Universität der Bundeswehr München
Institut für Sportwissenschaft

Mindfulness in health and sport integrating immersive virtual reality

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Vollständiger Abdruck der von der Fakultät für Humanwissenschaften der Universität der Bundeswehr München zu Erlangung des akademischen Grades eines

Doktors der Philosophie (Dr. phil.)

angenommenen Dissertation.

Gutachter:

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Die Dissertation wurde am 01.10.2025 bei der Universität der Bundeswehr München eingereicht und durch die Fakultät für Humanwissenschaften am 14.05.2026 angenommen. Die mündliche Prüfung fand am 18.06.2026 statt.

Vorwort & Danksagung

Die vorliegende Arbeit ist während meiner Tätigkeit als Wissenschaftliche Mitarbeiterin am Forschungs- und Lehrgebiet der Sportpsychologie an der Universität der Bundeswehr München unter Leitung von Herrn Univ.-Prof. Dr. Matthias Wagner entstanden. Neben dem persönlichen Interesse an der Thematik stand insbesondere die Frage im Fokus, inwiefern Achtsamkeit als wissenschaftlich fundierte Intervention in Anwendungsfeldern wie Gesundheit und Sport wirksam eingesetzt werden kann. Vor dem Hintergrund einer zunehmend digitalisierten Lebenswelt und der technologischen Ausrichtung des Forschungs- und Lehrgebiets wurde untersucht, inwieweit immersive virtuelle Realität als innovatives Medium zur Vermittlung achtsamkeitsbasierter Inhalte dienen kann. Ziel war es, theoretische Grundlagen mit praxisorientierten Fragestellungen zu verknüpfen und Potenziale sowie Herausforderungen bei der Integration von Achtsamkeit, auch unter Einsatz immersiver VR, in gesundheits- und sportbezogenen Kontexten systematisch zu untersuchen.

Mit der Fertigstellung dieser Dissertation geht ein bedeutendes Kapitel meines akademischen Weges zu Ende. Dies wäre jedoch nicht ohne die Unterstützung und Begleitung vieler Menschen möglich gewesen, denen ich an dieser Stelle aufrichtig danken möchte.

Mein erster Dank gilt meinem Doktorvater, Herrn Univ.-Prof. Dr. Matthias Wagner, für seine fachkundige Betreuung, seine wertvollen Anregungen und seine stetige Unterstützung während der gesamten Promotionszeit. Durch seine fortwährende Begleitung und Förderung hat er wesentlich zur wissenschaftlichen Weiterentwicklung dieser Arbeit beigetragen. Ich schätze die Möglichkeit, unter seiner Anleitung geforscht zu haben, und danke ihm für die investierte Zeit und die stets angenehme, vertrauensvolle Zusammenarbeit während des Promotionsprozesses.

Darüber hinaus gilt mein Dank auch meinen Co-Autorinnen und Co-Autoren, Herrn Univ.-Prof. Dr. Karl-Heinz Renner, Herrn Florian Schrank und Frau Franziska Pintz, für die produktive und konstruktive Zusammenarbeit bei unseren gemeinsamen Publikationen. Durch ihre wertvollen fachlichen Beiträge, kritischen Anmerkungen und anregenden Diskussionen haben sie maßgeblich zur wissenschaftlichen Qualität unserer Publikationen beigetragen.

Insbesondere möchte ich mich bei meiner Kollegin, Frau Franziska Pintz, bedanken, die mir während meiner Promotionszeit nicht nur fachlich, sondern auch menschlich stets zur Seite stand. Ihr unermüdlicher Einsatz, ihre Unterstützung und ihre aufmunternden Worte haben mir in vielen Momenten sehr geholfen und diese Zeit umso wertvoller gemacht. Ich danke auch meinen Kolleginnen Jessica Oppawsky, Kirstin Seiler und Kristina Klier für ihren hilfreichen Input und Zuspruch während meiner Promotionsphase.

Mein Dank gilt auch allen Probandinnen und Probanden deren engagierte Mitwirkung und Bereitschaft zur Teilnahme einen wesentlichen Beitrag zur Durchführung meiner Forschungsvorhaben geleistet haben.

Zuletzt möchte ich mich bei meiner Familie, meinen Freunden und meinem Partner für ihr Verständnis und ihre Geduld während der gesamten Promotionszeit bedanken. Ihr fortwährender Rückhalt und ihre liebevolle Unterstützung haben maßgeblich dazu beigetragen, dass ich diesen Weg erfolgreich bis zum Schluss gehen konnte.

Mindfulness is "the awareness that emerges through paying attention, on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment."

(Kabat-Zinn, 2003, p. 145)

Zusammenfassung

Achtsamkeit stellt ein multidimensionales Konstrukt dar, das sowohl in der wissenschaftlichen Forschung als auch im gesellschaftlichen Diskurs zunehmend an Relevanz gewinnt. Ihre Anwendungsfelder reichen heute weit über die ursprünglichen Wurzeln in meditativen und mentalen Praktiken des Buddhismus hinaus (Kabat-Zinn, 2003; Thera, 1962). Häufig wird Achtsamkeit definiert „(…) as a kind of nonelaborative, nonjudgmental, present-centered awareness in which each thought, feeling, or sensation that arises in the attentional field is acknowledged and accepted as it is." (Bishop et al., 2004, p. 232).

Nach Bishop et al. (2004) umfasst Achtsamkeit demnach eine besondere Form der Aufmerksamkeitslenkung, die sich durch eine bewusste Fokussierung auf das Erleben des gegenwärtigen Moments auszeichnet. Dabei werden innere Erfahrungen wie Gedanken, Gefühle oder Körperempfindungen in einer nicht-elaborierenden Weise wahrgenommen, das heißt, sie werden weder analysiert noch gedanklich weiterverarbeitet. Gleichzeitig erfolgt diese Wahrnehmung in einer offenen, nicht-bewertenden Haltung, bei der auftauchende Inhalte weder als gut noch als schlecht eingeordnet, sondern akzeptierend zur Kenntnis genommen werden.

Im Zuge mehrerer Entwicklungswellen sind unterschiedliche manualisierte, achtsamkeitsbasierte Programme entstanden, die vor allem im klinisch-therapeutischen Kontext Anwendung finden. Zu den bekanntesten zählen die von Kabat-Zinn (1982) entwickelte Mindfulness-Based Stress Reduction (MBSR) sowie die Mindfulness-Based Cognitive Therapy (MBCT) nach Teasdale et al. (1995). Beide Interventionen verfügen über eine umfangreiche Evidenzbasis, die ihre gesundheitsförderliche Wirkung belegt (Baer et al., 2006; Teasdale et al., 2000).

Auf Grundlage dieser etablierten Programme wurden achtsamkeitsbasierte Methoden auch zunehmend in den Sportkontext übertragen und dort kontextspezifisch weiterentwickelt. Ein Beispiel hierfür ist der Mindfulness-Acceptance-Commitment Approach von Gardner and Moore (2004), dessen Wirksamkeit ebenfalls empirisch belegt ist (Ivarsson et al., 2015; Josefsson et al., 2019). Dies zeigt bereits eine wechselseitige Verbindung zwischen psychologischen und sportpsychologischen Themen, die sich sowohl theoretisch als auch praktisch bei der Erkenntnisentwicklung unterstützen können (FEPSAC, 1995).

Vor diesem Hintergrund eröffnet insbesondere der Einsatz immersiver Virtual-Reality-Technologien neue Perspektiven für die Gestaltung und Vermittlung

achtsamkeitsbasierter Interventionen. Eine zentrale Voraussetzung für die Entwicklung und Evaluation solcher Interventionen ist jedoch die Verfügbarkeit geeigneter Messinstrumente zur Erfassung achtsamkeitsbezogener Kompetenzen im spezifischen Anwendungskontext.

Im ersten Projekt dieser Dissertation wird daher der Sportkontext gezielt adressiert. Ziel ist die Entwicklung eines deutschsprachigen, kontextspezifischen Messinstruments zur Erfassung von Achtsamkeitsfertigkeiten bei Athletinnen und Athleten (MIS-D). Die psychometrischen Eigenschaften des Instruments werden mittels konfirmatorischer Faktorenanalyse überprüft (Wieczorek et al., 2022).

Das zweite Projekt verlässt den sportlichen Anwendungskontext zugunsten einer breiteren gesundheitspsychologischen Perspektive. Im Rahmen einer systematischen Literaturrecherche gemäß den PRISMA-Richtlinien (Liberati et al., 2009) wird der aktuelle Forschungsstand zu den psychologischen und physiologischen Effekten immersiver VR-basierter Achtsamkeitsinterventionen mittels Head-Mounted Displays bei einer sportunabhängigen Zielgruppe strukturiert erfasst und durch eine hermeneutisch-analytische Auswertung (Boell & Cecez-Kecmanovic, 2014) vertiefend untersucht (Wieczorek et al., 2024).

An diese Analyse schließt sich eine Replikationsstudie an, in der psychologische und physiologische Effekte einer VR-basierten Achtsamkeitsatemmeditation mit integriertem Biofeedback unter Einsatz verschiedener subjektiver und objektiver Messinstrumente empirisch untersucht werden (Wieczorek et al., 2025).

Die Ergebnisse der drei Teilprojekte leisten einen bedeutenden Beitrag zum theoretischen und praktischen Erkenntnisgewinn im Schnittfeld von Achtsamkeit, Gesundheit und Sport unter Einbezug immersiver VR-Technologien. Insbesondere die beiden letzten Studien eröffnen innovative Perspektiven auf das Anwendungspotenzial VR-gestützter Achtsamkeitsinterventionen im sportlichen Kontext und liefern wertvolle Impulse für zukünftige Forschung.

Abstract

Mindfulness constitutes a multidimensional construct that is gaining increasing relevance both in scientific research and in societal discourse. Its fields of application today extend far beyond its original roots in the meditative and mental practices of Buddhism (Kabat-Zinn, 2003; Thera, 1962). Mindfulness is often defined as "(…) a kind of nonelaborative, nonjudgmental, present-centered awareness in which each thought, feeling, or sensation that arises in the attentional field is acknowledged and accepted as it is." (Bishop et al., 2004, p. 232).

According to Bishop et al. (2004), mindfulness thus includes a particular form of attentional regulation characterized by a deliberate focus on the experience of the present moment. Inner experiences such as thoughts, feelings or bodily sensations are perceived in a non-elaborative manner, meaning they are neither analyzed nor cognitively processed further. At the same time, this perception occurs in an open, nonjudgmental attitude, whereby emerging contents are neither classified as good nor bad but are accepted as they are.

Over several waves of development, various manualized mindfulness-based programs have emerged, primarily applied within clinical-therapeutic contexts. Among the most well-known are Mindfulness-Based Stress Reduction (MBSR) developed by Kabat-Zinn (1982) and Mindfulness-Based Cognitive Therapy (MBCT) introduced by Teasdale et al. (1995). Both interventions have an extensive evidence base demonstrating their health-promoting effects (Baer et al., 2006; Teasdale et al., 2000). Building upon these established programs, mindfulness-based methods have increasingly been transferred to the sport context and further developed in a context-specific manner. An example is the Mindfulness-Acceptance-Commitment approach by Gardner and Moore (2004), whose efficacy has also been empirically validated (Ivarsson et al., 2015; Josefsson et al., 2019). This already indicates a reciprocal relationship between psychological and sport psychological topics, which can mutually support theoretical and practical knowledge development (FEPSAC, 1995).

Against this background, the use of immersive virtual reality (VR) technologies opens up new perspectives for the design and implementation of mindfulness-based interventions. However, a key prerequisite for the development and evaluation of such interventions is the availability of suitable measurement instruments for recording mindfulness-related skills in the specific application context.

Accordingly, the first project of this dissertation specifically addresses the sport context. The aim is to develop a German-language, context-specific instrument for measuring mindfulness skills in athletes (MIS-D). The psychometric properties of the instrument are examined using a confirmatory factor analysis (Wieczorek et al., 2022). The second project (Wieczorek et al., 2024) moves beyond the sports application context in favor of a broader health psychology perspective. Within the framework of a systematic literature review conducted according to the PRISMA guidelines (Liberati et al., 2009), the current state of research on the psychological and physiological effects of immersive VR-based mindfulness interventions via head-mounted displays in a sport-independent target group is systematically captured and further explored through a hermeneutic-analytical evaluation (Boell & Cecez-Kecmanovic, 2014).
Following this, a replication study is conducted as third project to empirically investigate the psychological and physiological effects of a VR-based mindfulness breathing meditation with integrated biofeedback, employing various subjective and objective measurement instruments (Wieczorek et al., 2025).
The results of the three subprojects make a significant contribution to theoretical and practical knowledge advancement at the intersection of mindfulness, health and sport, integrating immersive VR technologies. In particular, the latter two studies open innovative perspectives on the application potential of VR-supported mindfulness interventions in the sports context and provide valuable impulses for future research.

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List of abbreviations

ACT	Acceptance and Commitment Therapy
AR	Augmented Reality
AVE	Average Variance Extracted
BA	Brodmann Area
BPSM	Biopsychosocial Model
CAVE	Cave Automatic Virtual Environment
CBT	Cognitive-Behavioral Therapy
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CI	Confidence Interval
CHIME-β	Comprehensive Inventory of Mindfulness Experiences beta
DBT	Dialectical Behavior Therapy
dlPFC	Dorsolateral Prefrontal Cortex
EEG	Electroencephalography
ERP	Event-Related Potentials
FEPSAC	European Federation of Sport Psychology
FLR	Fornell-Larcker Ratios
FR	Factor Reliability
GRR	Generalized Resistance Resources
GT	Generalizability Theory
HEDE	Health-Ease/Dis-Ease
HBM	Health Belief Model
HLC	Health Locus of Control
ICC	Intraclass Correlation Coefficient
IR	Indicator Reliability
IVR	Immersive Virtual Reality
fMRI	Functional Magnetic Resonance Imaging
fNIRS	Functional Near-infrared Spectroscopy
KIMS	Kentucky Inventory of Mindfulness Skills
MAAS	Mindfulness Awareness Scale
MAC	Mindfulness Acceptance Commitment Approach
MAIC	Mindfulness-Acceptance-Insight-Commitment

MBCT	Mindfulness-Based Cognitive therapy
MBI	Mindfulness-Based Intervention
MBSR	Mindfulness-Based Stress Reduction
MBT	Mindfulness-Based Therapy
MIS	Mindfulness Inventory for Sport
MIS-D	Mindfulness Inventory for Sport German Version
MM	Mindfulness Meditation
MMTS	Mindfulness Meditation Training for Sport
mPEAK	Mindful Performance Enhancement, Awareness and Knowledge
MR	Mixed Reality
MSI	Maximum Squared Intercorrelation
MSPE	Mindful Sports Performance Enhancement
MTC	Mindfulness Training for Coaches
MW	Mind-Wandering
NCAA Division I	National Collegiate Athletic Association
RMSEA	Root Mean Square Error of Approximation
RV	Reality-Virtuality
SRMR	Standardized Root Mean Residual
TAU	Treatment-As-Usual
TCM	Traditional Chinese Medicine
TLI	Tucker-Lewis Index
TMS	Toronto Mindfulness Scale
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
VR	Virtual Reality
VRMMB	Virtual Reality Based Breathing Meditation with Integrated Biofeedback
PC	Process of Change
PET	Positron Emission Tomography
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PST	Psychological Skills Training
PTSD	Posttraumatic Disorder
SM	Salutogenic Model of Health

SOC	Sense of Coherence
TTM	Transtheoretical Model of Health Behavior Change
WHO	World Health Organization
WLSMV	Weighted Least Squares Mean and Mean Adjusted
XR	Extended Reality

1 Introduction

1.1 Problem Statement

In the domain of health and sport, increasing attention has been directed toward psychological and physiological dimensions of performance, recovery and long-term well-being. Whether in high-performance athletes or in clinical an preventive health, individuals are confronted with different kinds of demands (Hong & Fraser, 2021; Rice et al., 2016; Rogers et al., 2024). To navigate these demands and challenges, mental strategies like mindfulness can help. Mindfulness is defined "(…) as a kind of non-elaborative, non-judgmental, present-centered awareness in which each thought, feeling, or sensation that arises in the attentional field is acknowledged and accepted as it is." (Bishop, 2002, p. 232).

