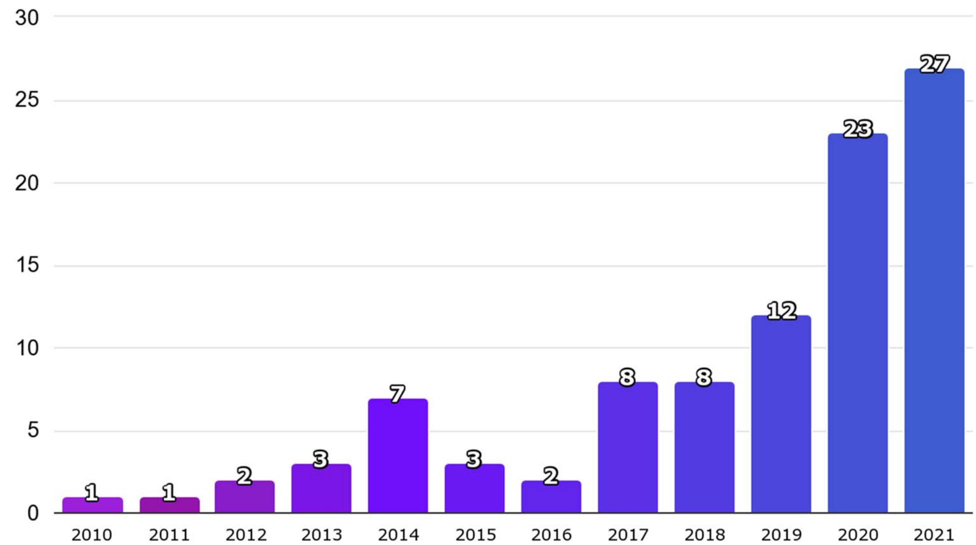

Fig. 2 Histogram of the studies according to the publication year. An increasing trend over the years is observed, especially after 2019

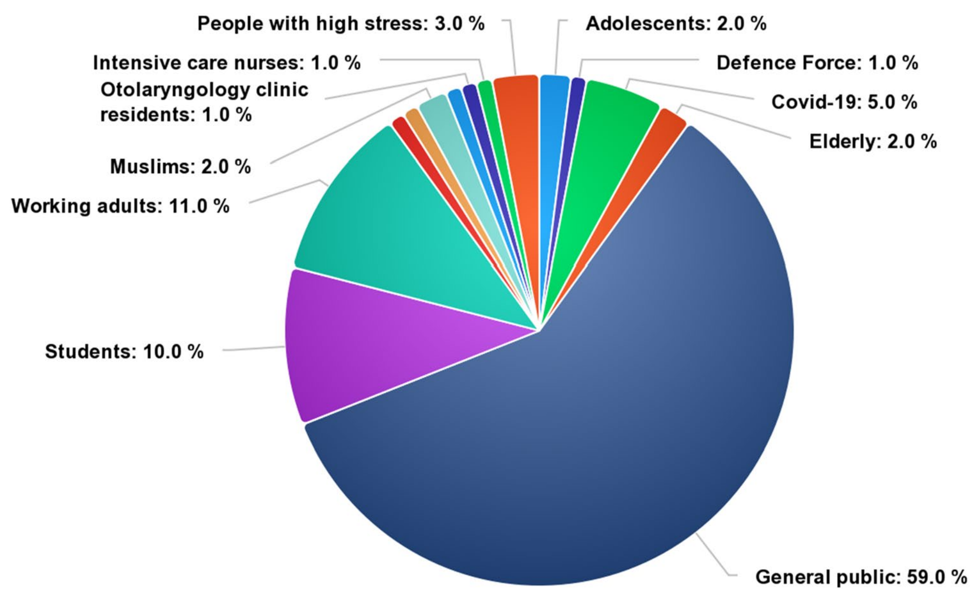

Fig. 3 Pie diagram that displays the target groups as identified in the studies. The target group refers to the target populations of the proposed solution

3.1.1 Target group

Only two of the studies included did not report their target group. The high percentage of reports on target groups (97.9%) is reasonable as it designates the interest of research teams to configure and adjust their developed systems on the needs and expectations of specific groups of people. Figure 3 depicts the identified target groups. Most of the studies defined as their target group the general public, i.e., healthy people that do not suffer from any pathological or psychological condition and experience daily life stress (59%). Working adults (11%) and students (10%) are also gathering high research interest as target groups, as they are experiencing daily conditions that may trigger significant stress physiological responses. Surprisingly, people that experienced the psychological burdens of lockdowns during COVID-19 pandemic, emerged due to the introduced confinement measures and the social isolation, are not reported as target group from many studies (5%), even though the number of studies significantly increased during the 2 years of pandemic (Fig. 2). Although not explicitly stated, a significant number of the studies addressing the general public took place during the last years, implicitly incorporating the pandemic elated challenges, e.g., social isolation, teleworking or even sickness. The rest of the identified target groups reflect the research interest on specific age groups (adolescents and elderly), specific occupation (intensive care nurses and defense force) and specific conditions (Muslims, older working people, otolaryngology clinic residents, homeless young people and people with high stress).

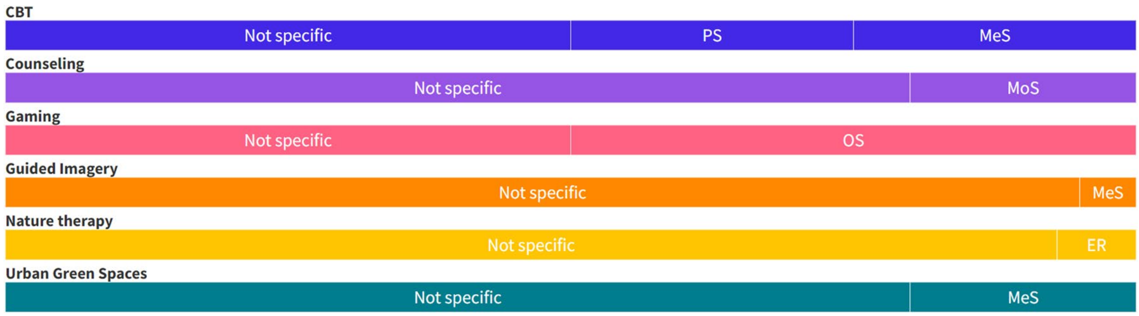

Fig. 4 Comparative bar chart of the methods used for specific stress types and not. Each bar represents the reported stress reduction method and is divided into parts with respect to the targeted stress types as stated in the studies. Not specific legend means that no specific stress type was stated. As for the other legends: *PS* psychological stress, *MeS* mental stress, *MoS* momentary stress, *OS* occupational stress, *ER* emotional recovery

3.1.2 System goal

Most of the papers monitored in this literature review set as a system target stress reduction/relief (56.7%), while stress management and treatment follow with 16,4%. A different category of system target is relaxation (11.3%), which includes techniques that are part of stress reduction methods. Moreover, another relatively big category of studies examined the effectiveness of specific techniques or approaches were identified (11.3%). Some of the studies are focused on improving well-being/mental variables (Ito et al. 2018; Gao et al. 2019; Cheng et al. 2020; Kaimal et al. 2020; Chan et al. 2021;) in general or alleviating psychological burdens caused by a condition (Wayment et al. 2015; Riva et al. 2020, 2021). There was one study that had as a system target work burnout reduction (Weitzman et al. 2021). There was some overlapping between the prementioned categories, which reveals the fine lines on the definition of system targets. It is noteworthy that, among the studies that aimed at stress reduction, there were subcategories like emotional recovery (ER) (Gu et al. 2021), mental stress reduction (MeS) (Taneja et al. 2017; Eswaran et al. 2018), momentary stress reduction (MoS) (Björling et al. 2020), occupational stress reduction (OS) (Broneder et al. 2021) and psychological stress reduction (PS) (Pallavicini et al. 2013; Yang et al. 2021a, b). This observation indicates that researchers are trying to approach distinct aspects of stress, although an interplay among such aspects may exist. The *System Goal* probably greatly affects the approach methodology and even the designed experimental protocol. The actual effect of different methods to different types of stress, as well as their evaluation/detection methodology, could lead to the disclosure of appropriation of each (relief and analysis) method for each stress type. However, the fact that only a few studies are referring to specific types of stress unveils the difficulties created by both the blurry definitions of stress and the nonspecific approach of the reported stress relief methods.

In Fig. 4, we can observe that the reported stress reduction methods for specific stress types are widely used for not specific stress types as well.