This conceptualization of mindfulness reflects core psychological processes, such as attentional regulation or awareness, that are not only central to general psychological functioning but also highly relevant within sport psychological contexts (American Psychological Association, 2008). The increasing integration of mindfulness-based approaches into health and performance settings underlines the conceptual overlap and methodological interconnectedness between psychological and sport psychological perspectives (FEPSAC, 1995).

Structured programs such as the Mindfulness Acceptance Commitment Approach (MAC) by Gardner and Moore (2004) or the Mindful Sports Performance Enhancement (MSPE) program by Kaufman et al. (2018) originate from therapeutic and clinical traditions like the Mindfulness Bases Stress Reduction (MBSR) from Kabat-Zinn (1990), which have laid an important theoretical and practical foundation for sport-specific mindfulness interventions. These approaches have been increasingly adapted to meet the unique psychological demands of athletes and are now an important part to many modern applications of mindfulness in sport.

A prominent example of mindfulness applied in elite sport is NBA coach Phil Jackson, who integrated meditation and present-moment awareness into team routines to enhance focus, cohesion and mental resilience. His success with teams like the Chicago Bulls and Los Angeles Lakers illustrates how mindfulness-based strategies can contribute to sustained high performance under pressure (Muse, 2023).

However, these mentioned programs are often based on time-intensive formats that are not compatible with the constraints of high-performance training schedules. The

cognitive and logistical demands of those manualized approaches limit their scalability and accessibility, especially for athletes who operate under rigid schedules and intense performance pressure.

In comparison, immersive VR is able to provide a more flexible and engaging alternative, offering a convenient way to practice mindfulness within the daily routine. Additionally, VR can create immersive environments that can enhance focus and make mindfulness exercises more interactive and enjoyable, potentially increasing engagement and effectiveness compared to traditional methods (Arpaia et al., 2022).

This dissertation aims to examine the potential of VR-based mindfulness interventions in sport, building on the close theoretical and methodological interconnection between sport psychology and general psychology. As outlined by FEPSAC (1995), sport psychology is shaped by sport practice, general psychology and other sport sciences, functioning both as an applied and empirical discipline. It not only applies psychological principles to sport-related contexts but also contributes to the broader field of psychology. In line with this integrative perspective, this dissertation draws on findings from non-sport-specific psychological research to inform the theoretical foundation, application potential and methodological considerations of VR-based mindfulness interventions in sport. In doing so, it also addresses existing research gaps concerning the validity, precision and applicability of measurement methodologies within this emerging field.

1.2 Structure of Thesis

This dissertation centers on four key entities: (1) mindfulness, (2) health, (3) sport and (4) virtual reality. Among these, mindfulness assumes a central role, serving as the conceptual foundation of the investigation. Health and sport serve primarily as the contextual areas in which mindfulness is explored, while virtual reality is introduced as a contemporary medium that opens new methodological avenues. The structure of the dissertation is organized as follows (see Figure 1): initially, each of the four entities is defined and conceptually situated (Level I). Subsequently, relevant relationships between these entities are analyzed across two deeper levels of integration (Levels II and III), drawing upon current research findings. Within these interconnections, research gaps are identified and addressed through targeted projects conducted as part of this dissertation.

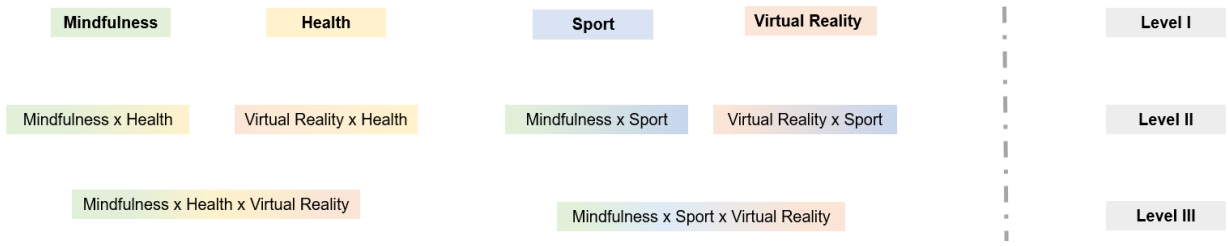


Figure 1: Organization and structure of key constructs

2 Theoretical Background

2.1 Level I

This following section provides a foundational framework by defining and conceptually delineating the four central entities, starting with mindfulness taking a central role as the initial and guiding concept.

2.1.1 Mindfulness

The historical roots of mindfulness practice lie in the meditative and mental practices of Buddhism: „(…) that the systematic cultivation of Right Mindfulness, as taught by the Buddha in his Dis-course on Satipatthana, still provides the most simple and direct, the most thorogh and effect method for training and developing the mind for its daily tasks and problems as well as for its highest aim: mind's own unshakable deliverance from Greed, Hatred, and Delusion." (Kabat-Zinn, 2003; Thera, 1962)

Although, mindfulness is a fundamental mindset of all Buddhist meditative techniques, it is not solely rooted in Buddhism, as it is seen as a general human capacity that differs from person to person. The contribution of the Buddhist tradition in the context of mindfulness lies in the support of simple and effective methods for developing and enhancing this capacity (Kabat-Zinn, 2003). Today's overall understanding of mindfulness can be described „(…) as a kind of nonelaborative, nonjudgmental, present-centered awareness in which each thought, feeling, or sensation that arises in the attentional field is acknowledged and accepted as it is." (Bishop et al., 2004, p. 232) So, a mindful behavior focuses attention and awareness on the current experience without further elaboration or identification of the situation. Furthermore, thoughts and feelings are categorized as events that only take place in the mind, without reacting to them with automatic and habitual behavioral patterns (Jansen et al., 2019).

Until 2004, there were no systematic efforts to define mindfulness. However, a clear definition is crucial for deriving testable predictions and validating the concept, particularly within scientific research (Jansen et al., 2019). Bishop et al. (2004) attempted an operational definition, identifying two key aspects: (1) self-regulation of attention and (2) orientation to experience. Further sub-aspects are shown in the following Figure 2.

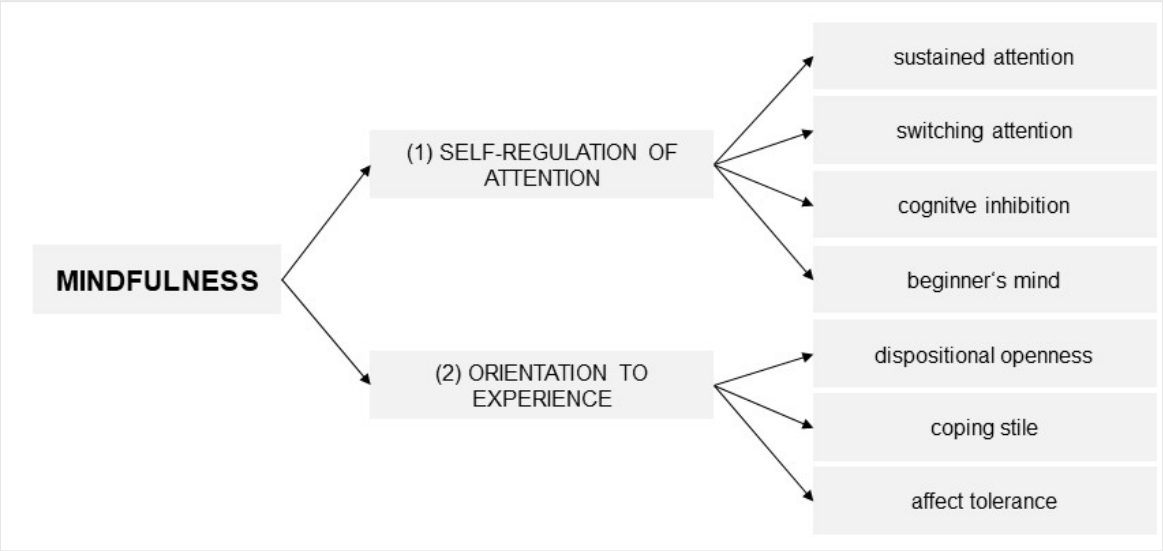


Figure 2: Operational Definition of Mindfulness after Bishop et al. (2004)

The first main aspect, *self-regulation of attention*, contains four sub-aspects. Bishop et al. (2004) consider *sustained attention* to be a necessary ability of self-regulation in order to maintain awareness of the present experience and thus a state of vigilance over a longer period of time. By practicing and training *attention switching*, the focus of attention can be corrected in the event of wandering. *Cognitive inhibition* reflects the ability of non-elaborative perception of thoughts, feelings and sensations. Consequently, relevant mental processes should be allowed and irrelevant ones suppressed or ignored (Bishop et al., 2004). The first main aspect is concluded with the fourth aspect, the *beginner's mind*. Here, the focus of mindfulness practice lies on an unbiased perception, which excludes filtered perception through beliefs, expectations and wishes (Bishop et al., 2004).

The second main aspect, *orientation to experience*, comprises three further sub-aspects. *Dispositional openness* can be described as an accepting attitude towards the reality of the moment (Bishop et al., 2004). The feelings, events and thoughts that emerge in the stream of consciousness are met with an open, receptive attitude. As a

result of an open attitude, less recourse is made to *coping styles* or strategies to avoid an experience. Furthermore, there is an increased *affect tolerance*, which contributes to coping with painful or unpleasant feelings and thoughts (Bishop et al., 2004). In addition to this definitional classification of mindfulness, Tang et al. (2015) and Tang (2017) pursue a more neuroscientific perspective. The focus lies on three components of mindfulness practice (Tang et al., 2015): (1) *attention control*, (2) *emotion regulation*, (3) *self-awareness*. Together, these aspects lead to a state of self-regulation. In terms of content, many parallels can be drawn with the mindfulness concept of Bishop et al. (2004). *Attention control* deals in particular with the aspect of focus and is therefore very similar to the *sustained attention* of Bishop et al. (2004). The aim of *emotion regulation*, the second aspect of Tang et al. (2015) and Tang (2017), is to develop a strategy for influencing emotions and moods. This is also addressed in *cognitive inhibition* by Bishop et al. (2004). The last aspect, *self-awareness*, is attributed, among other things, the function of meta-consciousness. As a result, the release of a static self-concept leads to more openness and acceptance (Tang et al., 2015), which is similar to the aspect of *orientation to experience* by Bishop et al. (2004). Furthermore, Tang et al. (2015) differentiate between different stages of mindfulness practice, which are characterized by different degrees of effort:

1. early stage – effortful doing
2. middle stage – effort to reduce mind
3. advanced stage – effortless being

The neuroscientific approach is particularly evident in the allocation of certain brain regions to the aspects and functions mentioned. As a result, functional changes in brain structures can be attributed to a higher level of mindfulness practice (Jansen et al., 2019). The influence and activity of neuronal regions during different mediation practices - both mindfulness-based and activity-based - was demonstrated in a systematic review by Acevedo et al. (2016). The review results offer valuable insights into the activation of various brain systems involved in attention, memory, learning, conscious perception, reward and emotional regulation. Notably, mindfulness-based meditation practice plays a key role in enhancing self-regulation and inner awareness, fostering more conscious behavior and lifestyle. Various electrophysiological and hemodynamic methods such as EEG (electroencephalography), ERP (event-related potentials), PET (positron emission tomography) and fMRI (functional magnetic resonance imaging) contribute to the expansion of empirical findings of brain structures

in meditation practitioners at a functional level. However, the possibility of functional imaging is also accompanied by points of criticism, such as ecological validity and interpretation limitations based on correlation measures (Eysenck & Keane, 2020). “Morphometric” neuroimaging makes an important contribution to the identification of structural changes, particularly in the gray and white matter of the brain (Fox et al., 2014). In their meta-analysis, Fox et al. (2014) identified several brain structures that show structural differences between meditation practitioners and the corresponding control group. In the context of mindfulness and its theoretical development, terms such as “reperceiving,” “decentering” and “mind wandering” also arise, though they will not be explored in detail here. However, these concepts share common elements which can be effectively illustrated by the so-called "meta-mechanism" of reperceiving. It’s the ability to change one’s own perception of thoughts and emotions. Mindfulness helps individuals to observe their inner experiences without getting caught up or reacting automatically. This shift promotes a more objective, detached awareness, that improves emotional regulation and mental clarity (Shapiro et al., 2006).

2.1.2 Health

In the following, health is delineated, contextualized and defined as one of the two primary application areas within the scope of this dissertation, in which mindfulness will likewise be examined in greater depth. To provide a conceptual foundation, this section introduces selected health models and frameworks that primarily reflect a multidimensional understanding of health and do not focus solely on behaviorist approaches, beginning with the World Health Organization’s definition of health as a common foundational starting point for further conceptualizations.

2.1.2.1 WHO Definition

The World Health Organization (WHO) is a specialized organization of the United Nations responsible for international public health, counting 194 member states – its mission is to promote global health, prevent diseases especially infectious ones and improve healthcare systems worldwide (WHO, 2024). The WHO (1946) defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.” The WHO has been criticized for this concept of well-being, but has never abandoned it (Jadad & O'Grady, 2008; Larson, 1999). Over time, its focus shifted to emphasize the social nature of health and that it depends on social

conditions. The path to the Alma-Ata Declaration in 1978 and the Ottawa Charter in 1986 was shaped by a growing recognition of the need for a holistic, prevention-oriented approach to health. Alma-Ata emphasized primary healthcare as a fundamental human right, while the Ottawa Charter expanded this vision by promoting health as a resource for daily life, highlighting social, economic and environmental determinants (Franke, 2012).

The issue with the WHO definition of health - as a state of complete physical, mental and social well-being - is that it is too broad and idealistic (R. Armitage, 2023), which makes it difficult to measure in research. This concept implies that almost no one is truly “healthy”, which limits its practical application. In research, such a broad definition leads to operationalization problems, making it difficult to develop clear, measurable health outcomes. For this reason, further models of health are discussed below.