3.1.3 System scenario

The majority of the studies (76.3%) chose to translate established stress reduction techniques, such as guided imagery, breathing technique and meditation, with relatively minimum interaction requirements for the user. In these VR applications, the user just needs to follow instructions projected in the environment, navigate in the environment and/or watch 3D videos without directly interacting with environmental elements. Various subcategories could be identified, including studies that:

- Integrate controlled breathing tasks (Weerdmeester et al. 2017; Naylor et al. 2019; Heyse et al. 2020; Rockstroh et al. 2021; Kluge et al. 2021; Ladakis et al. 2021),
- Use only the projection of a new environment (62.1%),
- Introduce intervention systems (Wayment et al. 2015; Thoondee and Oikonomou 2017; Rozmi et al. 2020; Broneder et al. 2021),
- Encourage users to navigate in the projected environment (Soyka et al. 2016; Eswaran et al. 2018; Sakhare et al. 2019; Reese et al. 2021),
- Integrate biofeedback for the navigation or the interaction (Pallavicini et al. 2013; Gu and Frasson 2017; Maarsingh et al. 2019),
- Promote meditation (Andersen et al. 2017; Cikajlo et al. 2017),
- Try to include sound, olfactory or sensory stimuli (Annerstedt et al. 2013; Latif and Ismail 2015; Taneja et al. 2017; Latif 2018; Hedblom et al. 2019; Kamińska et al. 2020; Schebella et al. 2020; Vaquero-Blasco et al. 2020, 2021),

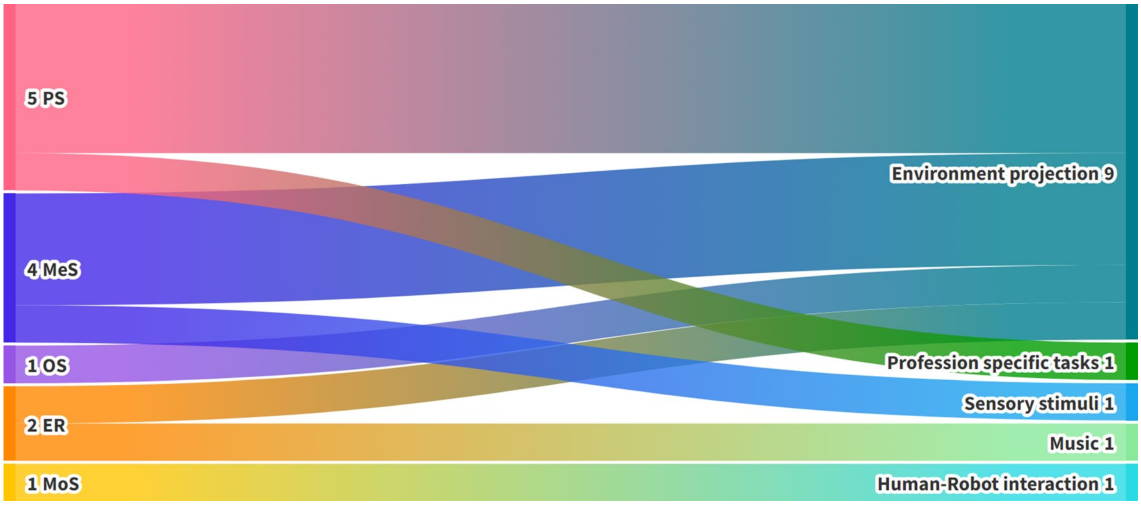

Fig. 5 Sankey diagram depicting the relation between specific stress types and the selection of system's scenario. It is observed that the environment projection (highly facilitated by VR technology) is selected from the majority of the studies that mention specific stress type. Acronyms: *PS* psychological stress, *MeS* mental stress, *MoS* momentary stress, *OS* occupational stress, *ER* emotional recovery

- Studies that included biophilic theory approaches (Yin et al. 2018, 2020) and
- One study that developed a projected storyline (Muhaiyuddin and Rambli 2018).

The rest of the studies included task-specific interaction aiming at the engagement of the user via interactive activities inside the virtual environment. The main target of these group of VR applications is to help the user get distracted via specific interactive tasks like gaming or art making as a method for stress relieve. In these environments, the user has the chance to actively manipulate and interact with the included game elements via:

- Art making (Kristensen et al. 2019; Kaimal et al. 2020; Richesin et al. 2021),
- Gaming (Ishaque et al. 2020; Xu et al. 2021),
- Human–robot interaction (Björling et al. 2020),
- Taking care of plants (Skulimowski and Badurowicz 2017),
- Hearing or playing music (Tivatansakul and Ohkura 2013; Lin et al. 2020),
- Consultancy on various stress reduction techniques (Modrego-Alarcón et al. 2021), including consultancy via virtual agents (Lin et al. 2021; Gonzalez et al. 2021; Madzin et al. 2021),
- Profession-specific tasks (Gaggioli et al. 2014).

The existence of so many different approaches depends on the specific target group of the system that leads to variations of the systems' requirements, but is also related to the lack of a 'golden' standard method in VR settings. The researchers are inevitably experimenting with different approaches trying to identify those that are actually impactful. Figure 5 presents the relation between specific stress types and the selection of system scenario. It is observed that the majority of the studies that refer to specific stress type selected environment projection as system scenario, a reasonable outcome as this is one of the most attractive features of VR technology.

3.1.4 System context

Following the results of *System Scenario*, the majority of the studies presented the development of VR applications (83.5%). By applications, we mean systems that did not include any gaming-oriented characteristic like interaction with other elements of the graphical VR environment to achieve objectives, etc. The rest of them presented the development of systems that engaged the user by involving him/her into interactive tasks in a gaming manner; thus, they were classified as games.

3.2 Employed methods

This section incorporates results related to the employed methods and techniques for stress reduction and management, as well as information regarding the reasoning and the theory behind these techniques.

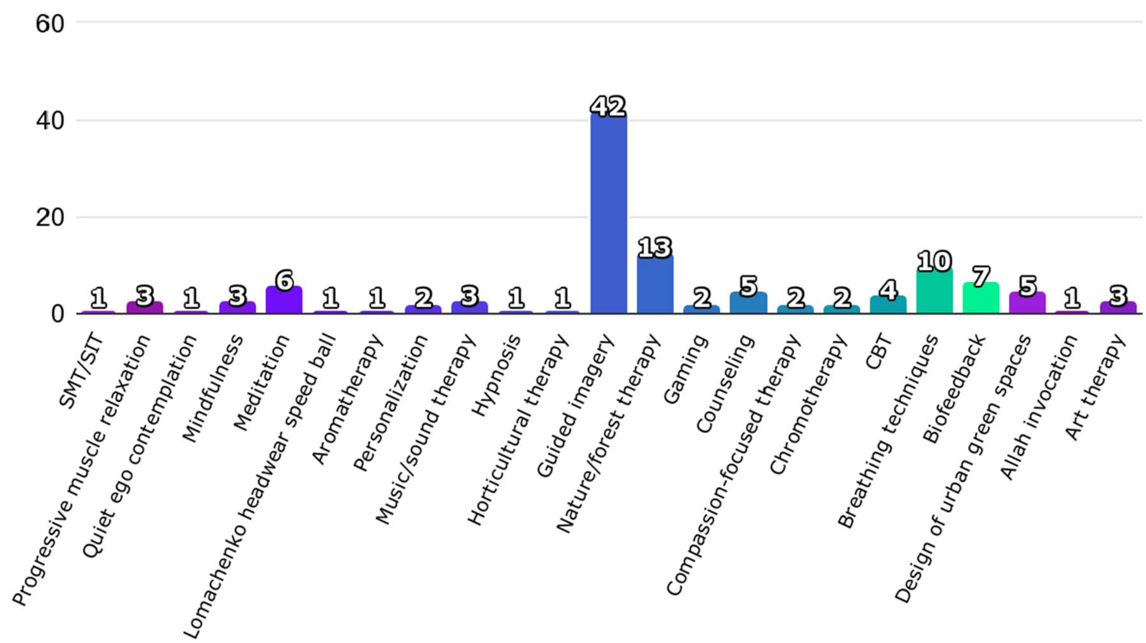

Fig. 6 This bar chart presents the identified methods that were translated into a virtual environment and their utilization frequency

3.2.1 Stress reduction method

Ninety-one studies in total reported the method that was implemented for stress reduction or regulation, while six failed to explicitly report any method. The bar chart of Fig. 6 depicts the methods that were identified and their frequency. It is obvious that guided imagery is the most preferable method (42 studies), as VR technology provides high quality immersive environments that can support the whole idea of guided imagery and can detach to some degree the user from the actual environment. Nature/Forest therapy (methods with similar philosophy) is the second most frequent method identified (13 studies), but it is interesting to observe that the two most frequent methods are trying to exploit the same capability of VR technology to develop and display immersive environments. Ten studies implemented breathing techniques as the main stress recovery method, while seven used some type of biofeedback (mainly based on breathing, but there were two studies that utilized HRV biofeedback (Blum et al. 2019; Rockstroh et al. 2019)). It can be stated as a general observation that all the systems exploited the aforementioned capability of VR technology, with some of them trying to extend it by integrating various established techniques for stress reduction. One study was religious-specific, utilizing Allah invocation was stated as main method (Madzin et al. 2021).

3.2.2 Theory

Contrary to the method feature, 34% (33 out of 97 studies) failed to report a supportive theory of the implemented method. This could be explained by the technical nature of a great number of the studies included, as they focus more on the technical aspects' presentation (especially in conference papers). Figure 7 displays the histogram of the identified theories. Nineteen studies reported nature or forest therapy as the main supportive theory, while 17 reported ART/SRT (attention restoration theory/stress restoration theory). The two most frequent theories reported agree with the high interest toward the development of immersive environments found in the analysis of method feature, as nature/forest therapy, ART and SRT theories are supporting the notion of beneficial exposure of a stressed individual to environmental elements (Ulrich et al. 1991; Song et al. 2016; Ohly et al. 2016; Rajoo et al. 2020;)**.** Virtual reality therapy (VRT) is emerging more as an approach than as an established theory, even though five studies reference it (Mahalil et al. 2014a; Gu and Frasson 2017; Eswaran et al. 2018; Amores et al. 2018; Ibrahim et al. 2021).