2.1.2.2 Transtheoretical Model of Health Behavior Change

A more behavioral-based model in the context of health is the Transtheoretical Model of Health Behavior Change (TTM) by Prochaska and Diclemente (2005). It emphasizes that behavior change is a gradual process, that unfolds through distinct stages. Initially, in the *(1) precontemplation stage*, individuals are not yet considering change, often unaware of the negative consequences of their behavior or resistant to making adjustments. As awareness grows, they enter the *(2) contemplation stage*, where they begin to recognize the need for change and weigh the pros and cons, though they may still feel ambivalent. Once they decide to take action, they move into the *preparation stage*, where they start making small changes and develop a concrete plan. With further commitment, they move into the *(3) action stage* and actively implement new behaviors and strategies to replace old habits. This phase requires significant effort and motivation. Over time, they reach the *(4) maintenance stage*, where they focus on preserving their progress, avoiding relapse and reinforcing positive changes. Ultimately, in the *(5) termination stage*, the new behavior becomes fully integrated into their lifestyle and the urge to return to the old habits disappears (Prochaska & Diclemente, 2005).

The *process of change* (PC) is guided by a series of cognitive and behavioral strategies that help individuals progress through different stages (see Figure 3). Early in the journey, cognitive-affective processes play a crucial role. *Consciousness raising* helps individuals become more aware of their behavior and its impact (e.g., observations,

confrontations and interpretations), while *dramatic relief* allows them to experience emotional reactions that motivate change (e.g., psychodrama or the Gestalt empty chair). Through *environmental reevaluation*, they assess how their actions affect those around them and *self-reevaluation* encourages deep reflection on their identity with and without the behavior (e.g., addicted individual: “How do I think and feel about living in a deteriorating environment that places me and my family in increasing risk of disease, death, poverty and/or imprisonment?”) (Prochaska & Diclemente, 2005).

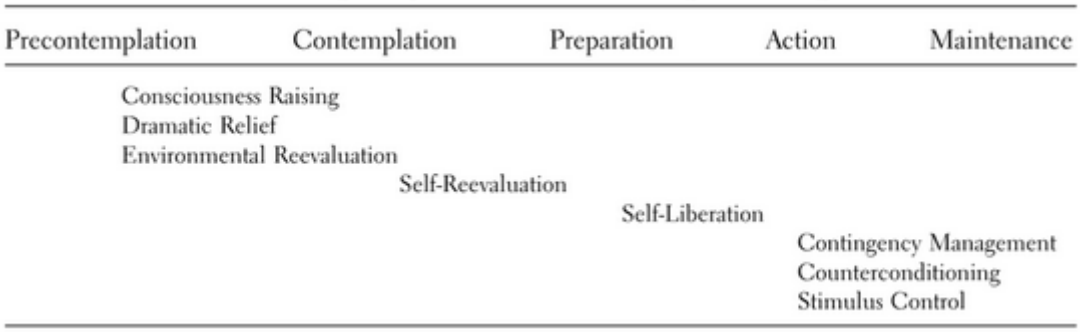


Figure 3: Process of change at particular stages of change after Prochaska and Diclemente (2005)

As individuals move forward, behavioral processes become more influential. *Self-liberatio*n involves making a firm commitment to change, reinforcing their belief in their ability to succeed, closely linked to self-efficacy (Bandura, 1977), which refers to a person's belief in their ability to successfully perform desired actions, even in extreme situations, based on their own skills and competencies. To replace old habits, they engage in *counterconditioning*, adopting healthier alternatives. Simultaneously, *stimulus control* helps them remove triggers that could lead to relapse. Finally, helping relationships provide essential support, encouragement and accountability from others, making the transition to a healthier lifestyle more sustainable. By integrating these processes at different stages, individuals can navigate the complexities of behavior change more effectively, increasing their chances of long-term success (Prochaska & Diclemente, 2005). In addition to the *process of change* (PC), two other components, *self-efficacy* (SE) and *decisional balance* (DB), play a crucial role in predicting how and when an individual will progress to the next stages. SE, as already introduced earlier, can facilitate an individual’s progression through the stages of change and lead to more successful and sustained behavior change (Abbaspour et al., 2017). DB refers to the process of weighing the perceived advantages (pros) and disadvantages (cons) associated with a particular behavior. So, this concept is crucial

for understanding an individual's readiness to change. As individuals progress through the stages of change - from precontemplation to maintenance - they typically perceive more benefits than drawbacks in adopting a new behavior, which can motivate them to initiate and sustain change. By assessing and addressing the DB, health professionals can tailor interventions to enhance the perceived pros and reduce the perceived cons of behavior change, thereby facilitating progression through the stages of change (Abbaspour et al., 2017). The TTM is applied in various areas where behavioral change is needed, for example in prevention interventions for chronic conditions such as diabetes and various forms of cancers (Hashemzadeh et al., 2019).

2.1.2.3 Biopsychosocial Model

Leaving the behavioral perspective on health and health behavior, a more holistic model that emphasizes the interconnectedness of biological, psychological and social factors in understanding health and disease is the Biopsychosocial Model (BPSM) by Engel (1977). It was developed as an alternative to the traditional biomedical model, which primarily focuses on the physical aspects of illness and disease. *Biological/physical factors* involve the physical aspects of health, such as genetics, immune function and overall physical well-being. *Psychological factors* include emotional and mental health, such as cognition, mood, stress and coping mechanisms. *Social factors* encompass environmental and social influences, such as relationships, socioeconomic status and cultural norms. These components interact with each other, affecting a person's overall health and influencing their behavior, treatment and recovery processes (see Figure 4).

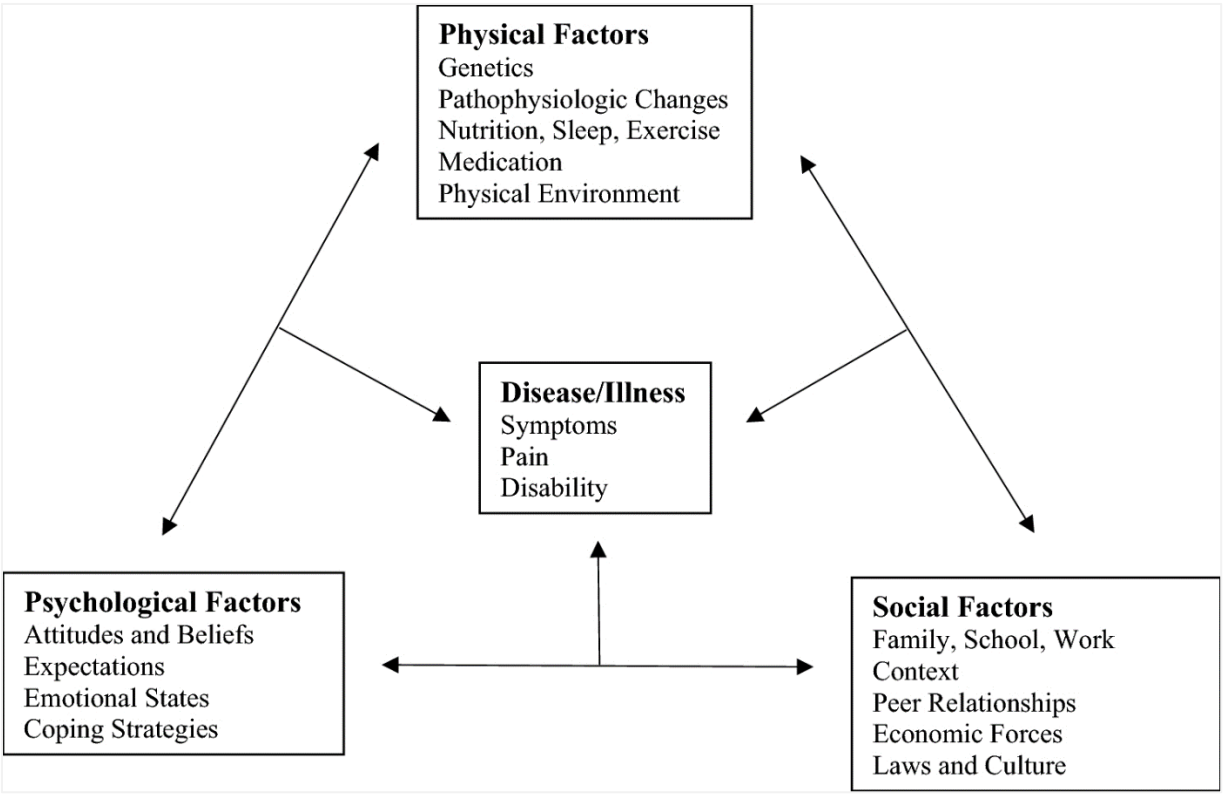


Figure 4: Biopsychosocial Model after Roberts (2023)

Roberts (2023) illustrate that from a BPSM-based perspective, chronic pain, for example, cannot be solely attributed to a bodily damage. Instead, it is also shaped by the individual's perception of that damage, which is influenced by psychological factors such as attitudes. These psychological components, in turn, are affected by other psychosocial or biological elements, creating a complex, interdependent relationship that affects the experience of pain. The model has been criticized for being too vague and lacking scientific detail (Bolton, 2019; Ghaemi, 2009, 2011). While it includes biological, psychological and social factors in understanding health, it does not provide a clear methodology to define disease or establish causality. It is not possible to distinguish between disease and non-disease and there is a lack of epistemological tools to distinguish true causal relationships from false correlations (Roberts, 2023). Despite these limitations, Roberts (2023) come to the following conclusion that the BPSM serves as a valuable conceptual framework for organizing and communicating factors that influence health, though it should not be used as a definitive scientific model for disease or causality.

2.1.2.4 Salutogenesis Model of Health

The Salutogenesis Model of Health (SM), developed by Antonovsky (1979), presents a shift from the traditional focus on disease (pathogenesis) to understanding the origins of health. This approach views health as a dynamic continuum, where individuals move between conceptual endpoints of either total health (health-ease; HE) or illness (dis-ease; DE). So, health is not merely the absence of illness but can be seen as a lifelong process of adaption. Central to this model is the concept of the *sense of coherence* (SOC), which reflects an individual's capacity to perceive life as comprehensible, manageable and meaningful. A strong SOC enables effective stress management and fosters movement toward the health end of the HEDE-continuum (Mittelmark, 2022). The first component, *comprehensibility*, is seen as a cognitive aspect of SOC that determines how structured and predictable the world appears. When individuals perceive life's events as logical and coherent, they are less likely to feel overwhelmed, as challenges become something to be understood rather than feared. The second component, *manageability*, a more behavioral dimension, which strengthens confidence in one's own ability to deal with the demands of life. Those with a strong sense of manageability believe that they have access to the necessary resources - whether internal strengths or external support systems - to cope effectively with difficulties. The last component of the SOC is *meaningfulness*, seen as a motivational component. When people see challenges as rewarding and valuable, they take a proactive approach to life rather than just enduring difficulties. Meaningfulness fosters the emotional drive to endure, so that struggles feel purposeful rather than burdensome (Mittelmark, 2022). Individuals with a strong SOC are better able to cope with stressors and effectively utilize the necessary resources so that they can move towards the healthier end of the continuum. In contrast, individuals with a low SOC often have difficulty coping with life's challenges, making them more likely to shift toward the negative end of the continuum (Faltermaier, 2023). Besides SOC, the *generalized resistance resources* (GRR) play a crucial role in shaping an individual's ability to cope with stress and maintain a strong SOC *(*see Figure 5*)*. These resources come from various aspects of life and create a foundation for resilience (Antonovsky, 1979, 1988). At a fundamental level, *(1) material resources* such as financial stability and access to essential goods and services provide security and reduce uncertainty, allowing individuals to focus on long-term well-being rather than immediate survival. Complementing this, *(2) knowledge and intelligence* enhance problem-solving skills,

enabling individuals to analyze challenges, adapt strategies and make informed decisions in complex situations. A strong (3) *ego identity* also contributes to resilience by fostering a stable yet flexible sense of self. Similarly, effective *(4) coping strategies* such as emotion regulation and problem-oriented approaches also help to deal constructively with stressors. Equally important is *(5) social support*, which includes family, friends and community networks that provide both emotional encouragement and practical assistance. This social safety net reinforces a sense of belonging and helps individuals overcome difficulties more effectively. (6) *Commitment and cohesion with one's cultural root* as another resource and focus on the personal connection and emotional attachment to one's cultural background. It reflects how strongly people identify and engage with their cultural heritage rather than the stability of the culture itself. This factor contributes particularly to meaningfulness, as individuals derive a sense of purpose and belonging from their cultural identity. *(7) Cultural stability*, rooted in consistent values, traditions and belief systems, offers guidance and a sense of purpose, creating a reliable framework for understanding life's challenges. This resource refers to the consistency and continuity of cultural values, beliefs and traditions over time. When individuals grow up in a stable cultural environment, they experience a predictable and structured worldview. Furthermore, Antonovsky (1979) mentions further resources such as (8) *magic or ritualistic activities* and (9) *religion and philosophy* providing individuals with a stable set of beliefs and answers to life's perplexities. Finally, a *(10) preventive health orientation* strengthens well-being by encouraging proactive behaviors, such as healthy lifestyle choices, regular medical check-ups and stress management techniques (Faltermaier, 2023; Mittelmark, 2022). GRR accumulate over the course of a lifetime and are shaped by the environment and circumstances in which the individual grows up, which ultimately determines the resources they can develop. When these resources are abundant and well-integrated, people experience greater consistency, balanced challenges and active involvement in decision-making, which strengthens their SOC and improves their ability to cope with stress. Conversely, a lack of these resources can lead to chronic stress and diminished resilience, emphasizing the importance of promoting GRR at *individual*, *community/group/family* and *subcultural/societal levels* (Antonovsky, 1988; Faltermaier, 2023).

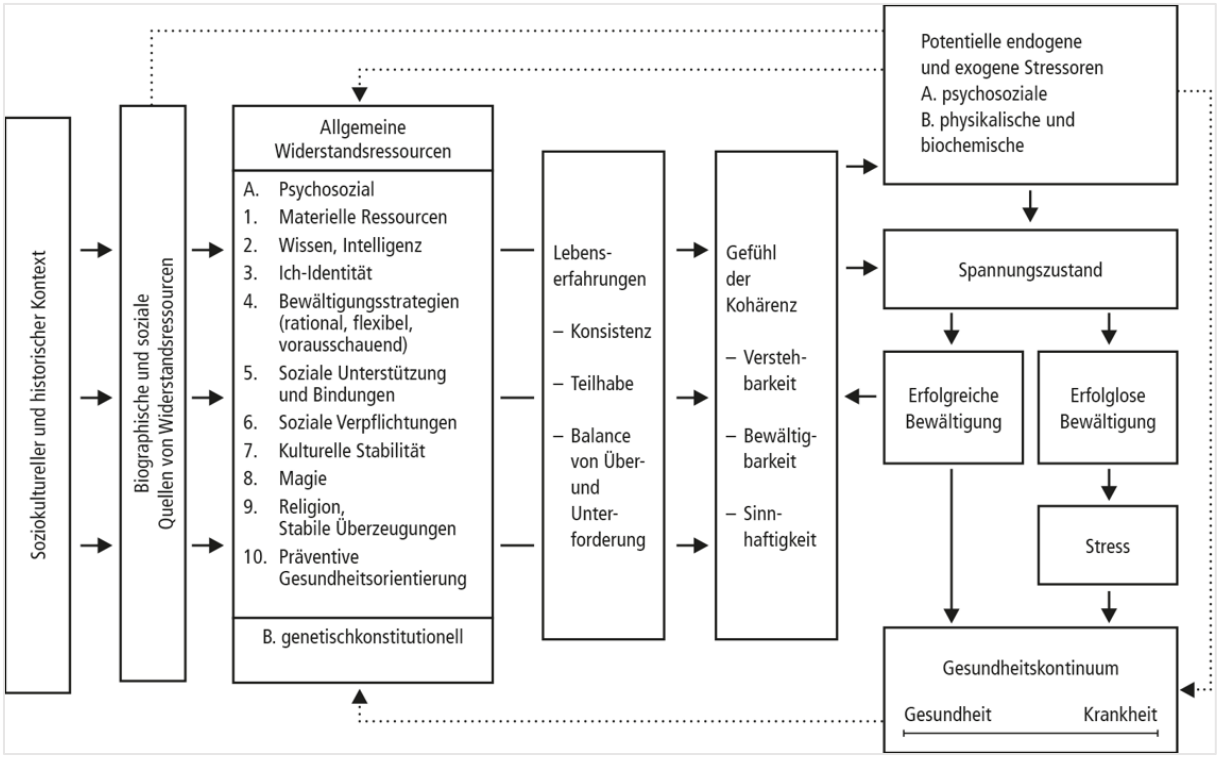


Figure 5: Salutogenic Model of Health according to Antonovsky (1979, p. 184) see Faltermaier (2023, p. 80)

2.1.3 Sport

In the following, sport is delineated, contextualized and defined as second application area of research within the scope of this dissertation alongside health, in which mindfulness will be examined in more detail.