3.2.3 Biofeedback

Probably because of the complexity of the inclusion and development of a biofeedback system, most of the

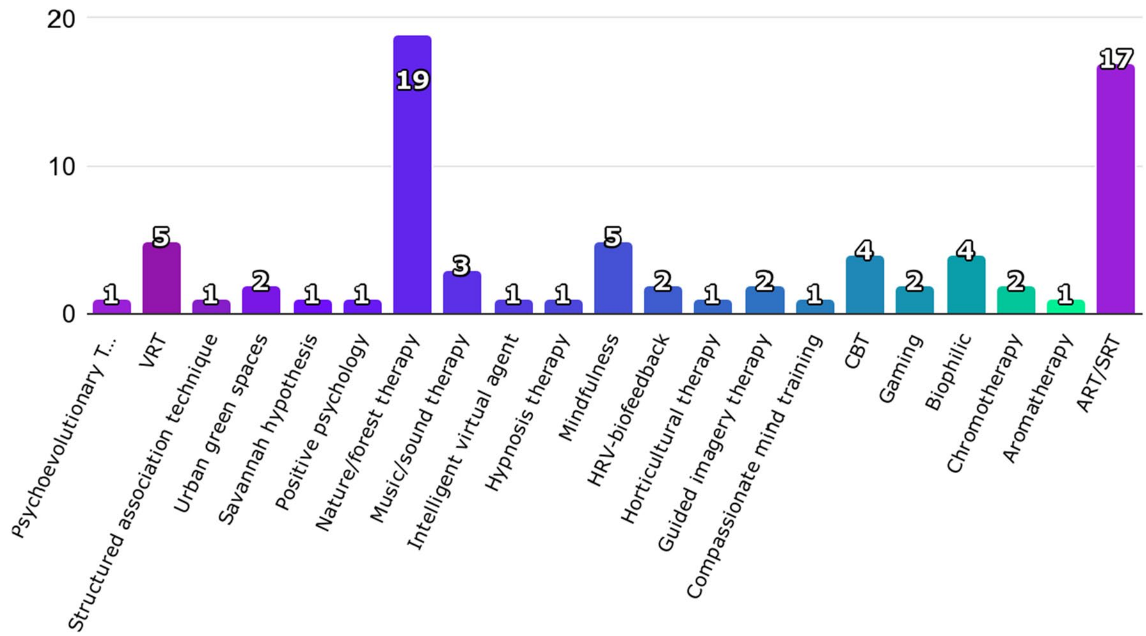

Fig. 7 This figure displays the identified theories on which some of the studies based their implementation and their frequency

studies (77%) did not use any kind of biofeedback. From the rest of the studies (20%), there were two that did not clarify if they are using biofeedback or not. Moreover, one study declared that VR was used as a supportive system for actual biofeedback technique (Kim et al. 2021). Finally, we should mention that there was one study that utilized HRV biofeedback (Maarsingh et al. 2019). Most of the biofeedback approaches eventually introduced audiovisual feedback based on simple measurements, e.g., breathing patterns or pace or even HR detection via various sensors. The aforementioned study that introduced HRV biofeedback tried to actually present an innovative/alternative more sophisticated approach, as it had to be supported by a back-end ECG or HR analysis system and to constantly extract HRV features to evaluate stress responses. Such approaches need extra analysis to be performed in a timely manner, without delays. In addition, biofeedback, either via simple or complex features, needs to accomplish a robust and artifact-free mapping between the feature controlled by biofeedback and measured and the stress level, in order to achieve the desired goal. Finally, the metaphor used in biofeedback (the object to control via controlling the measured parameter) needs to be carefully selected and should bear personalized characteristics. These aspects introduce a number of technical challenges that make biofeedback less appealing for some researchers, despite its potential merit, as suggested by the fields in which it has been applied.

3.2.4 User's participation—interaction

User's participation—interaction was another feature straightforward to classify as it could take only two values (active or passive), just like biofeedback feature. Active participation required the interaction of the user with elements of the virtual environment to unlock the system's potential impact to stress levels, while passive participation did not required user—system interaction for this purpose. (The interaction level was limited at selecting options/preferences from menu elements.) To be more precise, active participation means that the interaction with elements of the VR environment is vital for the procedure. (The user has to move, shape or apply any change to the environment via a sensor or a simple joystick.) The simple movement of the head to observe a virtual environment is not an interaction with the environment (is part of the procedure, but the movement of the user does not affect the environment); thus, this movement appertains to passive participation. Interactivity was required as a main component in studies that developed games, as it is considered as a vital part in the gaming experience. Moreover, some of the developed VR applications included features like navigation in space, counseling in the form of notifications, suggestions or even human–virtual agent communication, art making or the projection of breathing patterns and their translation into environmental changes; thus, they integrated interaction functionality at limited (low) levels as described above. In general, passive user participation systems invested in the

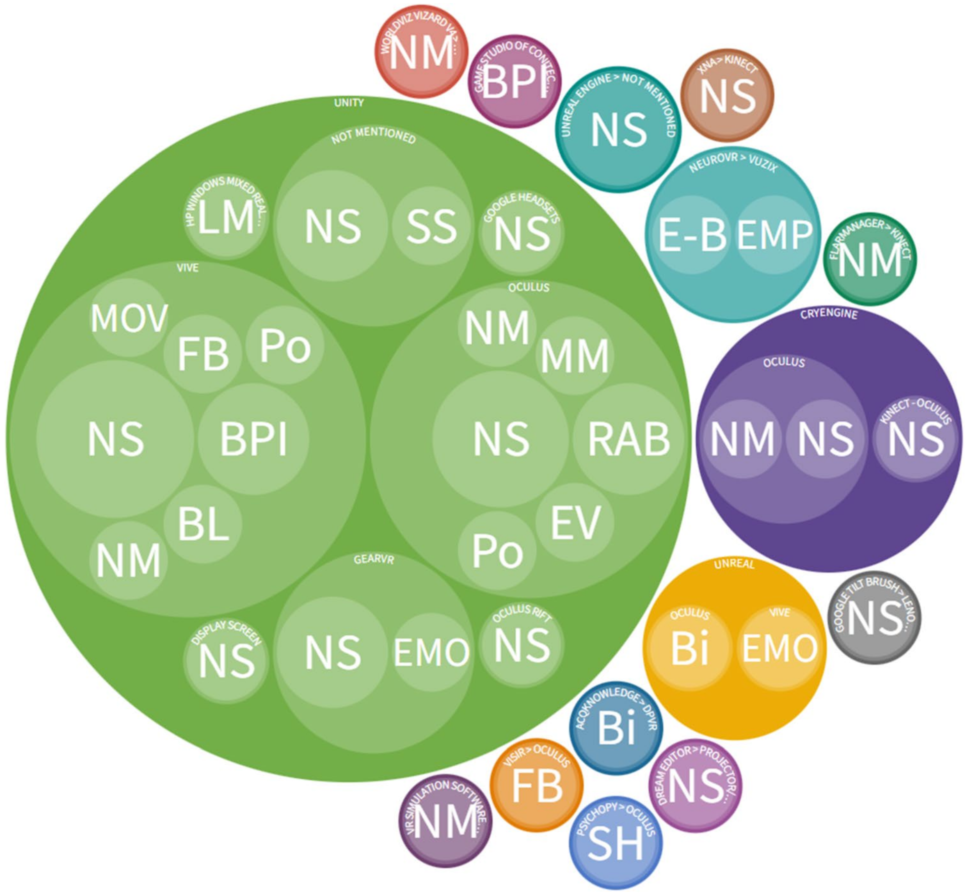

Fig. 8 Bubble cloud presenting the relation between VR Technology—Development Software—Sensors Features. The clusters are depicted by bubbles of different colors and represent the utilized technological features, such as Vive and Oculus. The main clustering feature is Development Software, such as Unity. The sensors are depicted in the smaller bubbles (with the use of acronyms). The wide use of Unity software as well as the Oculus and Vive technologies can be extracted as the main observation of this graph. Acronyms: *BIO/Bi* Biopac, *BL* Bitalino, *BPI* BioGraph ProComp Infiniti, *EMO* Emotiv, *EMP* Empatica, *EV* Equivital, *FB* Fitbit, *LM* Leap motion, *MM* Moodmetric, *MOV* Movisens, *NM* not mentioned, *NS* no sensor, *Po* polar, *RAB* RABio, *SH* Shimmer, *SS* SuperSpec

minimization of the interaction levels and in the increased level of detachment and immersion as an approach to regulate stress levels.

The interaction level is not necessarily related to biofeedback, as the latter is not basically used to introduce interaction with the system itself. The majority of the studies were passive (61.8%), while the rest adopted the opposite approach to promote the system's target. Four studies were identified that did not clarify the passiveness of the system.

3.3 Technologies adopted

This section discusses about the utilization of different technologies toward the development of a VR system, including information regarding the VR-specific technology, the sensors and the software that was used for the development of the virtual environment and its various modalities/functionalities.