First, it is essential to clarify the distinction between terms like *physical activity*, *exercise* and *sport*, as they are often used interchangeably in both public discourse and academic literature, despite representing distinct forms of bodily movement that differ in their structure, purpose and degree of intentionality.

Physical activity is the broadest term, encompassing all forms of movement produced by skeletal muscles that result in energy expenditure, which can be measured in kilocalories. This includes everyday activities such as walking, gardening or taking the stairs and is not necessarily planned or structured (Caspersen et al., 1985; World Health Organization, 2020).

Exercise, by contrast, is a subcategory of physical activity that is deliberately planned, structured and repetitive with the primary goal of improving or maintaining physical fitness. Activities such as jogging, resistance training or aerobic workouts fall into this category (Caspersen et al., 1985).

Sport, in turn, is a more specific form of physical activity and exercise that involves organized, rule-governed and often competitive elements. It typically requires specific skills and training and is practiced not only for physical benefits but also for enjoyment, performance and sometimes professional achievement and can be undertaken individually or as a part of a team (Khan et al., 2012). The following Figure 6 shows all three terms and their relationship to each other.

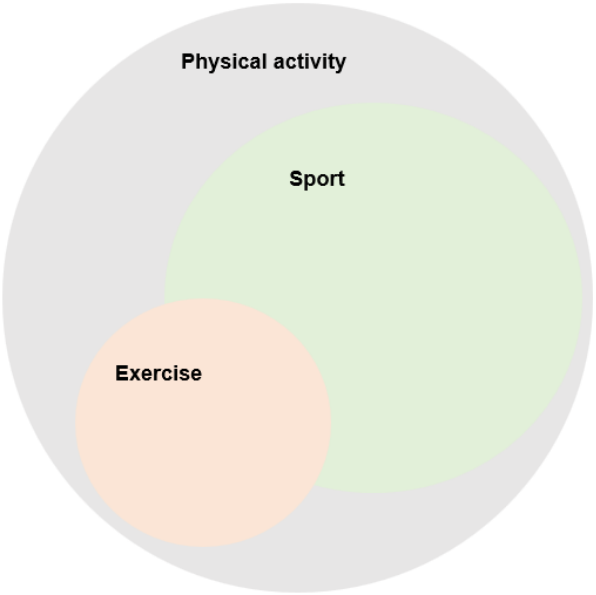


Figure 6: Differentiation between the terms physical activity, exercise and sport according to Khan et al. (2012)

In the context of this dissertation, the term 'sport' is conceptualized as a distinct and structured subset of physical activity and exercise, defined by its adherence to formalized rules, organizational frameworks and often competitive orientation. It entails the acquisition and application of specific skills through systematic training and is pursued not solely for its physiological benefits, but equally for intrinsic enjoyment, performance development, and, in certain contexts, professional advancement. Sport, as understood here, encompasses both individual and team-based practices.

Building upon the prior conceptual distinction between exercise, physical activity and sport, Guttmann's (2012) theory of *modern sport* provides a rigorous historical framework for understanding the unique social and structural characteristics that define modern sport. From this historical perspective, Guttmann (2012) systematically contrasts modern sport with its pre-modern and traditional counterparts, highlighting the transformation of physical contests from ritualistic, localized activities into highly organized and institutionalized social phenomena. Whereas traditional games were

often closely tied to religious ceremonies and cultural rituals, modern sport is distinguished by a set of defining features that embody broader processes of social modernization. These include *(1) secularism*, whereby sport is separated from religious contexts and established as an autonomous social practice; *(2) equality*, emphasizing fair competition and universal access; *(3) specialization*, reflecting the development of expertise and differentiated roles; *(4) rationalization*, through codified rules and strategies to optimize performance; *(5) bureaucratization*, with formal organizational governance; *(6) quantification*, involving precise measurement and record-keeping; and an *(7) obsession with records*, denoting a continuous drive to surpass previous achievements. Together, these characteristics delineate modern sport as a rationalized, performance-orientated and institutionalized domain, fundamentally distinct from the ceremonial and ritualistic practices of earlier eras.

These characteristic features not only distinguish (modern) sport from more general physical activities and exercises, but also make it a culturally and institutionally distinct field characterized by performance-oriented ideals and structured competition.

Furthermore, Heinemann (2007) offers a sociologically-based typology of sport models that further refines the understanding of the various manifestations of sport. Heinemann (2007) identifies four constitutive elements of sport: *(1) physicality and movement*, *(2) performance and competition orientation*, *(3) sporting and social rules* and *(4) non-productivity*. *Physicality and movement* entail a specific and goal-directed manner of engaging with the body, relying on the application of particular physical abilities, skills and knowledge. *Performance and competition* orientation serves as a mechanism for comparing performance, whereby the participants can initially be regarded as equal or unequal. Sport also functions on the basis on *sporting and social rules* that regulate and structure the allowed actions within a particular discipline, which leads to a reduction in complexity by clearly delineating what is allowed and expected. Actions in sport do not have to fundamentally produce or create something, meaning that sport is not inherently productive in the conventional sense, it refers more to a kind of end in itself. The varying degrees to which these elements are present give rise to different sport models as shown in the following Figure 7.

Elemente	Bewegung	Leistung	Sportart-typische Regeln	Unproduktivität
Traditioneller Wettkampfsport	+	+	+	+
Professioneller Showsport	+	+	+	-
Expressives Sportmodell	+	(+)	-	+
Funktionalistisches Sportmodell	+	(+)	-	-
Traditionelle Spielkulturen	+	(+)	(+)	+

Legende: + = gegeben, (+) = bedingt gegeben, - = nicht gegeben. (Quelle: Heinemann 1998, S. 35)

Figure 7: Models of sport according to Heinemann (2007) and their construction elements after Güllich and Krüger (2022)

At the core is the *traditional competitive sport*, where individuals participate out of personal interest rather than economic motivation. A figure skater who trains and competes as a hobby - perhaps even in the same events as professionals - exemplifies this model. In contrast, the *professional show sport* turns sport into a career. A skater who earns her livelihood through competitions or shows represents this model, as her performance contributes to the economy and entertainment industry. Moving away from competition, the *expressive sport model* highlights creativity and personal expression. Dance or gymnastics performances at a club's Christmas celebration, for example, are not about winning, but about aesthetic presentation. These activities still follow rules and values - just different ones than in traditional sport - and demand physical performance. The *functionalist sport model* uses sport as a tool to fulfill specific goals beyond sport itself. School sport is a prime example: it is not practiced for competition or self-expression, but to achieve educational and developmental outcomes within a structured setting. *Traditional play cultures* form the fifth and last model referring to culturally rooted and informal games often found at local festivals. These activities prioritize social bonding and tradition over formal competition or individual performance (Güllich & Krüger, 2022).

These models highlight the variety of roles sport can play, from personal development to professional performance, creative expression, educational purpose and cultural tradition. In conclusion, while Heinemann's (2007) sport models reveal the diversity of sporting practices, this dissertation adopts a definition of sport based on Khan et al. (2012), emphasizing its organized, rule-governed and often competitive nature as core characteristics that distinguish sport from other forms of physical activity or expression.

2.1.4 Virtual Reality

In addition to mindfulness, health and sport, virtual reality appears as a fourth entity, in the context of this dissertation, namely in the form of an innovative medium that can transfer mindfulness to the application areas of health and sport.

Before taking a closer look at virtual reality (VR), in particular immersive virtual reality, and explaining more about those so-called head-mounted displays (HMD), the concept of the reality-virtuality (RV) continuum (see Figure 8), a framework that illustrates the spectrum between the completely real environment and the completely virtual environment will be introduced (Milgram et al., 1995). Within in this continuum, several key terms are defined: (1) virtual reality (VR), (2) mixed reality (MR), (3) augmented reality (AR) and (4) augmented virtuality (AV). According to Milgram et al. (1995) VR refers to environments that are entirely virtual, with no elements of the real world incorporated. Users are fully immersed in a computer-generated environment that can simulate real or imaginary scenarios. Furthermore, MR encompasses the middle part of the RV continuum and involves the merging of real and virtual worlds to create new environments where physical and digital objects coexist and interact in real time. MR includes both AR and AV. AR refers to scenarios where the real world is enhanced with virtual objects, such as overlaying computer-generated images onto a real-world view. In contrast, AV involves a predominantly virtual environment that incorporates elements from the real world, seamlessly blending physical and digital components. The main difference between AR and AV is the degree to which reality is present. AR starts with a real-world view and adds virtual enhancements, while AV starts with a virtual environment and integrates real-world components into it (Milgram et al., 1995).

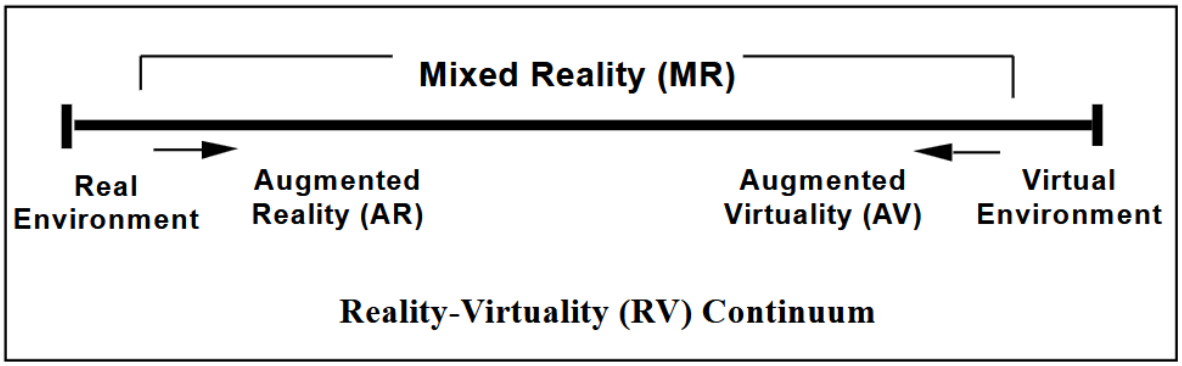


Figure 8: Simplified representation of a RV Continuum after Milgram et al. (1995)

Another term like extended reality (XR) often appears in the VR context and is understood as an umbrella term encompassing AR, VR and MR. It refers to the seamless integration of real and virtual environments, where human interaction with computer-generated content creates an immersive and interactive experience (Rauschnabel et al., 2022). Furthermore, a VR experience is defined by multiple factors like the user interface, elements of the virtual world and user's experience as the following Figure 9 shows, but there are the so-called three I's of virtual reality – *interaction*, *immersion* and *imagination* – that serve as key pillars that define and enhance the user's experience in virtual environments (Burdea & Coiffet, 2003).

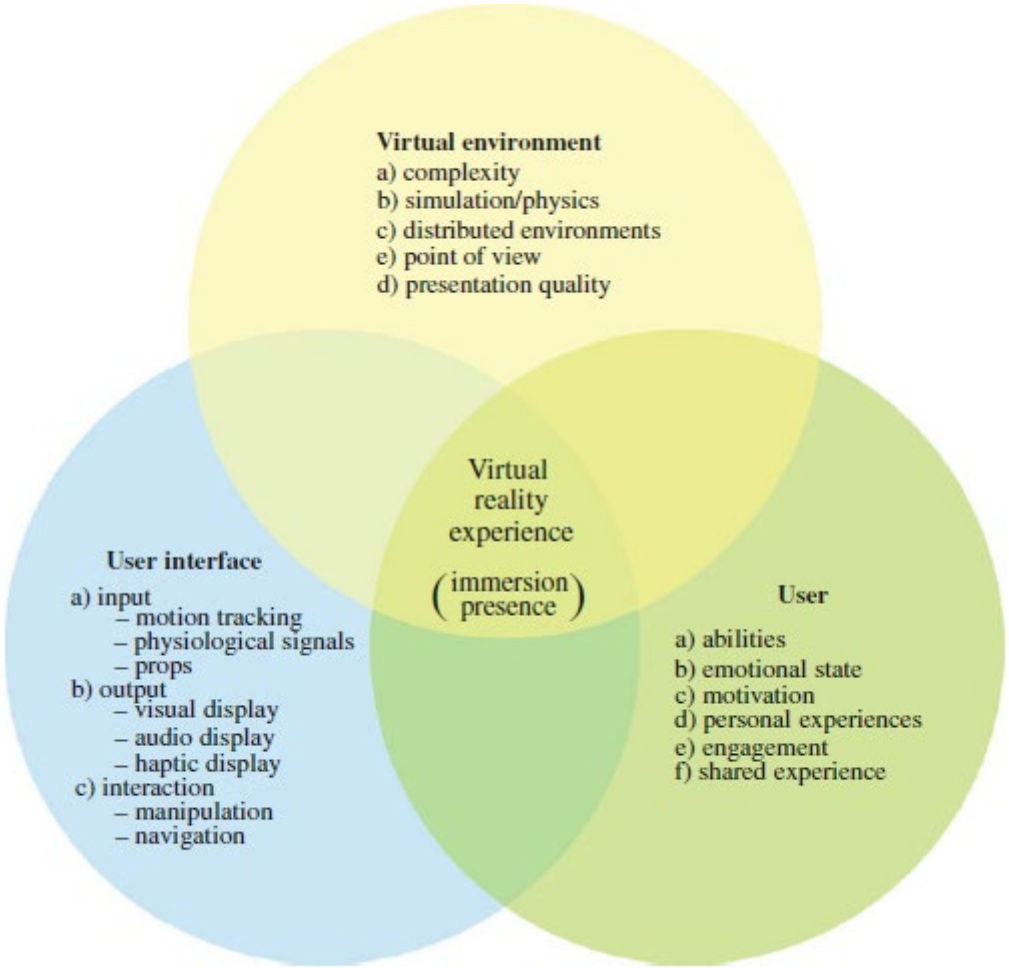


Figure 9: VR experience and its multiple factors after Mihelj et al. (2014, p. 12)

First, *interaction* is commonly described as the ability of users to control or manipulate virtual objects and environments through input devices. These inputs can include things like controllers, gestures or even body movements (Sherman & Craig, 2003). Secondly, *immersion*, sometimes called sensorimotor immersion, refers to the degree

of physical stimulation impinging on the sensory systems and the sensitivity of the system to motor inputs (Bohil et al., 2011). The level of immersion is determined by the number and range of sensory and motor channels connected to the virtual environment and the extent and fidelity of sensory stimulation and responsiveness to motor inputs (e.g., head and body movement and hand gestures to make commands). The psychological product of immersion is presence referring to the sensation of being in the virtual environment rather than the physical world and interacting with the media (Bohil et al., 2011). It is often described as “the perceptual illusion of nonmediation” (Lombard & Ditton, 1997) or the sensation of “being there” in the virtual space (Biocca, 1997). Last but not least, *imagination* refers to the mental capacity of users to create and perceive experiences, objects and environments that do not physically exist (Burdea & Coiffet, 2003). This characteristic enables users to believe in and engage with the virtual world, even though they are fully aware that it is not their physical reality (Burdea & Coiffet, 2003; Rebelo et al., 2012). Imagination allows users to experience things beyond their physical limitations. For example, they might feel like they are touching or moving objects that are not physically present or they may explore entirely new worlds that only exist in the simulation. Imagination creates the space for users to suspend disbelief, fully embracing the virtual environment and interacting with it as if it were real (Logan, 1998). Additionally, it is essential to note that immersion and interaction directly influence a user’s level of imagination. This influence depends on the VR system's input devices, graphics and objectives, as not all VR setups prioritize all three aspects. For instance, full immersion is typically achieved with a head-mounted display (HMD), semi-immersion is facilitated by large projection or LCD screens and non-immersion occurs with standard desktop setups using keyboards and mice (Gutiérrez et al., 2008; Parsons, 2015; Rebelo et al., 2012).