3.3.1 VR technology

92.7% of the studies included utilized a VR headset to deploy their system. The high percentage seems reasonable, as *VR technology* is highly represented by VR headsets. Most of the studies used either Oculus (38%) or Vive products (21%), while a significant percentage of the studies did not mention the exact technology that was used (21%). We should mention that there was one study that tested the developed system in more than one headset (Richesin et al. 2021), while there was one study that integrated Kinect system with a VR headset (Zainudin et al. 2014a, b). Among the seven studies that remained, two used Kinect as the main component of the system (Lui et al. 2012; Tivatansakul and Ohkura 2013), three used computer technology (Zhao et al. 2015; Taneja et al. 2017; Muhaiyuddin and Rambli 2018), one used iPhone (Wiederhold et al. 2014) and one exploited CAVE system technology (Annerstedt et al. 2013). Finally, there was one system that mentioned a prototype hardware development (Ergan et al. 2019). It is obvious that the use of widely used commercial products prevailed (over 60%), probably as a means to promote the goals of the studies, e.g., low-cost, portable systems, open to the general (or specified) public. Another reason for the prevalence of widely used

Table 2 List of studies that used commercial sensors for the capture of physiological signals

Studies	Sensors	Signals
Tinga et al. (2019)	AcqKnowledge	EEG, ECG
Anderson et al. (2017), Huang et al. (2020) and Gu et al. (2021)	Biopac	EDA, HRV
Villani and Riva (2012), Kim et al. (2021), Manaf et al. (2021), Eftekharifar et al. (2021) and Alyan et al. (2021)	BioGraph ProComp Infiniti	EDA, HR, EMG, BVP, Respiration rate
Gaggioli et al. (2020) and Chan et al. (2021)	Bitalino	HR, HRV
Ishaque et al. (2020)	Captiv	ECG, GSR, RESP, HRV
Gu and Frasson (2017) and Yeom et al. (2021)	Emotiv	EEG
Gaggioli et al. (2014), Wiederhold et al. (2014), Yin et al. (2018), Schebella et al. (2020), Pfeffel et al. (2020)	Empatica	HR, HRV, EDA
Klug et al. (2021)	Equivital	Respiration rate and variability
Naylor et al. (2019), Gonzalez et al. (2021), Crosswell and Yun (2022)	Fitbit	HR
Soyka et al. (2016)	g.RespSensor	Respiration
Ahmaniemi et al. (2017), Yin et al. (2018), Wang et al. (2019) and Yin et al. (2020)	OMRON	BVP
Amores et al. (2018)	Muse Headband	EEG
Skulimowski and Badurowicz (2017)	Microsoft band	HR
Yin et al. (2018) and Yin et al. (2020)	Movisens	ECG
Mostajeran et al. (2021)	Neulog	HR, GSR
Vaquero-Blasco et al. (2020) and Vaquero-Blasco et al. (2021)	RaBio w8	EEG
Eswaran et al. (2018)	RSM SuperSpec	EEG
Lin et al. (2020)	Leap Motion	–
Kristensen et al. (2019), Blum et al. (2019), Rockstroh et al. (2019) and Kamińska et al. (2020)	Polar	HR, HRV
Valtchanov et al. (2010), Annerstedt et al. (2013), Hedblom et al. (2019)	Powerlab	HR, HRV, SCL, Respiration
Ergan et al. (2019), Biber et al. (2020)	Shimmer	PPG, GSR, EEG
Ladakis et al. (2021)	Moodmetric	EDA
Jo et al. (2021)	Ubiomacpa	EEG, HRV
Gao et al. (2019) and Gu et al. (2021)	Neurosky	EEG
Koinuma and Ohkura (2018)	Nexus	ECG
Ladakis et al. (2021)	Scosche Rhythm +	HR
Soyka et al. (2016)	Brain products (blood pressure)	BVP

commercial products could be the level of familiarization with them, as well as the existing development tools and support. The combination of different VR technologies or the development of cross-technology systems is not frequent as it could raise the level of development difficulties.

3.3.2 Development software

With regard to the development software of the introduced systems, almost half of the studies (51%) used third-party developed application or game for their system or did not mention anything around the development procedure. The rest of the studies used various games or VR engines specialized in the development of virtual world. The most frequently utilized game engine happens to be also the most commercially popular, Unity (31%). One interesting open-source software for the development of virtual worlds found in the literature review is NeuroVR. This software allows non-expert clinical professionals to easily develop and modify virtual worlds; thus, it could be proven as a valuable tool for the exploitation of VR technology from medical institutions and professionals. Figure 8 presents a bubble cloud of the interrelation between the technical features, i.e., *VR technology*, *Development Software* and *Sensors*. The clusters are based on the *Development Software* after the removal of the studies that did not develop the utilized VR environment or did not mention it. It seems that Unity and Unreal game engines provided a straightforward set of tools for the development of VR environments and their deployment on specific VR devices, especially Oculus and Vive. Most of the studies did not move toward the integration of a sensor regardless of the device or the development software.

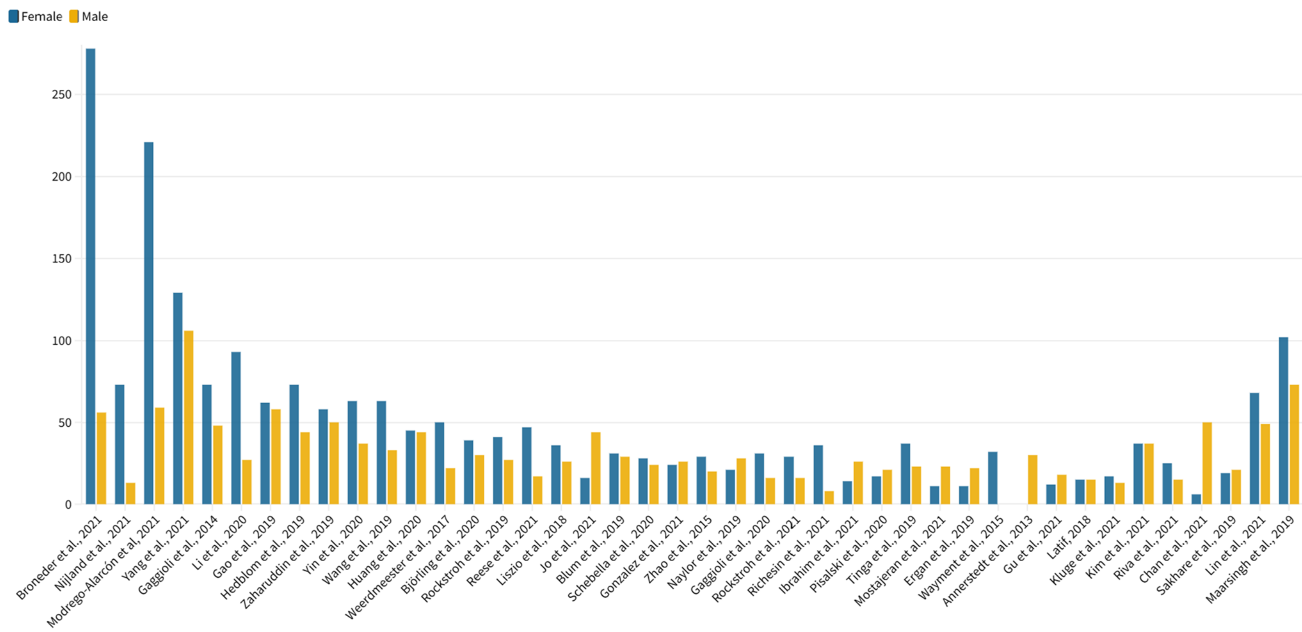

Fig. 9 Histogram depicting the number of female and male participants on studies that included that information and registered a number of participants over 30

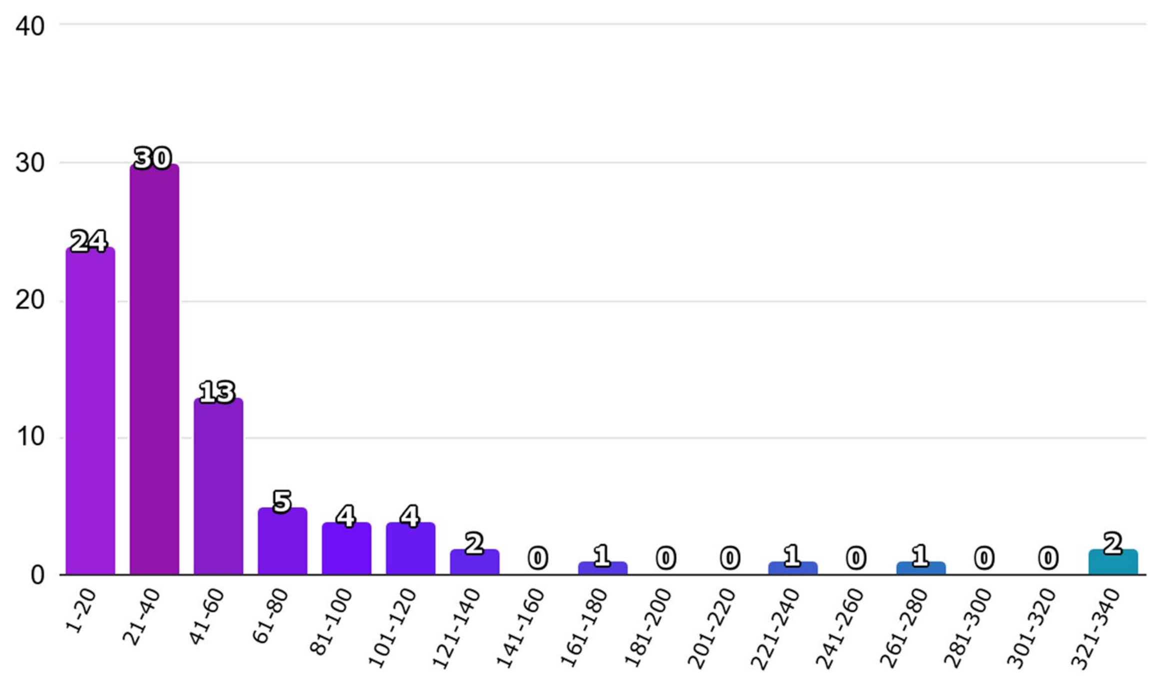

Fig. 10 Histogram with classes based on the number of participants. It is clearly observed that most of the studies recruited 40 or less participants, as the first two classes reached a percentage of 56% of the monitored studies