In the following, the focus lies on immersive VR (IVR), which includes experiences accessed through devices like HMDs or CAVE systems (cave automatic virtual environment), as they are typically regarded as offering the highest level of immersion. (Makransky & Petersen, 2021). The typical characteristics of IVR include head and position tracking, the ability to render different images for each eye to provide depth perception and an expanded visual field of view compared to a monitor (Makransky & Petersen, 2021) as well as portability, personalized use and potential cost-effectiveness. Building on this general overview of virtual reality, a brief digression will now examine its interface with biofeedback, highlighting how physiological data can be

integrated into immersive environments, thereby contributing to a deeper understanding of the third dissertation project.

Excursus: Virtual Reality x Biofeedback

Biofeedback refers to the real-time monitoring of physiological signals through sensors, allowing individuals to access information about bodily functions that are typically difficult to perceive (Giggins et al., 2013; Yu et al., 2018). This process provides what is known as augmented or extrinsic feedback, meaning it supplements the naturally available sensory input with additional information. In contrast, intrinsic feedback comes directly from the individual's own sensory receptors without external assistance. The core principle of biofeedback lies in measuring a specific physiological variable and presenting it to the user in a structured manner. This can be done through two main strategies. The first is direct feedback, in which the measured parameter, such as heart rate or heart rate variability (HRV), is displayed numerically on a wearable device, like a smartwatch. The second is transformed feedback, where the collected data is converted into an adaptive signal, such as a visual representation, auditory cue or tactile feedback, to guide the user's response (Onate et al., 2001). By making biological processes and their changes perceptible, biofeedback enables individuals to gain a better awareness of their physiological state. With consistent practice, users can develop the ability to regulate these processes independently, leading to improved self-regulation of both physical and psychological functions (Haus et al., 2020). The biological signals monitored in biofeedback training can include heart rate, heart rate variability, respiration, electrodermal activity, muscle activity and brain activity, among others. The ultimate goal is to improve health or performance by promoting behavioral changes that enhance self-regulation of physical and psychological processes (Fuller, 1978).

It is hypothesized that combining biofeedback with VR, particularly through head-mounted displays (HMDs), could enhance the effectiveness of biofeedback mechanisms. Since immersive VR technology provides a high level of immersion, which can directly increase the feeling of presence, this heightened sense of presence may facilitate a stronger connection between users and their physiological signals, making self-regulation more intuitive and effective (Gradl et al., 2018). Various studies have shown that integrating biological signals as biofeedback within virtual reality scenarios can be effectively implemented (Rockstroh et al., 2021). Research has successfully applied biofeedback in VR using different physiological measures, including electroencephalographic oscillations (Berger & Davelaar, 2018; Kosunen et al., 2016), electrodermal activity (Gromala et al., 2015; Rockstroh et al., 2020), heart rate (Gradl et al., 2018; Houzangbe et al., 2019) and heart rate variability (Blum et al., 2019; Rockstroh et al., 2019). In their scoping review, Lüddecke and Felnhofer (2022) were

able to show, that the combination of biofeedback and VR can reduce anxiety (Gaggioli et al., 2014; Gorini et al., 2010; Repetto et al., 2013), stress (Blum et al., 2019; Rockstroh et al., 2019, 2020) and pain (Tong et al., 2015).

This promising combination of biofeedback and virtual reality presents an approach to enhance attentional focus and promoting relaxation. In particular, HMDs, which fully cover the user's field of view (Slater & Wilbur, 1997) may facilitate sustained attention, making them particularly suitable for biofeedback applications. Research has shown that highly immersive and interactive virtual environments, especially those depicting natural scenes such as beaches or mountains, are effective in reducing stress and promoting relaxation (Annerstedt et al., 2013). Virtual nature environments are especially well-suited for biofeedback interventions, as they can restore attentional resources in a calming and immersive manner while providing meaningful feedback elements (Blum et al., 2019). Additionally, the complexity and interactivity of virtual environments may enhance the transfer of learned self-regulation skills to real-world settings. Compared to traditional 2D-screen-based tasks, virtual environments are considered more ecologically valid (Kothgassner & Felnhofer, 2020), as they provide contextually rich and sensory-vivid scenarios that closely resemble everyday environments, even when depicting fantasy worlds like underwater settings. The dynamic integration of the sensorimotor system in VR also evokes more natural behavioral and physiological responses than abstract stimuli (Bohil et al., 2011). Given these advantages, VR-based biofeedback is expected to facilitate a more effective generalization of learned skills to daily life compared to traditional biofeedback methods (Pallavicini et al., 2009). This can also include an increased relaxation-based self-efficacy by providing real-time feedback on successful relaxation techniques, making progress immediately visible (Giardino et al., 2004; Paul & Garg, 2012; Rockstroh et al., 2021; Teufel et al., 2013). Combined with VR, the experience of success in managing physiological processes in a supportive and immersive environment can boost their belief in their ability to handle stress in real-life situations, so the feedback becomes even more impactful (Blum et al., 2019; Rockstroh et al., 2021; Weerdmeester et al., 2017).

2.2 Level II

The following paragraph focuses more specifically on relevant interrelationships among the four key entities introduced at Level I, examining their connections through both theoretical frameworks and empirical evidence. In this context, particular attention is given to mindfulness as the central construct of this dissertation and virtual reality as an innovative medium within the domains of health and sport.

2.2.1 Mindfulness x Health

The subsequent section discusses the selection of an appropriate health model within the context of mindfulness, serving as the theoretical foundation for especially two of three projects presented in this dissertation. This is followed by a paragraph that provides empirical insights into various applications of mindfulness in health-related contexts, with a particular focus on established, therapeutically orientated programs and concludes with an overview of selected movement-based mindfulness practices.

2.2.1.1 Integrating Mindfulness into Health

This section explores the integration of mindfulness into the three main health models introduced earlier - the Transtheoretical Model, the Biopsychosocial Model and the Salutogenesis Model – with the aim of identifying the most suitable framework for this dissertation.

To begin, the integration of mindfulness within the Transtheoretical Model (TTM) offers a promising yet underexplored avenue for supporting behavior change. Mindfulness, which emphasizes present-moment awareness without judgment (Kabat-Zinn, 1990), may help enhance self-awareness and emotional regulation throughout the change process. A systematic review by Nicoară et al. (2024) examines the relationship between Cognitive-Behavioral Therapy (CBT) techniques and the TTM in the context of substance use disorders. The review highlights key CBT methods including cognitive restructuring, mindfulness, problem-solving and skills training and examines how they align with the stages of change in the TTM. The findings indicate that these techniques are particularly effective in helping individuals move from *contemplation* to *preparation* and from *action* to *maintenance*. While mindfulness is one of the techniques discussed, its specific role in facilitating progression through the stages of change remains less clear, as the evidence on its impact is limited.

In the context of the Biopsychosocial Model (BPSM), mindfulness likewise presents a valuable yet still evolving intervention. Drawing on the integrative nature of the BPSM, which emphasizes the dynamic interplay between biological, psychological and social dimensions of health, Test and Test (2014) explore how mindfulness-based interventions can be situated within this framework, particularly in the management of stress-related conditions. Their review highlights mindfulness helps regulate biological responses like cortisol levels, supports psychological well-being by reducing anxiety and enhances social interactions through improved emotional regulation. While these

findings suggest that mindfulness aligns well with the holistic principles of the BPSM, the authors also note that further empirical research is required to substantiate its efficacy (Test & Test, 2014).

Last but not least, the following paragraph aims to integrate the concept of mindfulness into the Salutogenesis Model (SM) by examining potential conceptual overlaps. Integrating mindfulness into this framework as a "way of being," which emphasizes living in an open and fully engaged manner, encourages responding to life's challenges rather than just reacting (Kabat-Zinn, 1990). Therefore, mindfulness can function as a GRR, acting as a coping strategy that enhances the SOC and thus serves as a kind of mediator in progressing toward the health endpoint of the HEDE-continuum. To achieve this, the following section discusses how mindfulness can positively influence the three aspects of SOC. In order to enhance *manageability*, mindfulness promotes adaptive coping by encouraging present-moment awareness and non-judgmental observation of thoughts and emotions (Kabat-Zinn, 1990). This allows individuals to respond to stressors with a sense of control, rather than feeling overwhelmed or reactive. By improving emotional regulation and cultivating awareness, mindfulness might help individuals to feel more capable of managing life's demands. Moreover, in terms of *comprehensibility*, this present-moment awareness and non-judgmental observation of internal experiences cultivated through mindfulness may also help individuals to interpret events in a way that feels understandable and coherent. Additionally, mindfulness can also promote *meaningfulness* by helping individuals develop a sense of purpose and significance in their lives. The practice might encourage individuals to explore the present moment and reflect on their values, goals and the significance of their experiences. By creating space to reflect and find meaning in daily life, mindfulness can contribute to the motivational aspect of SOC. This interpretation is also reflected in a pilot follow-up study conducted by Foureur et al. (2013) among 38 nurses and midwives, in which an eight-week daily mindfulness-based program was implemented (Mittelmark, 2022). The mindfulness-based content including knowledge of stress on the body, mind, emotion and behavior, as well as daily meditation, practical mindfulness strategies and habit formation embodies typical generalized resistance resources (GRRs) out of the categories *knowledge and intelligenc*e and *coping strategies* as introduced earlier.

The objective of this dissertation is to integrate mindfulness into an established theoretical model of health to provide a structured foundation for subsequent projects.

At this stage, the SM has been chosen as the guiding theoretical framework in the context of health. Therefore, mindfulness can be seen as a form of GRR that supports individuals in progressing along the HEDE-continuum toward the ease-pole, acting as a mediator in this process. The SM also differs from the TTM, which views behavioral change as a staged process by promoting a continuous and adaptable approach to health. Its classification of behavior change into a series of five distinct stages is also one of the most popular criticism (C. J. Armitage, 2009). Concerns also include ambiguity in defining time frames for stage transitions, reliance on cross-sectional studies that fail to establish causality and the need for longitudinal research to validate stage progressions (C. Nigg et al., 2005; C. R. Nigg et al., 2011). Additionally, the model's integration of behavioral and experiential components within a cognitive framework raises philosophical inconsistencies and its hypothesized temporal sequencing remains largely untested (C. R. Nigg et al., 2011). Lastly, while the Biopsychosocial Model (BPM) considers biological, psychological and social factors, it lacks a structured framework for explaining how individuals actively maintain or enhance their health - an aspect that the SM tries to address through the SOC concept. Criticism of the BPM, particularly in the field of psychiatry, includes its lack of specificity, leading to challenges in practical application and measurement. Additionally, the model has been criticized for not adequately addressing the complex interplay between biological, psychological and social factors, potentially oversimplifying the multifaceted nature of mental health conditions (Benning, 2015).

By incorporating mindfulness into the Salutogenesis Model, this dissertation aims to build on its strengths in explaining the dynamic and resource-focused nature of health. This approach offers a more holistic framework for understanding both psychological and physiological health, which will be addressed with varying degrees of emphasis in the following projects.

2.2.1.2 Application Areas of Mindfulness in Health

The practice of mindfulness in the health context can be primarily found in psychological, mental respectively medical and therapeutic fields. Sedlmeier et al. (2012) found in their meta-analysis that mindfulness practices, such as meditation, have positive effects on psychological parameters. Analyses identified medium to large effects in areas like interpersonal relations, trait anxiety, negative emotions, cognition,

behavior and intelligence. Small effects were found in emotion regulation and neutral personality aspects.

In addition to psychology, mindfulness techniques are also widely used in biology, medicine and clinical psychology for the prevention and treatment of illness. Ludwig and Kabat-Zinn (2008), based on the Buddhist-influenced concept of mindfulness, see the cause of many illnesses in people's lifestyles. Meditative mindfulness practice is intended to promote responsibility for one's own health and thus strengthen internal resources. Disease patterns such as diabetes, cancer, chronic illnesses, but also post-traumatic stress disorder or eating disorders can be positively influenced by a mindfulness practice (Bishop et al., 2004; Ludwig & Kabat-Zinn, 2008). Mindfulness practice is also a potential therapeutic tool for (chronic) pain, depression and anxiety (Chiesa & Serretti, 2011; Grossman et al., 2004; Hofmann et al., 2010).This is also shown, for example, by the meta-analytical review by Hofmann et al. (2010), which focused on examining the effectiveness of mindfulness-based therapies (MBT) for anxiety and depression using a psychiatric-medical study collective. Anxiety and depression were also included in the research as symptoms or concomitant symptoms of clinical conditions such as cancer. Moderate effects of MBT on anxiety and mood symptoms were found in the entire study collective. Furthermore, the effect of mindfulness-based therapy in patients with severe anxiety and mood symptoms was large and robust to the year of publication or number of treatments and persisted over the follow-up period (Hofmann et al., 2010).

The popularity of mindfulness practice today is primarily due to the mindfulness-based stress reduction (MBSR) method (Kabat-Zinn, 1982). This manualized movement program was primarily designed for pain patients and aims to adapt emotional reactions and consequently improve coping and acceptance of pain. Common mindfulness techniques include a wide range of different forms of movement and meditation. The following section offers a brief overview of various mindfulness methods, each designed with specific intentions tailored to their target groups. These methods incorporate a range of static and dynamic elements, such as meditation and movement-based exercises. Their development has unfolded in several waves over time, evolving in response to changing focal points and the diverse needs of different populations (Jansen et al., 2019).

2.2.1.3 Therapeutic-Based Mindfulness Approaches

The Mindfulness-Based Stress Reduction *(*MBSR) program from Kabat-Zinn (1982) plays a pioneering role, particularly in the field of meditative methods. The program is based on the construct of mindfulness and uses techniques such as the body scan, a mental walk through the body while lying down, sitting and walking meditations as well as elements of focus, concentration and letting go and hatha yoga (Kabat-Zinn, 2011). In addition to these specific techniques, the eight to ten-week stress reduction program emphasizes applying the learned skills to everyday life. The MBSR program is no longer limited to disorder-homogeneous groups but has also shown effectiveness for individuals from the general population and those with various mental health conditions. Meta-analytical analyses resulted in effect size estimates between $d = 0.15$ and $d = 1.65$ (Baer, 2003).

The Mindfulness-Based Cognitive Therapy (MBCT), developed by Teasdale et al. (1995), is a group therapy approach designed for relapse prevention in depression (Kunz, 2014; Segal, 2015; Segal et al., 2013). This mind-body intervention integrates components of Cognitive Behavioral Therapy (CBT) with elements of the MBSR program, which served as its foundational framework. The program emphasizes core themes such as *managing obstacles*, *breath awareness, present-moment awareness* and *allowance and acceptance*, which are explored during group sessions. Participants are also encouraged to engage in daily mindfulness practices to reinforce these concepts (Kunz, 2014; Segal, 2015). The efficacy of the therapy can be shown for example in a randomized controlled trial, which specifically demonstrated its effectiveness in patients with a history of three or more depressive episodes who completed the MBCT program, compared to those assigned to the "Treatment-As-Usual" (TAU) group. Results indicated a nearly 50% reduction in the risk of relapse within the MBCT group (Teasdale et al., 2000).

In a subsequent wave, new forms of behavioral therapy emerged, emphasizing themes such as emotions, emotion regulation, acceptance, mindfulness and meditation techniques (Chapman, 2006; Hayes, 2004). These include the Dialectical Behavior Therapy (DBT), developed by Linehan (1987), and the Acceptance and Commitment Therapy (ACT) by Hayes (2004). A key similarity between these two approaches is their shared focus on mindfulness and acceptance practices (Chapman, 2006). Linehan (1987) has strongly approached her dialectical philosophy through classical cognitive behavioral therapy to address the specific needs of her original target group

- individuals with borderline personality disorder and chronic suicidal behavior. Consequently, her evidence-based approach for DBT integrates elements of acceptance alongside the change-oriented focus characteristic of traditional cognitive-behavioral interventions (Chapman, 2006). On one hand, patients are encouraged to accept themselves, their past and their current circumstances, while on the other hand, they are supported in modifying their behavior and environment to create a better life. The integration of these seemingly contradictory goals is the central focus of DBT. This approach has since been adapted and evaluated for other populations (Robins & Chapman, 2004). Several randomized controlled trials examined the effectiveness of the DBT (Michalak et al., 2006). The Acceptance and Commitment Therapy (ACT) is based on an analysis of language and cognition from the early 1980s, which culminates in a theoretical model of psychopathology known as Relational Frame Theory (Hayes, 2004; Hayes et al., 1996). This model explains how language and cognition influence human behavior, proposing that abstract internal rule systems lead to rigid behavior, often characterized by avoidant tendencies. This, in turn, typically results in the suppression of unpleasant experiences and emotions. ACT promotes acceptance of the self and one's private experiences aiming for behavioral change and a reduction in associated symptoms. Controlled efficacy studies of the ACT program report effect sizes ranging from d = 0.48 to d = 0.83 (Michalak et al., 2006). Mindfulness practice is anchored in both therapy approaches, but is used differently. DBT sees it as a behavioral skill and a point of view or behavior of the therapist and the person undergoing therapy. In ACT, it is used as a tool against experiential avoidance (Chapman, 2006).

2.2.1.4 Movement-Based Mindfulness Practices

Therapeutic and meditation-based mindfulness approaches are supplemented by movement-based practices like yoga, tai chi and qigong. Yoga, in particular, has gained widespread global popularity and encompasses various forms and styles, with Hatha Yoga being the most prevalent (Swan, 2011). The Sanskrit meaning of yoga comes from yug (to join) or "to yoke" and describes the essential element of connection and unification, especially of body, mind and soul (Jansen et al., 2019). Yoga has ancient roots, with its earliest known origins dating back to 1000–1500 BC. However, it wasn't until the late 19th century that it gained recognition in the West (Swan, 2011). According to Indian legend, Patanjali - often called "The Father of Yoga" - taught that

true healing and self-realization begin with the purification of the body's organs and systems through asanas (postures) and pranayama (breath control). Through this practice, yoga becomes a spiritual journey, guiding individuals toward inner joy and outer harmony by mastering the mind and emotions (Garfinkel & Schumacher, 2000). Systematic reviews and meta-analyses have demonstrated the benefits of yoga, particularly in alleviating back and neck pain (Cramer et al., 2017; Crow et al., 2015). Beyond its physical respectively physiological advantages, research has also highlighted the positive impact of asanas and breathing exercises on mental health conditions such as schizophrenia, insomnia and depression (Klatte et al., 2016). Tai Chi and QiGong are both movement-based practices with many similarities. However, QiGong has older historical roots and emphasizes the concept of "Qi" as essential for maintaining function and enhancing life. Both practices incorporate a wide range of slow, meditative and dance-like movements, performed either standing or seated, often complemented by explosive or powerful motions (Jahnke et al., 2010). A key difference is that Tai Chi typically consists of longer, choreographed and complex sequences, while QiGong is generally simpler, more repetitive and easier to learn. Both methods are grounded in Traditional Chinese Medicine (TCM) and aim to cultivate "Qi", also known as vital energy or life force, through the integration of body, breath and mind (Jahnke et al., 2010). Meta-analytical research by Lauche et al. (2017) has shown that both Tai Chi and QiGong can positively impact risk factors associated with conditions like a stroke.

2.2.2 Mindfulness x Sport

The following paragraph first provides a theoretical conceptualization of mindfulness within the context of sport, followed by an overview of various mindfulness-based programs and a presentation of their effectiveness based on empirical evidence.

2.2.2.1 Integrating Mindfulness into Sport

Mindfulness-based approaches have gained interest beyond the behaviorally-driven/therapeutic context, extending into (elite) sports.

Consistent with our understanding of sport according to Khan et al. (2012), with an organized, rule-governed and often competitive nature as core characteristics that distinguish sport from other forms of physical activity or expression, this expansion reflects the evolving relevance of mindfulness within structured athletic environments.

Achieving peak athletic performance requires a healthy athlete in order to reach an optimal psycho-physiological state, which can vary based on the specific demands of the sport. Only when both physical health and mental well-being are in balance can an athlete perform at their highest level (Birrer et al., 2012).

Figure 10 below illustrates the demands, skills and techniques associated with world-class athletic performance (Birrer et al., 2012). The first layer outlines the objective psychological requirements athletes must meet in various sports. These requirements, in turn, dictate the specific psychological skills necessary to effectively handle the demands of the respective sport. The second layer outlines psychological skills that are believed to assist in regulating an athlete's behavior to meet the requirements of a specific sport. These skills are learned abilities that enable an individual to effectively perform tasks related to the sport's requirements. The third layer of the model consists of techniques designed to enhance the psychological skills identified in the previous layer. These techniques are designed to develop and strengthen the psychological skills required to meet the specific demands of a sport, with mindfulness practices included in this category. Birrer et al. (2012) view mindfulness-based interventions not simply as a psychological technique but as meta-techniques due to their versatility, allowing for diverse applications in sports.

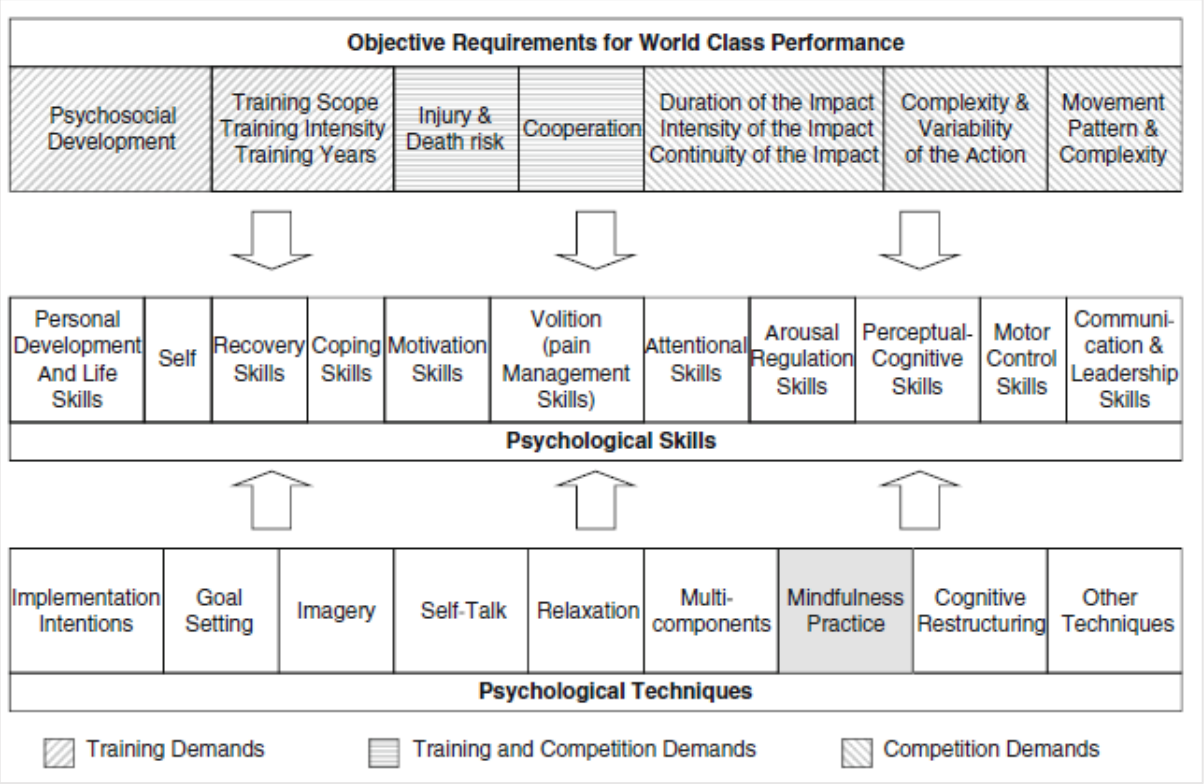


Figure 10: Psychological Requirements for World-Class Performance after Birrer et al. (2012)

Psychological skills training (PST) has been the leading psychological technique or method for enhancing athletic performance in recent decades, effectively reducing negative states like performance anxiety while boosting positive traits such as self-confidence in athletes (Daw & Burton, 1994). However, traditional PST seem to have limits in helping athletes manage their cognitive processes despite investing in mental effort (Gardner & Moore, 2006; Moore, 2009). This can be explained by two theories: (1) the theory of ironic mental processes of mental control (Janelle, 1999; Wegner, 1994) and (2) the theory of reinvestment (R. S. W. Masters, 1992). Ironic mental processes cause athletes to unintentionally focus on unwanted outcomes (Janelle, 1999) and reinvestment involves overthinking, where an athlete disrupts automatic movements by consciously trying to control them through declarative knowledge (R. Masters & Maxwell, 2008). Mindfulness-based interventions could address these issues by promoting a non-judgmental, accepting mindset, which helps athletes focus on the present moment, reducing cognitive interference and enhancing performance despite the potential paradox of mindfulness in goal-oriented sports (Birrer et al., 2012). To effectively integrate mindfulness into high performance sport, athletes must recognize that acceptance does not equate to agreement or resignation, but rather a non-judgmental awareness of their present experience. This view is consistent with

third-wave behavioral therapy (Hayes, 2004), which views thoughts and feelings as temporary mental events rather than absolute truths. By shifting the focus away from controlling or altering internal states, mindfulness techniques help athletes cultivate a mindset that supports goal-directed behavior and optimizes automatic performance processes (Birrer et al., 2012).

Furthermore, Birrer et al. (2012) differentiate between *mindfulness practice* and *dispositional mindfulness*. *Mindfulness practice* refers to a method that trains mindfulness, encompassing (1) an intention for practices like self-regulation and wisdom (Dorjee, 2010), (2) bare attention to internal or external stimuli with the possibility of sustained attention, shift and inhibition and (3) an attitude of non-judgmental, acceptance, openness and non-reactivity (Birrer et al., 2012). *Dispositional mindfulness* is conceptualized as a stable trait respectively "a performance-relevant trait in sports" (Birrer et al., 2012), reflecting a personality characteristic and a tendency for mindful behavior in daily life (Baer et al., 2008; Bergomi et al., 2013; Brown & Ryan, 2003).

Several instruments for measuring dispositional mindfulness, such as the Comprehensive Inventory of Mindfulness Experiences beta (CHIME-β) by Bergomi et al. (2013) or the Mindfulness Awareness Scale (MAAS) by Brown and Ryan (2003) and the Kentucky Inventory of Mindfulness Skills (KIMS) by Baer et al. (2004) are known and are applied, but yet none of these specifically relate to the sports context until the Mindfulness Inventory for Sport (MIS) was developed by Thienot et al. in 2014. This leads to our primary research objective: adapting and validating the English Mindfulness Inventory for Sport (MIS) for the German-speaking population (MIS-D) to establish a context-specific assessment tool. Further details on this project will be discussed later. The following section looks at established and innovative mindfulness programs in sports, evaluating their impact on health and performance. Notable approaches include the Mindfulness Acceptance Commitment Approach (MAC) by Gardner and Moore (2004) and the Mindful Sports Performance Enhancement (MSPE) by Kaufman et al. (2018).

2.2.2.2 Mindfulness Approaches in Sport

2.2.2.2.1 Mindfulness-Acceptance-Commitment Approach

The MAC approach represents a systematically developed mindfulness-based intervention program specifically designed for elite sports practice (Gardner & Moore,

2004). In contrast to traditional cognitive-behavioral methods and techniques, which primarily focus on self-regulation of internal states, the MAC approach is rooted in contemporary meta-cognitive and acceptance-based theories and practices. This performance-enhancement framework integrates key concepts from ACT and MBSR, as outlined above. Gardner and Moore (2004) integrate both a competition-oriented self-regulation component to optimize athletic performance and a value-driven commitment component to enhance training quality and support the long-term development of each athlete within their MAC approach. The goal is not to establish an internal focus of attention but rather to cultivate awareness and acceptance of internal processes and sensations. This, in turn, enables athletes to deliberately and actively direct their attention toward task-relevant stimuli. The program consists of seven modules and was specified and manualized for German-speaking countries as can be seen in the following Figure 11.