3.3.3 Sensors

Various sensors were integrated in approximately half of the studies, mainly to facilitate the evaluation procedure as regards stress reduction. For systems that implemented a biofeedback method, sensors were vital for the usage of the system itself. The range of the utilized sensors is quite impressive. Almost half of the studies (46.39%) did not utilize any sensor or failed to report the usage of a sensor. The reason why most of the studies did not use any sensor

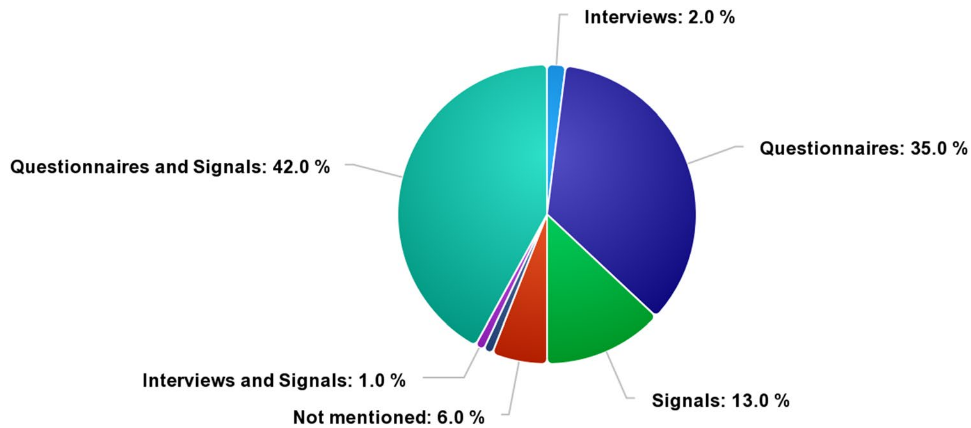

Fig. 11 Pie diagram that presents the methods that were utilized for the evaluation of the studies. These methods vary from questionnaires utilization to physiological signals collection and are aimed at collecting valuable information to evaluate the efficiency

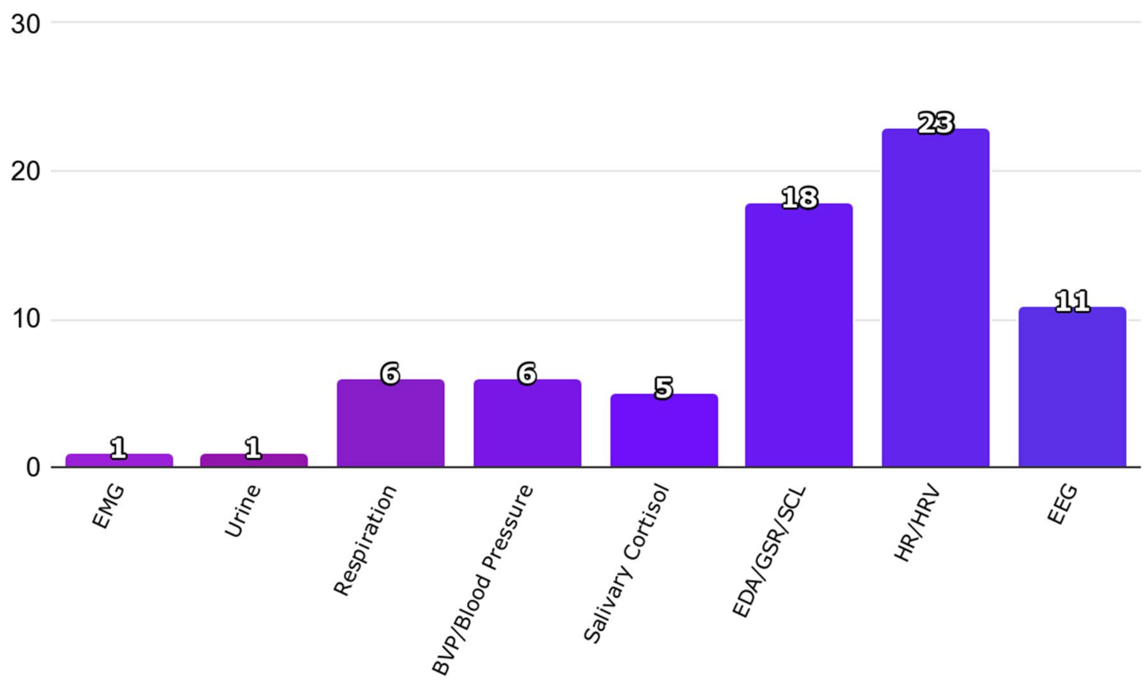

Fig. 12 Bar chart with the identified signal collection methods for the evaluation of the proposed solutions' impact on stress levels

could be found in the technical (integration) difficulties that may arise.

Table 2 presents the list of the studies that utilized commercial sensors and the corresponding targeted signal for the evaluation of the system's efficiency. From this table, it is clear that most of the studies involving objective metrics via biosignals focused on the collection of ECG/PPG in combination with EDA/GSR signal. HR and HRV features are extracted from ECG or PPG measurements as they are identified as reliable indicators and metrics of stress levels. There are also some studies (12 in total) that tried to identify brain waves patterns and variations for stress detection. These observations are in agreement with the existing literature regarding biosignal recording and analysis for the detection/evaluation of stress (Giannakakis et al. 2019; Ladakis and Chouvarda 2021). There is one study that utilized Leap Motion for user experience purposes (interaction with the system) and not for data collection reasons (Lin et al. 2020).

3.4 Evaluation

This section presents information on the evaluation efforts reported by each study, discussing the conduction of pilot experiments and deployment, the delineated methodology and the validation of the systems' usability and efficiency.

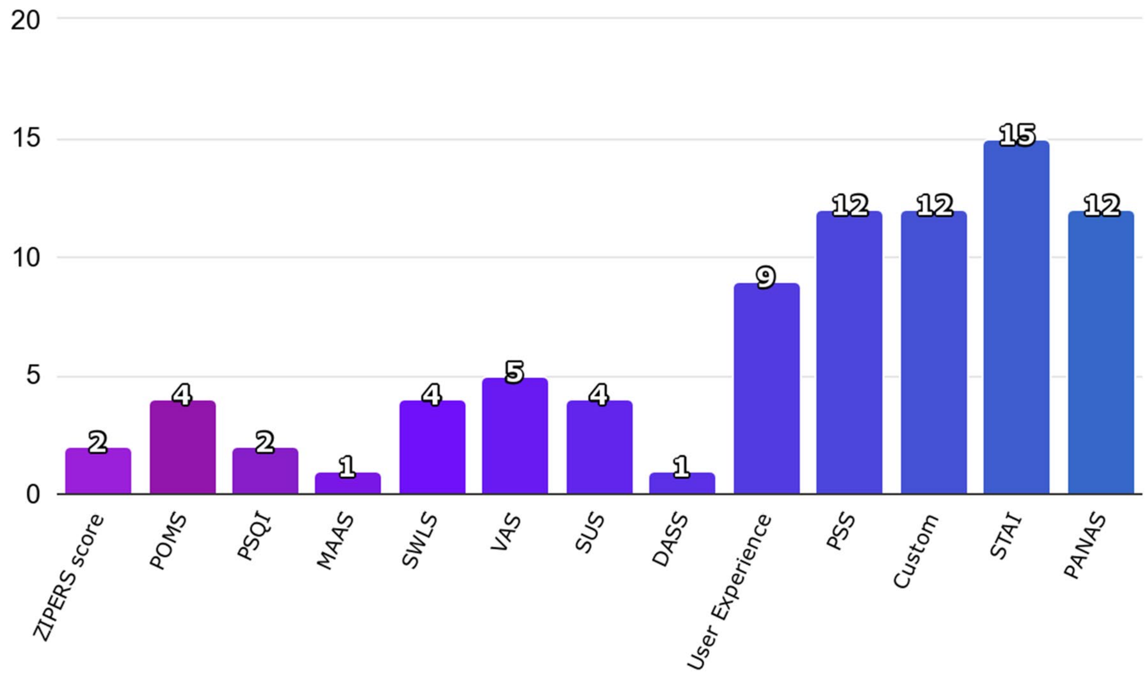

Fig. 13 Bar chart that presents the most frequently used questionnaires for the evaluation of the proposed solution. Some of the questionnaires aim at evaluating the system from user experience/usability perspective, while others aim at identifying their actual impact on stress levels