	Modulbezeichnung	Inhalte
1	Psychoedukation	Vermittlung des theoretischen Grundprinzips (inkl. Kopplung an Erfahrungen der Teilnehmenden)
2	Achtsamkeit und Kognitive Defusion	Einführung in Achtsamkeit Einführung in das Konzept der kognitiven Defusion (Entkopplung von Gedanken als handlungsweisende innere Befehle)
3	Werte und wertegeleitetes Verhalten	Erarbeitung der (Leistungs-)Werte der Athleten Unterscheidung von emotions- vs. wertegeleitetem Verhalten
4	Akzeptanz	Zusammenhang zwischen Vermeidung und emotionsgeleitetem Verhalten Darstellung von Akzeptanz als Alternative zu vermeidendem Verhalten
5	Commitment	Erweiterung von wertegeleitetem Verhalten (Commitment zu eigenen Werten und Zielen)
6	Konsolidierung von Achtsamkeit, Akzeptanz und Commitment	Zusammenhänge der verschiedenen Konzepte werden endgültig hergestellt
7	Aufrechterhaltung von Achtsamkeit, Akzeptanz und Commitment	Erarbeitung eines „Trainingsplans“

Figure 11: MAC approach after (Heinz et al., 2011)

The seven modules can be summarized in five phases. The first phase is dedicated to psychoeducation and provides participants with a rationale for the MAC intervention. Followed by phase two, in which the concept and techniques of mindfulness are introduced, participants should gain the ability to become aware of the present moment. Mindfulness-based techniques include, for example, the body scan, mindful breathing or a sports-specific pre-game stretch. The third phase is characterized by goal setting and goal achievement. The concept of cognitive defusion is also

introduced. This states that thoughts should no longer be perceived as action-guiding reality, but only as thought content. In phase four, participants should recognize connections between thoughts, feelings and behavior. The focus is on breaking down automated behavior patterns that are triggered reflexively by thoughts and emotions (implementation of cognitive defusion) as well as acceptance, which enables a more open experience. The final phase involves the integration and implementation of the concepts and skills relating to mindfulness, acceptance and commitment in everyday sporting and non-sporting activities (Gardner & Moore, 2004; Heinz et al., 2011; Jansen et al., 2019; Jekauc & Kittler, 2015). Based on case and intervention studies, the results suggest that the MAC approach has the desired effect on attention and performance (Gardner & Moore, 2004, 2007; Ivarsson et al., 2015; Josefsson et al., 2019; Schwanhausser, 2009).

2.2.2.2.2 Mindful Sports Performance Enhancement

The Mindful Sports Performance Enhancement (MSPE) approach developed in 2009 (Kaufman et al., 2009; Kaufman et al., 2018) is rooted in the tradition of the Mindfulness-Based Stress Reduction (Kabat-Zinn, 1982) and the Mindfulness-Based Cognitive Therapy (Segal et al., 2002; Teasdale et al., 1995). Specifically adapted to meet the needs of elite sports, MSPE is a mindfulness-based mental training program designed for both athletes and coaches. Like the MAC approach, it emphasizes the development of mindfulness skills and the concept of acceptance. However, elements such as values, value-driven behavior and commitment are not incorporated into the MSPE framework. The program consists of six structured sessions, integrating educational, empirical and discussion-based components, along with take-home exercises. The structured protocol aims to cultivate mindfulness through personal and shared experiences. Exercises are learned intuitively and progress step by step - from seated practices to mindfulness exercises in movement and ultimately, to sport-specific applications. A key feature of the MSPE approach is the seamless and natural integration of mindfulness into workouts, training sessions, competitions and even everyday life (Kaufman et al., 2018). The following Figure 12 presents the original protocol.

Overview of the Mindful Sport Performance Enhancement (MSPE) Protocol

Session	Key concepts	Exercises
Session 1: Building Mindfulness Fundamentals	Defining mindfulness Rationale for MSPE Getting off of automatic pilot	Candy Exercise Diaphragmatic Breathing Sitting Meditation With a Focus on the Breath
Session 2: Strengthening the Muscle of Attention	Overcoming practice obstacles Core performance facilitators Present-moment attention	Body Scan Sitting Meditation With a Focus on the Breath review
Session 3: Stretching the Body's Limits Mindfully	Recognizing the power of expectations The body as a route to awareness	Mindful Yoga Sitting Meditation With a Focus on the Body As a Whole
Session 4: Embracing "What Is" in Stride	Letting go of attachments Acceptance versus resignation	Mindful Yoga review Walking Meditation
Session 5: Embodying the Mindful Performer	Achieving through nonstriving Choice in self-care	Sport Meditation Sitting Meditation With a Focus on the Breath, Body, and Sound
Session 6: Ending the Beginning	Ending MSPE Building an ongoing practice routine	Body Scan review Sport Meditation review

Figure 12: MSPE approach after Kaufman et al. (2018)

The introductory session primarily serves to familiarize participants with the concept and theoretical foundations of mindfulness. Key components include establishing a foundation of trust, providing a rationale for mindfulness and the MSPE program, engaging in the *candy exercise* and introducing diaphragmatic breathing and sitting meditation. The second session focuses on strengthening the *muscle of attention*. To achieve this, participants are introduced to the body scan technique, which involves systematically directing attention through different areas of the body in connection with the breath. In the third session, the emphasis shifts to developing mindful awareness of the body and its physical boundaries. In addition to the sitting meditation, a mindful yoga exercise is incorporated to enhance bodily awareness. The fourth session introduces the concept of acceptance. A modified walking meditation, adapted specifically for sports, is included in this session. During the walking meditation, participants focus on the sensation of each step, with the option to extend their awareness to the breath. This session marks a clear progression toward movement-based mindfulness elements. The fifth session centers on applying mindfulness within the sports context. Alongside familiar sitting meditation exercises, sport-specific mindfulness practices are introduced. The final session serves as the conclusion of the MSPE program and aims to encourage regular mindfulness practice, integrating it into

athletes' routines to establish long-term habits (Jansen et al., 2019; Jekauc & Kittler, 2015; Kaufman et al., 2018).

The effectiveness of MSPE was confirmed in an intervention study by Kaufman et al. (2009) with eleven archers and 21 golfers with regard to the athletes' flow experience, mindfulness and self-confidence. In another study involving 25 recreational runners, an MSPE intervention led to improvements in state mindfulness and trait attention, as well as a reduction in sport-related worries. However, actual running performance remained unchanged (Petrillo et al., 2009). Based on both study samples a one-year follow-up revealed a significant increase in awareness as a subcomponent of trait mindfulness, as well as in overall trait mindfulness across the athlete groups. Additionally, there was a significant decrease in task-relevant worries, an aspect of cognitive interference during athletic activity. Among long-distance runners, a significant improvement in their mile run time was also observed (Thompson et al., 2011). An intervention study by Glass et al. (2019) with college athletes found that the MSPE protocol improves the athletes' well-being both within and outside of the athletic context. Depressive symptoms did not decrease during the intervention compared to the control group. Additionally, among participants who completed all six MSPE sessions, a pre-post comparison showed a significant improvement in trait mindfulness, worry levels, life satisfaction, flow and self-rated athletic performance, with effect sizes ranging from moderate to large (Cohen, 1988). The continued interest in this topic, particularly in the MSPE program, is demonstrated by a more recent intervention study with elite swimmers (Chen & Meggs, 2020). The MSPE program showed improved trait flow characteristics and an enhanced overall trait. However, the significance of the results is somewhat limited due to the small sample size of the MSPE group (n = 9).

2.2.2.2.3 Other Mindfulness-Based Approaches in Sports

This sustained interest in sports psychology research focused on mindfulness and mindfulness-based interventions is reflected in the fact that numerous other mindfulness programs have been developed in sport over the years. A modified version of the MAC approach was used with NCAA Division I (National Collegiate Athletic Association) college athletes. The original 8-week program was reduced to five weeks and included 1-2 exercise sessions per week, each supplemented by a 60-minute yoga session. A total of eight units lasting 90 minutes were therefore completed as part of

group sessions. Improvements in mindfulness and goal-oriented energy were observed (Goodman et al., 2014).

Si et al. (2016) designed a mindfulness-based intervention, the Mindfulness-Acceptance-Insight-Commitment (MAIC) program, which is specifically made for Chinese athletes. This framework integrates cultural and systemic aspects of the Chinese sports domain while incorporating principles derived from ACT. Empirical evaluation of the program, conducted with six Olympic swimmers, demonstrated enhancements in mindfulness and cognitive flexibility. Additionally, in a case study of an Olympic diver, mindfulness-based training was associated with a reduction in anxiety levels (Si et al., 2016).

Other mindfulness-based interventions, such as the Mindfulness Meditation Training for Sport (MMTS), place a primary emphasis on meditation. Over a six-week period, a group-based intervention was conducted with female soccer players from an NCAA Division I team, comprising 12 meditation sessions, each lasting 30 minutes. The training program focused on four core components: (1) open awareness capacity, (2) caring thoughts for self and teammates, (3) concentration exercise and (4) practicing acceptance of negative mind-state. The findings of the study highlight the positive effects of MMTS on mindfulness among female soccer players (Baltzell & Akthar, 2014).

The Mindful Performance Enhancement, Awareness and Knowledge program (mPEAK) represents another mindfulness-based training approach, which is derived from the traditional MBSR program (Haase et al., 2015). In addition to athletes as the primary target group, there are also mindfulness-based programs specifically designed for coaches. One such example is the Mindfulness Training for Coaches (MTC) program. The program begins with an initial session that introduces coaches to the rationale behind MTC and provides foundational mindfulness techniques, such as mindful breathing and walking meditation. This is followed by a six-week at-home training program, which includes daily 20-minute mindfulness exercises (Longshore & Sachs, 2015).

A meta-analytical review by Bühlmayer et al. (2017) examined the impact of mindfulness practices on performance-related parameters and outcomes in sports. Analyzing nine studies with 290 athletes across various disciplines, the review found that mindfulness interventions led to significant improvements in mindfulness levels, psychological performance factors (e.g., concentration or attention) and actual

performance outcomes especially in precision sports like shooting and dart throwing. The authors suggest incorporating mindfulness practices as a complementary mental training approach for athletes, particularly in precision sports, while advocating for more high-quality, randomized controlled trials to further explore these effects across diverse sports settings. While mindfulness can also have health benefits, this review specifically evaluates its effectiveness in enhancing sports performance rather than broader health-related outcomes. This meta-analysis, together with the other empirical findings mentioned above, underlines the positive effects of mindfulness interventions on performance-related parameters and overall athletic performance. These findings not only highlight the effectiveness of mindfulness in improving athletic performance, but also encourage more extensive research into its potential benefits for overall well-being.

2.2.3 Virtual Reality x Health

Regarding health and health care, VR has been applied successfully in different areas, for example in motor rehabilitation (Kamińska et al., 2022). One key group benefiting from such VR applications are post-stroke patients with mobility issues, such as those using an upper limb rehabilitation system that provides interactive exercises with feedback (Powell et al., 2017). VR is also used as a motor skills training tool for rehabilitating balance and gait disorders, particularly in neurological patients with conditions like Parkinson's disease, multiple sclerosis, stroke, traumatic brain injury or cerebral palsy (Cano Porras et al., 2018). Virtual reality is also utilized in professional psychotherapy, particularly in cognitive behavioral therapy. It has been employed to treat patients with anxiety disorders, phobias (Reyna et al., 2018), post-traumatic stress disorder (Rizzo & Talbot, 2015), addictions and other conditions that significantly impact the patient’s daily functioning (Kamińska et al., 2022). The various areas of application of VR in the healthcare context and its effectiveness can also be shown in the systematic review by Snoswell and Snoswell (2019). This paper also demonstrates the substantial potential of immersive VR (IVR) in acute healthcare from 58 studies conducted in 19 countries across multiple domains like pain management, phobia treatment, neurological training and psychological interventions. About half of the studies were feasibility and user-acceptance evaluations, while the others were efficacy trials comparing IVR interventions to conventional treatments. Preliminary findings are promising, indicating that IVR is at least as effective - if not superior - to

traditional interventions for certain conditions. However, most research remains exploratory and does not yet provide robust evidence for widespread clinical implementation. This brief overview offered an initial insight into the current applications of VR in the promotion of health and is followed by a paragraph that examines how VR is being applied within the field of sport.

2.2.4 Virtual Reality x Sport

The application of VR in sports is primarily examined through the lens of how sporting activities are translated into virtual environments and subsequently implemented within these settings. A systematic review by Neumann et al. (2018) examined the application of interactive virtual reality in sports, analyzing 20 studies involving healthy participants and formed a model of interactive VR in sport and sport-related exercise (see Figure 13). The findings indicated that interactive VR applications have enhanced various performance, physiological and psychological outcomes *(concurrent outcomes)*. These effects were influenced by factors related to both the *athlete* and the *VR system*, including the presence of others in the virtual environment, competitiveness, task autonomy, immersion, attentional focus and feedback. The majority of research has been conducted on endurance sports, such as running, cycling and rowing, highlighting the need for further studies on the use of interactive VR in skill-based sports.

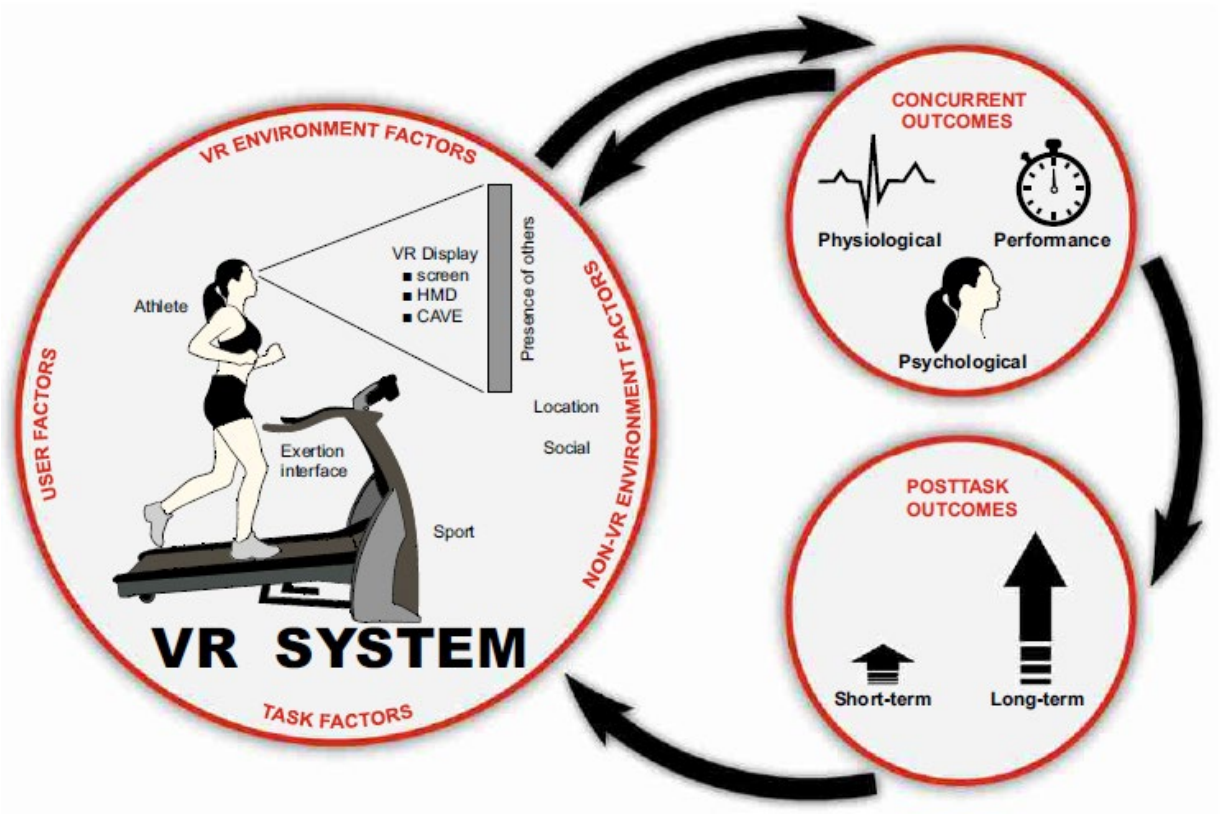


Figure 13: Model of interactive VR in sport and sport-related exercise after Neumann et al. (2018)

Another review by Akbaş et al. (2019) explored the use of VR in competitive sports in three key areas: *performance analysis* (e.g., to assess athletes' decision-making, reaction times and motor skills in controlled virtual settings), *simulation improvement* (e.g., to provide athletes with realistic, repeatable scenarios for practicing game situations, particularly in sports like soccer or basketball) and *virtual training* (e.g., to improve technique, coordination and cognitive skills). Most studies used VR to analyze performance, particularly in goalkeeping tasks in handball, soccer and ice hockey, leveraging VR's ability to create controlled, replicable environments for studying specific factors affecting athlete performance. Some studies explored VR's effectiveness as a training tool, but only one applied it directly to enhance motor abilities in athletes. Research has also shown that VR training can increase motivation, improve performance and reduce perceived exertion due to its engaging nature (Akbaş et al., 2019). Despite the potential of VR for high-performance training, its application among competitive athletes remains limited. While VR is widely used for novice athletes, clinical rehabilitation and high-risk occupations such as aviation and medicine, its training potential in elite sports remains largely untapped. This review highlights the significant but underexplored potential of VR as a training tool for

competitive athletes, emphasizing the need for further research into its effectiveness in sports performance enhancement (Akbaş et al., 2019).