Table 3 Studies that collected more than one signal

Studies	Combination of signals
Li et al. (2020)	BVP + GSR
Soyka et al. (2016)	BVR + Respiration Rate
Tinga et al. (2019)	ECG + EEG
Tivatansakul and Ohkura (2013) and Koinuma and Ohkura (2018)	ECG + salivary a-amylase
Gu et al. (2021)	EEG + GSR
Ergan et al. (2019)	EEG + PPG + GSR
Manaf et al. (2021)	HR/HRV + BVP + Breathing patterns + GSR
Ahmaniemi et al. (2017) and Yin et al. (2020)	HR/HRV + BVP + GSR
Kim et al. (2021)	HR/HRV + BVP + Respiration Rate + GSR + Temperature + EMG
Wang et al. (2019)	HR/HRV + BVP + salivary a-amylase
Jo et al. (2021)	HR/HRV + EEG
Yeom et al. (2021)	HR/HRV + EEG + GSR
Valtchanov et al. (2010), Anderson et al. (2017), Schebella et al. (2020), Biber et al. (2020), Ladakis et al. (2021), Alyan et al. (2021) and Mostajeran et al. (2021)	HR/HRV + GSR
Yin et al. (2020)	HR/HRV + GSR + BVP
Richesin et al. (2021)	HR/HRV + GSR + salivary a-amylase
Pallavicini et al. (2013)	HR/HRV + Respiration Rate
Ishaque et al. (2020)	HR/HRV + Respiration Rate + GSR
Annerstedt et al. (2013)	HR/HRV + Respiration Rate + T-wave amplitude + salivary a-amylase
Liszio et al. (2018)	HR/HRV + salivary a-amylase

3.4.1 Pilot studies

81 out of 95 studies reported the conduction of a pilot, while pilot studies with more than 30 participants were conducted for almost half (51.57%) of the monitored studies. As observed in Fig. 9, a small number of studies managed or aimed at enlisting equal numbers of male and female participants and, as a consequence, just a few studies reported the outcomes of a gender-based statistical analysis, reporting differences in the psychological perception utility (Zhao et al. 2015), in the acceptance of an application (Hedblom et al. 2019), and in a collected signal (SCL) on the relaxation phase (Villani and Riva 2012). The average age of the participants varies depending on the target group, with a major part of the selected studies reporting an average age under 30 years old (53%), while around 20% of the studies leaving the targeted age groups open (18–60). Two studies reported higher ages (Cheng et al. 2020; Broneder et al. 2021), as they aimed at stress alleviation for older people (> 55 years old and 82 years old on average, respectively). It is worth mentioning that most of the studies do not deal with the gender factor as part of their analysis, fact that is depicted in the unbalanced representation of the genders in the pilot design and conduction. Figure 10 presents an overall picture of all studies that report the conduction of a pilot. It is obvious that most of the studies recruited not more than 40 participants on their pilots (56%), depicting the existing difficulties of the recruiting procedure.

3.4.2 Evaluation methodology and metrics

The evaluation methods are displayed in Fig. 11. Most of the studies (42%) evaluated their systems by combining standardized questionnaires with objective measurements, i.e., based on biosignal measurements. 35% of the studies used only standardized questionnaires for the evaluation of their system, while 13% tried to deduce a conclusion via the collection and analysis of biosignals.

Only 6% of the studies failed to report an evaluation method, indicating that most of the research teams recognized the importance in evaluating the systems for their actual impact. More details about the different signals and standardized questionnaires used for the evaluation of the systems are presented in Figs. 12 and 13, respectively.

The most frequently used signals collected for the evaluation of the systems are HR/HRV and EDA, a result aligned with the information extracted from *Sensors* feature, while the most frequently used questionnaires are State-trait-anxiety-inventory (STAI), Positive and Negative Affect Schedule (PANAS), Perceived Stress Scale (PSS) and customized questionnaires developed for the needs of each project. It is noteworthy that all the studies utilized self-reported questionnaires to facilitate the collection of user's perception regarding their mental (stress, anxiety and mood) state. User experience was also included as an evaluation feature from various studies utilizing user experience questionnaire (UEQ) or custom user experience scales and System Usability Scale (SUS). The selection of the evaluation methods was based on the attempt to determine the impact of the system on the user's stress state and to promote its efficiency as the main attribute it has to offer.

Table 3 presents the studies that collected more than one signal. It is easily observed that most of the studies collected HR or HRV signal in conjunction with some other measurements. Seven studies reported that collected a combination of HR/HRV and EDA/GSR signal, emerging as the most frequent combination of signals. This combination is used for other studies too, with other signals as supplementary sources of information. Breathing patterns or respiration rate are measured for some studies, as well as blood volume pulse (BVP) and salivary a-amylase. The collected signals are aligned with the reports of the existing literature that underline the use of HR/HRV and EDA signals as the most investigated indicators of stress level. Salivary a-amylase is also reported as a significant indicator of stress level (Ali and Nater 2020), but the extra effort required for the collection of this biomarker in contrast to those that require only the use of a wearable sensor is probably the main reason for not being used so frequently. The extraction of the stress indicators/stress-related features is mostly based on continuous physiological signal measurements (e.g., ECG, HR, EDA, etc.) with the exception of salivary cortisol, urine and blood pressure the assessment of which is based on discrete measurements at time defined by the experimental protocol of each study.

Physiological measurements have been widely used to quantify stress responses as they can provide objective data and can offer insights into the physiological changes associated with stress. However, physiological measurements alone may not capture the subjective experience of stress or individual variations in stress perception. Additionally, they require specialized equipment and expertise for accurate measurement and interpretation, limiting their practicality in large-scale studies or real-world settings. Questionnaires are commonly used to assess self-reported stress levels and psychological well-being. They provide valuable information about individuals' subjective experiences and perceptions of stress. Still, self-report measures are subjective in nature and can be influenced by various factors, such as response biases and individual interpretation of stress. Additionally, relying solely on questionnaires may overlook the physiological or behavioral measures that could enhance the objectivity of an analysis and its conclusions. Behavioral measures, on the other hand, including observation of behavior, task performance and sleep patterns, offer additional avenues to assess stress and its impact on daily functioning. They can

Table 4 Validation results and comments

Studies	Validation report outcome	Comments
Koinuma and Okhura (2018)	A-amylase, LF/HF significantly lower—positive results	Impact compared to 2D videos; VR environments more relaxing than videos
Naylor et al. (2019) and Rockstroh et al. (2021)	Breathing + Questionnaire positive results	Qualitative results, preliminary indications of improved breathing and significant impact on relaxation
Soyka et al. (2016)	Equally effective results on VR regarding relaxation	–
Rockstroh et al. (2019)	Equivalent to standard version of method	HRV analysis, methods equally effective on increasing short-term HRV. Higher motivation on VR
Yin et al. (2020)	HR + RMSSD increased recovery rate	STAI score decreases too, as well as systolic and diastolic blood pressure
Annerstedt et al. (2013)	Increased SNS recovery rate	Sounds facilitate stress recovery; no significant impact on peripheral nervous system (PNS)
Tivatansakul and Ohkura (2013), Wang et al. (2019), Gaggioli et al. (2020), Yang et al. (2021a, b), Broneder et al. (2021), Vaquero-Blasco et al. (2021), Alyan et al. (2021) and Jo et al. (2021)	Indications of VR potential	Either presenting no significant results or the results are based on self-reports and interviews
Wayment et al. (2015)	Least improvement in VR	–
Reese et al. (2021)	VR more stressful	Positive impact on mood; lower stress reported only on non-interactive mode of VR environment
Manaf et al. (2021)	No impact of immersiveness on stress reduction	Positive impact on stress
Chavez et al. (2020)	No impact on stress	Slightly positive impact on anxiety, but not on physiological stress
Kaimal et al. (2020), Weitzman et al. (2021) and Mostajeran et al. (2021)	No impact on stress validation	No significant impact on stress, positive impact on mood
Crosswell and Yun (2022)	No indications for VR superiority	Comparisons with other conditions showed that VR is not equally impactful
Kim et al. (2021)	No significant differences between VR-relaxation and biofeedback. Significantly reduced EMG, LF/HF, LF, NN50, STAI	–
Eswaran et al. (2018) and Kristensen et al. (2019)	No significant results, indications of VR efficiency	–
Vaquero-Blasco et al. (2020) and Pfeffel et al. (2020)	No significant signal analysis results	–
Dayang et al. (2011), Pallavicini et al. (2013), Zainudin et al. (2014a, b), Mahalil et al. (2014a), Fassbender and Heiden (2014), Cikajlo et al. (2016), Thoondee and Oikonomou (2017), Muhaiyuddin and Rambli (2018), Zaharuddin et al. (2019a, b, c), Heyse et al. (2019), Riva et al. (2020), Heyse et al. (2020), Rozmi et al. (2020), Ladakis et al. (2021), Lin et al. (2021) and Sonney et al. (2021)	No validation	–

Table 4 (continued)

Studies	Validation report outcome	Comments
Wiederhold et al. (2014), Anderson et al. (2017), Amores et al. (2018), Latif (2018), Gao et al. (2019), Li et al. (2020), Weitzman et al. (2021), Gonzalez et al. (2021), Eftekharifar et al. (2021) and Yeom et al. (2021)	Questionnaire + signals positive results	More concrete results as they conclude based on both subjective and objective measurements
Valtchanov et al. 2010	Questionnaire + signals positive results (immersion evaluation)	Positive impact on mood and stress
Tinga et al. (2019)	Questionnaire + signals positive results (no additional value of biofeedback in reducing arousal)	Subjective and objective arousal decreased during VR meditation, no significant impact of respiratory biofeedback
Liszio et al. (2018)	Questionnaire + signals positive results (significantly reduces stress)	Stress and mood investigated, HR/HRV and a-amylase included in signal analysis
Mahalil et al. (2014b), Gaggioli et al. (2014), Zhao et al. (2015), Taneja et al. (2017), Weerdmeester et al. (2017), Gu and Frasson (2017), Cikajlo et al. (2017), Ito et al. (2018), Maarsingh et al. (2019), Blum et al. (2019), Björling et al. (2020), Lin et al. (2020), Cheng et al. (2020), Kamińska et al. (2020), Schebella et al. (2020), Nijland et al. (2021), Riva et al. (2021) and Madzin et al. (2021)	Questionnaire positive results	Questionnaire scores-based analysis
Yang et al. (2021a, b)	Questionnaire positive results (anxiety)	Significantly reduced anxiety feeling, implicitly affecting stress. No significant differences between VR and AR experience
Xu et al. (2021)	Questionnaire positive results (depression)	Significantly reduced depression feeling, implicitly affecting stress
Kluge et al. (2021)	Questionnaire positive results + reduced objective measurements	Overall positive results, only respiration rate included in signal collection/analysis
Modrego-Alarcón et al. (2021)	Questionnaire-based indications for VR potential	–
Villani and Riva (2012)	Self-reports + HR analysis-based indications for VR potential	Combination of self-reported questionnaires and signal analysis reports (better improvement on VR)
Lui et al. (2012), Latif and Ismail (2015), Andersen et al. (2017), Sakhare et al. (2019), Pisalski et al. (2020) and Ibrahim et al. (2021)	Self-report-based indications for VR potential	Mostly user experience reports
Skulimowski and Badurowicz (2017), Yin et al. (2018), Ergan et al. (2019), Ishaque et al. (2020), Biber et al. (2020) and Chan et al. (2021)	Signal positive results	Positive effects on various mental variables like stress, mood, arousal, etc.; these variables are affected or evaluated on similar changes of physiological responses
Ahmaniemi et al. (2017) and Huang et al. (2020)	Signal positive results (significantly reduced stress)	GSR features significantly lower (HR also in one of the studies)
Hedblom et al. (2019)	Significant reduced stress, no significant difference between methods	Three soundscapes, all significantly reduced stress
Richesin et al. (2021)	VR—HR decrease	Positive impact on stress, anxiety and mood, HR partially correlated with qualitative results
Zainudin et al. (2014a, b)	VR stress therapy more effective	Investigated impact on emotional state

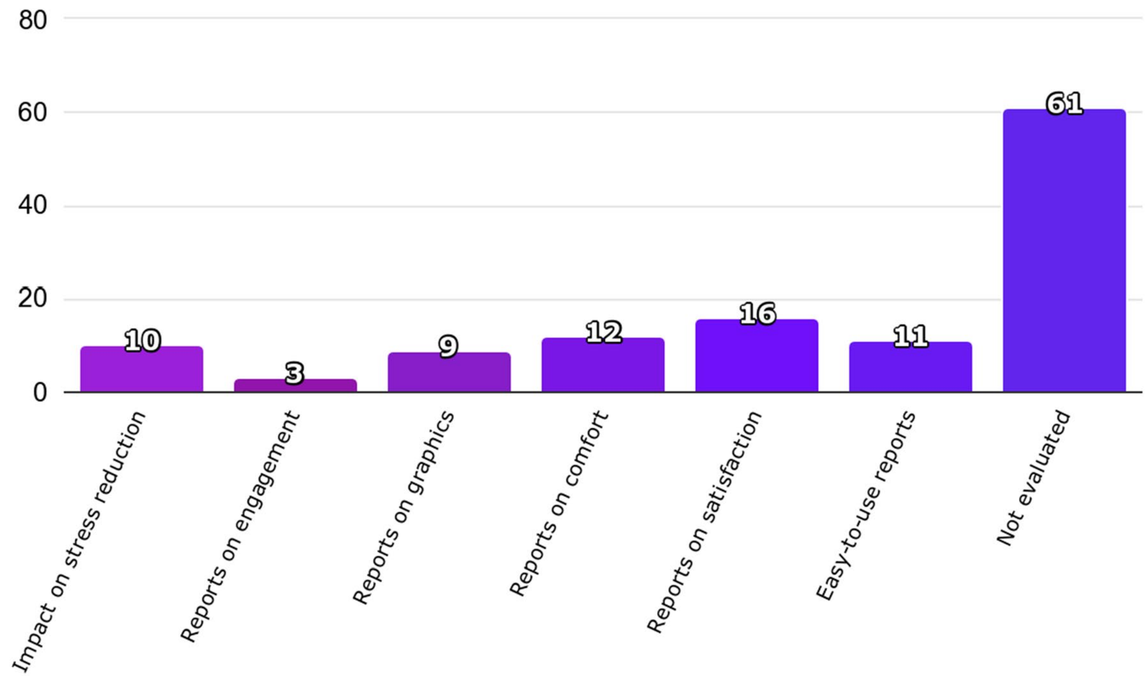

Fig. 14 Usability evaluation methods bar chart. Most of the studies did not include a usability evaluation method. The identified methods focused mainly on the system's features acceptability, while the impact on stress reports played an important role for the evaluation of some studies (10)

provide objective data on stress-related behaviors, such as avoidance or agitation, and capture the functional consequences of stress in real-world contexts. Nevertheless, they may not directly reflect internal psychological states and can be influenced by various confounding factors, making interpretation and standardization challenging. Considering the limitations of each measurement approach, a comprehensive and multi-method approach combining physiological, self-report and behavioral measures can provide a more holistic understanding of stress and its reduction. Integrating objective physiological measures with self-reported experiences, as was the approach of many studies (42%), and observable behaviors can offer a more insightful perspective on stress and its management. Furthermore, advancements in wearable technologies and mobile health applications have the potential to improve the feasibility of stress assessment in real-world settings.

3.4.3 Validation

Validation reports are summarized in Table 4. Most of the studies that reported validation results underlined VR potential to positively affect stress levels by presenting questionnaire-based positive results and/or signal analysis-based positive results or just self-reports by the users (more than 50% in total). Some studies reported no positive impact on stress levels or even slightly negative, while some reported on the equivalence between VR and standard version of the utilized method. In general, validation reports denoted the potential impact of VR-translated stress reduction methods.

3.4.4 Usability evaluation

Figure 14 displays the *Usability Evaluation* methods. Sixty-one studies did not include a usability evaluation method in their protocol. The rest of the studies tried to collect feedback regarding various aspects of a system's usability, namely reports on satisfaction levels (16 studies), reports on comfort (12 studies), easy-to-use reports (11 studies) and impact on stress reduction reports based on the users' perception (10 studies). Some studies evaluated the satisfaction level regarding the graphical environment(s) of the system (nine studies), while three studies investigated the engagement level achieved via the interaction with the system. The aforementioned reports, combined or not, provide crucial information for the efficiency of the system in conjunction with the results extracted from the analysis of objective measurements and questionnaires. Usability directly relates with the capability of a system to engage the user and to affect his/her physiological responses, a vital part of systems aiming at stress reduction/regulation.

4 Discussion

This scoping review aims at exploring the trends around the implementation of stress reduction methods or techniques via VR technology. Each one of the research questions was extensively investigated via the analysis of specific features. The results indicate an increasing interest over the last decade. The rapid evolution of VR technology seems to have inspired new research approaches for the confrontation of stress. There is currently a wide range of VR devices (Oculus, Vive, GearVR, etc.) that are hosting environments aiming at regulating stress responses. Most of the systems integrated the capabilities of various (mainly commercial) sensors capturing physiological signals (HR, EDA, EEG, etc.) for evaluation reasons to determine their impact on stress level, while there were some interactive systems that required the use of such a sensor both for boost their efficiency and to increase the engagement level of the user.

This scoping review explores key aspects related to the translation of stress reduction methods into virtual reality (VR) environments. The investigation focuses on identifying the methods and techniques, along with supporting theories, that are currently being translated into VR settings for stress alleviation. Additionally, the review aims at mapping the translation methodologies employed during the development of these virtual environments, encompassing the utilized technologies and tools. It seeks to understand the characteristics embedded as functionalities of these VR systems. Finally, the review examines the evaluation methodologies and tools used to gather evidence regarding the efficiency of these systems, identifying the populations on which experiments were conducted and analyzing the outcomes derived from these experiments.

One of the main advantages of this study is that it presents an overall overview of the current state of the existing VR-based stress reduction systems. The motivation behind this scoping review was the development of a better understanding regarding the approaches emerging in this research field. This study presents a set of features that reveal a common research direction and depict a complete guide over the utilized VR technology, the scope of the research attempts and the integrated tools both during the design/development phase and during the evaluation phase.

Results depict the increasing research interest in the domain of VR-based stress reduction systems, an interest that has escalated over the years, probably because of the increase in VR commercial solutions. Statistical outcomes are presented in the section Results. The aim of the analysis is to enable us to examine various aspects of the research approaches in this domain. Most of the studies monitored in this review reported stress reduction/relief as their main target. This outcome is reasonable as it aligns with the very aim of this review. The developed systems included in this review were basically addressed to the general public (59%). The rest of the studies tried to be more precise about the target group, i.e., it is the (temporary or permanent) living or working conditions. The frequent selection of the general public as a target group indicates the wideness of the problem that concerns the average healthy individual in the modern world. However, the studies that focused on special conditions recognized situations of everyday life in which the average person may experience significantly higher stress responses.

Moreover, it was observed that most of the studies presented the development steps of VR applications rather than games, i.e., interactive graphical environments with strong presence of gaming elements. This result agrees with the most frequently reported game scenario that is immersive graphical environments or 360 videos and images. As it concerns the utilized technology, more than 90% of the studies reported the deployment of the developed system on a VR headset. The literature review revealed a wide range of commercially available VR devices; the most common among them are Oculus and Vive products. Regarding the *Development Software* of the introduced systems, more than half of the studies used third-party developed applications or games or failed to report anything about the development procedure. This is quite understandable, as a considerable number of studies focused on presenting experimental protocols and results (from the medical point of view) rather than providing details on the development of the application or its integration. The majority of the remaining studies reported the utilization of Unity game engine as the main development component.

Furthermore, there is a lengthy selection of sensors and their combinations utilized for the support of the systems. The technological evolution provides researchers with affordable solutions and tools that contribute to the realization of their ideas and the evaluation of their efficiency. As ECG/PPG, EDA and HR features are denoted as the most credible biomarkers of stress levels (Ladakis and Chouvarda 2021), most of the utilized sensors were specialized at collecting these signals. Nowadays, such sensors can be embedded in wearables, e.g., smartwatches and rings, making the recording at different environments even easier and more unobtrusive.

One of the most interesting features extracted in terms of the analysis is the mapping of the established stress reduction/regulation methods translated into a VR application. This feature is greatly related with *Theory* feature that is the supportive theory behind a method. Most of the studies reported the implementation of guided imagery method, while almost all studies implicitly used this method as part of the exploitation of VR technology capability to capture the attention of the user via various immersion levels. Many studies (33 out of 97 studies) failed to report a theory behind the utilized method. The most frequently reported theories were attention restoration theory/stress restoration theory and nature/forest therapy, result that aligns with the implemented method or in general with the main attribute and advantage of VR technology, as Nature/Forest Therapy as well as ART/SRT require the immersion into peaceful, relaxing environments, able to partly detach the user from reality's burdens.

As it concerns the *Evaluation Methodology*, it is noteworthy that almost all studies tried to evaluate their system by organizing the collection of subjective and objective measurements, as only 6% of the studies failed to report an evaluation methodology. 42% of the studies evaluated their system based on both subjective and objective metrics, while the second most popular category identified regarding this feature reported evaluation methodologies based on standardized questionnaires. HR/HRV was the most frequently used biosignal for the evaluation of stress level, mainly as the principal metric supplemented by other signals like EDA, EEG, etc. Regarding questionnaires, STAI, PANAS and PSS were the most frequently used for the evaluation of stress and mood level. Most of the studies used more than one questionnaire for the evaluation to collect as much subjective information as possible.

Detailed information is presented on *Validation* reports (Table 4). Most of the studies reported positive results based on questionnaire and/or signal analysis, while 16 studies failed to report any validation results. There was a high interest in the actual efficiency of the systems to reduce stress, that is why various approaches regarding evidence extraction were reported. However, as solid evidence is needed in order to generate citizen support services, a framework for validating and reporting such efforts would be of benefit (Maramis et al. 2017; Chouvarda et al. 2019).

Few studies reported on usability of their system although this is a vital indicator of the efficiency of a VR application. Those who included a *Usability Evaluation* methodology mainly examined the satisfaction levels, the easiness of use, the comfort and the impact on stress reduction perception. The last two features included in our analysis concern *Biofeedback* and *User's Participation—Interaction*. Regarding *Biofeedback*, it is a possible explanation that the technical difficulties and the extra development effort of integrating a sensor or real-time signal analysis with the VR system kept many research teams from attempting to introduce a biofeedback-based system. That is the case for *User's Participation* as well. 62% of the studies did not report on an active system. In this case, the implemented method could play a critical part in the passiveness of the system, as most of the implemented methods did not require the active participation of the user. These can be regarded as gaps in the domain, and could be the focus of future research, as sensor technology and AI mature rapidly.

Research on stress reduction has been a topic of significant interest, with various practices and interventions implemented to alleviate stress and promote well-being. However, these approaches often require active participation, and their effectiveness may vary depending on the subject. Translating stress reduction strategies into VR applications emerges as a promising solution to overcome these challenges. VR technology offers immersive and engaging environments that can provide a sense of presence and escapism, allowing individuals to temporarily detach from stressful situations (Freeman et al. 2017). Based on the variation of the applied settings, VR environments have the potential to induce relaxation responses and reduce stress levels (Valmaggia et al. 2016; Rina et al., 2016). Still, several challenges need to be addressed toward an effective utilization of VR technology for stress reduction. Our findings can be summarized by the following points:

- Firstly, ensuring the development of evidence-based VR interventions that are specifically tailored to target stress-related mechanisms is crucial (Botella et al. 2017) and not always properly addressed. This includes identifying appropriate stress detection and assessment measures within VR environments and establishing standardized protocols for evaluating the efficacy of VR interventions (Felnhofer et al. 2015; Fodor et al. 2018). Even though most of the studies reported positive results (Validation section) regarding the potential of VR technology, there are not many that can boast about convincing evidence.
- From the technical aspect, it is understood the interest toward VR technology follows its evolution; thus, the exploitation of both VR devices and sensors is highly interrelated with the technological advances.
- Each person has different needs and responses (both physiologically and perceptively) to stressful situations. Even though personalization techniques were reported, significant effort should be paid toward personalized stress assessment algorithms and VR environments tailored per user.
- Furthermore, there is a need to enhance/ensure user acceptance for VR interventions. Factors such as motion sickness, discomfort and the need for specialized equipment may hinder widespread adoption (Freeman et al. 2017).
- Finally, it was found that not many studies considered the investigation of gender-specific differences, a factor that could contribute to the development of more robust and efficient VR systems.

While current stress reduction practices exist, incorporating VR applications has the potential to offer unique benefits in promoting relaxation and alleviating stress. Addressing the challenges of evidence-based interventions, appropriate assessment measures and user acceptance will pave the way for the successful utilization of VR technology in stress reduction strategies.

The inherent broadness of stress definition is one of the main limitations of this review. We should mention that the vagueness of stress definition was something that we identified in many papers, especially in studies that did not try to specify the type of targeted stress, and that is the picture that we tried to depict. The definition of stress can actually vary across disciplines and contexts, leading to some vagueness in its conceptualization. Stress can be understood as a complex, multifaceted phenomenon encompassing psychological, physiological and behavioral components. Different fields of study approach stress from distinct perspectives, resulting in variations in how it is defined and operationalized. The variation in stress definitions and conceptualizations across disciplines can lead to inconsistencies and challenges when comparing findings or integrating research from different fields. However, it also highlights the multidimensional nature of stress and the need for interdisciplinary approaches to fully understand and address stress-related phenomena. The *System Target* feature revealed subcategories regarding stress reduction, such as psychological stress, momentary stress and occupational stress. This fragmented scenery regarding subcategories or special definitions of stress is apparently not depicted on the different methods that are used to address the potential problems it causes. Another limitation could be that this review falls under the domain of biomedical research rather than clinical research. As such, the objective is not to explore or investigate specific techniques that are clinically used for stress reduction, but rather to examine existing approaches that have been translated into VR applications. In other words, in the current review we tried to focus on the technical aspects of stress reduction using VR rather on the clinical evaluation. In addition, in the Validation section the results of the various systems on stress alleviation are presented based on the evaluation methodology utilized and we omitted to tackle the clinical aspect. However, the aim was to shed light on the current state of research and identify the ways in which VR technology has been utilized in addressing stress reduction.

The use of inclusion criteria tried to identify and include all studies that aimed at the reduction of any kind of stress, while the exclusion criteria filtered out any such system that reported as target groups patients of any kind, factor that could also be a limitation of this study. However, we are confident that the included studies were more than sufficient to map the current state of VR-based stress reduction systems for healthy subjects, helping us end up to safe conclusions. Keeping in mind the extremely rapid evolution of VR technology and the highly increasing interest of the research community for this topic, another limitation of this study could constitute the possibility that it may be out of date at the time of the publication.

5 Conclusion

Stress is a common problem of contemporary society affecting the overall quality of life of individuals. From the time that stress was recognized as a potential burden in daily life, researchers tried to develop and implement ideas for its regulation. VR technological development exposes its potential as a facilitator for the confrontation of this problem as well as for the improvement of the efficiency of stress reduction techniques. During the last decade, there is a significant number of publications aiming at stress reduction via the exploitation of VR technology. This number indicates the increasing interest of the research community toward the integration of VR technology with established practices. The main goal of this study was to present a complete survey based on the publication of the last decade. As a conclusion, this review maps a number of factors, variables and features that indicate the usefulness and efficiency of VR technology, as well as the weaknesses and challenges that need to be addressed. Although numerous approaches have been reported for VR-based stress reduction systems, more evidence is required for their actual impact on stress levels, as well as their capability to increase user's motivation and engagement. The development of a framework with the integration of real-time signal collection and analysis in combination with the consideration and evaluation of gold standards defined by established qualitative metrics could lead to the production of more concrete evidence in the vast problem of detecting, evaluating and managing such a subjective experiential factor as stress.

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Declarations

Conflict of interest None declared.

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