The narrative review by Richlan et al. (2023) examined sports performance enhancement through interventions in virtual reality with novice, amateur and expert athletes. The review encompasses various sports disciplines, including target and precision sports (e.g., archery, bowling, curling, darts, golf), bat/racquet and ball sports (e.g., baseball, table tennis), goal sports (e.g., football/soccer, basketball), martial arts (e.g., karate) and sport-unspecific processes such as bodily sensations and balancing. The findings suggest that VR interventions hold potential for enhancing sports performance by training motor and psychological skills including perception-action skills, strategic, tactical and decision-making, responding to unexpected events and enhancing psychological resilience and mental performance under pressure (Richlan et al., 2023).

These three papers collectively demonstrate the broad applicability of VR within the sports context. On the one hand, sport provides the content of VR and on the other hand, VR serves to promote and analyze different skills in sport. However, this may not cover the entire spectrum of applications as Bird (2020) sees further application areas within applied sport psychology like relaxation or injury rehabilitation.

With mindfulness as the central construct of this dissertation, the latter application areas identified appear particularly promising and point to a potential research gap that could be addressed through the targeted use of VR. In contrast to approaches that integrate sport content into VR or use VR primarily to train motor skills, the present focus is on employing VR as a medium to convey mindfulness and facilitate the practice of a psychological technique.

2.3 Level III

The following section (Level III) examines the intersection by linking mindfulness and VR with the two main application areas health and sport, thereby completing the foundation for identifying the research desideratum and formulating corresponding research questions.

2.3.1 Mindfulness x VR x Health

This subchapter explores the existing empirical evidence on the effects of VR-based mindfulness interventions within the health context. Several review articles with differing thematic emphases have synthesized the current state of research, offering valuable preliminary insights into the effectiveness and potential applications of such interventions. Two of these reviews were particularly relevant to the identification of the present research focus and are therefore examined in greater detail in the section that follows. To provide a comprehensive perspective, insights from additional reviews are also incorporated.

Zhang et al. (2021) conducted a systematic review to assess the effectiveness of virtual reality (VR)-based mindfulness interventions on psychological and physiological health outcomes in adults. Specifically, the review was guided by three central research questions: First, do VR-based mindfulness interventions produce beneficial psychological and physiological outcomes, such as reduced anxiety, depression or pain? Second, how do these VR-supported interventions compare to conventional mindfulness practices in terms of effectiveness? And third, are there long-term effects associated with these interventions and to what extent have follow-up assessments been conducted to evaluate the durability of observed changes? The findings suggest that VR-based mindfulness programs are generally associated with positive short-term outcomes. Participants often reported decreased stress, anxiety and physical discomfort and many found the immersive nature of VR helpful in maintaining focus and engagement during mindfulness practice. However, the review also notes that most studies did not demonstrate clear advantages of VR over traditional mindfulness techniques. Moreover, long-term effects remain largely unknown, as follow-up assessments were rarely included in the study designs.

The narrative review by Arpaia et al. (2022) offers a comprehensive overview of how VR is being integrated into mindfulness-based interventions, particularly in clinical contexts. Guided by three central questions, the review explores whether there is scientific evidence that VR technology can enhance the practice of mindfulness; whether existing experimental studies examine the specific ways in which VR may support core mindfulness components such as interoceptive awareness and decentering and whether innovative VR design solutions have emerged in this domain, along with their intended purposes. The findings reveal a wide range of clinical applications, including for pain, stress, anxiety, depression, borderline personality

disorder and addiction. Reported benefits include enhanced relaxation self-efficacy, reduced mind-wandering and improved attentional control. However, despite these promising outcomes, over 90% of the included studies were rated as methodologically weak, indicating a substantial need for more rigorous research designs.

To complement the broader perspective, additional insights from reviews with narrower scopes, particularly those focusing on specific target populations, are presented below. Mitsea et al. (2022) found that mindfulness training delivered through immersive technology led to significant improvements in cognitive and socio-emotional meta-skills, emotional regulation and various mental and physical health outcomes, including academic performance and well-being, particularly in special education contexts. Similarly, O'Connor et al. (2022), in a scoping review on chronic pain, reported preliminary evidence suggesting that VR may support mindfulness-related processes such as relaxation, centeredness and distraction. These mechanisms show promise in reducing pain and improving sleep and mobility in certain individuals. Further targeted reviews, such as Mitsea et al. (2023), confirmed that immersive mindfulness interventions enhance cognitive and socio-emotional meta-skills in individuals with mental disorders. In contrast, Failla et al. (2022) demonstrated that in nonclinical populations, VR-based mindfulness interventions effectively reduced negative mood states while enhancing mindfulness skills.

Overall, the current body of research points to a range of promising findings regarding the potential of VR-based mindfulness interventions. These interventions appear to offer notable benefits across various domains and populations. Nevertheless, a research gap remains from both a methodological and conceptual standpoint, particularly concerning the specific health effects of immersive VR-based mindfulness interventions delivered via head-mounted displays (HMDs). Given this gap, the focus within this dissertation lies specifically on immersive VR using HMDs. The aim is to first consolidate reliable evidence, both theoretically and empirically, within the health context before considering any transfer to sport settings. As will be demonstrated in the following section, VR-based mindfulness interventions are largely absent in the sport context, further highlighting the importance of establishing a solid evidence base within health-related applications first, where substantially more findings have already been established. This focus forms the basis for the two subsequent projects of this dissertation.

2.3.2 Mindfulness x VR x Sport

At Level II (Mindfulness x Sport), existing research has demonstrated numerous positive effects of manualized mindfulness programs, like MAC (Gardner & Moore, 2004) or MSPE (Kaufman et al., 2009; Kaufman et al., 2018) on performance-relevant variables and athletic performance outcomes. Building upon this, the present section (Level III) explores the extent to which mindfulness-based content has already been implemented in sport contexts using VR (Mindfulness x VR x Sport) and whether any positive effects on health or performance have been observed.

Empirical research on VR-based mindfulness interventions in sport remains scarce, with little focus on immersive applications using head-mounted displays (HMDs).

At the outset of this dissertation, the field was still in its infancy. However, over the course of the doctoral research, significant developments took place, not least within the research group itself - a dynamic that will be illustrated in the following excursus.

Up to this point, studies that combine VR and mindfulness in athletic contexts have tended to rely on traditional mindfulness methods, such as guided meditation, while embedding these practices within sport-specific VR environments. One illustrative example is a recent study investigating the effects of a brief (20-minute) pre-competition mindfulness meditation (MM) session on attentional control and performance among university athletes (Gao & Zhang, 2023). In this study, a virtual reality shooting competition was used to simulate a realistic sport scenario, allowing researchers to compare attentional and neural responses following MM versus mind-wandering (MW) conditions. The results indicated that participants in the MM group showed significantly longer fixation durations on task-relevant stimuli ($F_{(1, 61)} = 5.84$, $p = 0.02$, $\eta_p^2 = 0.09$), fewer fixations on the ranking screen ($F_{(1, 61)} = 22.98$, $p < .001$, $\eta_p^2 = 0.27$) and improved shooting performance ($F_{(1, 70)} = 6.047$, $p = 0.016$, $\eta_p^2 = 0.08$). Neuroimaging data via functional near-infrared spectroscopy (fNIRS) further revealed enhanced activation and functional connectivity in the dorsolateral prefrontal cortex (dlPFC), especially in Brodmann areas (BA) 9 ($F = 8.07$, $p = .006$, $d = 0.85$) and 10 ($F = 10.95$, $p < .001$, $d = 1.04$), suggesting increased recruitment of attentional control mechanisms during shooting performance.

These findings highlight the potential of brief mindfulness interventions to enhance focus and performance in closed-skill sports. However, the VR component in this study served primarily as a simulated competition environment, while the mindfulness content remained conventionally structured and was not delivered through (immersive)

VR technologies, which leads over to the following excursus that provides first insights into how VR-based mindfulness interventions are gradually finding their way into sports.

Excursus: Recent Evidence in the Context of Mindfulness x VR x Sport

Study I: Ego-Depletion and Motor Skill Performance Under Pressure – Experimental Effects of a Short-Term Virtual-Reality Based Mindfulness Breathing Meditation with Integrated Biofeedback (Wagner & Wieczorek, 2024)

This study by Wagner and Wieczorek (2024) investigated whether a brief VR–based mindfulness breathing meditation with integrated biofeedback (VRMMB) can mitigate the performance declines associated with ego depletion during high-pressure motor tasks in reference to the study conducted by Shaabani et al. (2020).

This study was situated at the intersection of several theoretical frameworks, including choking under pressure, ego-depletion, mindfulness and virtual reality. For a better understanding, the first two constructs will be briefly examined, as mindfulness and virtual reality have been comprehensively addressed in earlier sections of this manuscript. Choking under pressure can be understood as an acute and significant drop in skill execution and performance triggered by increased anxiety (Mesagno & Hill, 2013), which either distracts the athlete or shifts attention to monitoring their actions (Oudejans et al., 2011). It is often associated with reduced self-control, especially if this resource is strained by previous tasks, a relationship that can be theoretically explained by the ego depletion model. Ego depletion refers to a capacity for self-control that can be temporarily depleted after a previous (primary) self-control action (Baumeister et al., 2007), which can, in consequence, impair athletic performance.

From a methodological point of view, this study involves two counterbalanced crossover experiments, basketball free throw and penalty kicks, each involving a within-subjects design. In both experiments, participants first completed a cognitively demanding Stroop test to induce ego depletion (manipulation) and then either took a 15-minute rest break (condition A) or underwent a 15-minute VRMMB session (condition B). Performance was assessed both pre- and post-manipulation under simulated pressure: 20 basketball free throws in experiment 1 ($N = 18$; 61.1% male; M_{age} = 23.89 years; SD_{age} = ± 14.4 years) and 20 soccer penalty kicks targeting goal quadrants in experiment 2 ($N = 16$; 100% male; M_{age} = 23.06; SD_{age} = ± 2.44 years). To induce pressure, participants were told their trials were being video-recorded (Wolch et al., 2020) and wore wireless headsets through which they heard 21 distracting, worry-inducing sentences (e.g., “It’s going badly, I really need to improve now”), translated from Nieuwenhuys and Oudejans (2012) and spoken in a neutral tone by male and female voices.

In the experiment 1 (basketball free throws), free-throw scoring performance in the resting condition did not significantly differ before and after manipulation (F (1, 17) = 1.05, p = 0.321, *part.* η^2 = 0.061; *1−ß* = 0.16). Under VRMMB, however, performance improved significantly from pre- to post-session (F (1, 17) = 11.41, p < 0.05, *part.* η^2 = 0.416; *1−ß* = 0.89). This suggests that VR-enhanced mindfulness boosts performance beyond baseline under pressure. In the experiment 2 (penalty kicks), penalty performance dropped in the resting condition following manipulation (F (1, 15) = 9.15, p < 0.01, *part.* η^2 = 0.379; *1−ß* = 0.81), but increased when manipulation was followed by VRMMB (F (1, 15) = 36.22, p < 0.001, *part.* η^2 = 0.707; *1−ß* = 1.00).

The results showed that in the basketball task (experiment 1), participants did not exhibit a performance drop after depletion under condition A, possibly due to recovery during the rest period. However, performance significantly improved after the VRMMB intervention. In the penalty task (experiment 2), ego depletion led to a performance decline under condition A, while performance improved after the VRMMB session. These findings suggest that the VRMMB not only mitigated the effects of ego depletion but also enhanced performance under pressure. So, these results can be seen as evidence that brief, immersive mindfulness interventions delivered via VR can replenish self-regulatory resources, foster emotional regulation and increase perceived relaxation and breath awareness (Rockstroh et al., 2021; Tyler & Burns, 2008) . While the results are promising, there are also some limitations. Emotional responses were not directly measured and the effects of VR versus mindfulness alone could not be separated. Moreover, participants were amateurs, which may have amplified the benefits observed. Despite the limited ecological validity, since real-world game conditions are more complex, the findings suggest that integrating VR mindfulness into regular training could help athletes better cope with pressure and maintain performance. Further studies involving professional athletes and real-world settings are recommended to validate and extend these findings.

In addition to the study conducted by our own research group, others have also begun to engage with this still largely unexplored field, with one further study being presented here as an illustrative example.

Study II: Assessing A Virtual Reality Mindfulness Application To Promote Wellbeing and Sport Performance in Elite Athletes (Simons et al., 2024)

This prospective pilot study examined the use of a VR-based mindfulness application among division I collegiate athletes. Conducted over six weeks with a small cohort (n = 8), the observational study aimed to explore the intervention's impact on wellbeing and sport performance. The results revealed a significant increase in overall self-reported well-being

throughout the four-week intervention. However, no significant changes were observed in mindful attention or objective sport performance measures. Trends suggest a possible reduction in perceived stress and increased excitement about sport, though the authors emphasized that a larger sample would be necessary to draw more robust conclusions. Since this work was only presented as a poster contribution, no detailed results are available. However, these preliminary findings offer initial support for the potential of immersive VR mindfulness applications to promote athlete well-being but highlight the need for further empirical validation in larger, controlled studies.

3 Research Desideratum & Research Questions

Based on the theoretical background and current state of research of the introduced entities and their interrelations, the following three global research questions were formulated:

I) How can mindfulness be validly and reliably assessed within a sport-specific context in German-speaking populations?
II) What are the psychological and physiological health effects of VR-based mindfulness interventions within the health context?
III) What are the psychological and physiological health outcomes associated with a VR-based mindfulness breathing meditation incorporating biofeedback?

Therefore, the research desideratum was to address three key gaps: (1) the development of a valid and reliable German-language instrument for assessing mindfulness in athletes; (2) a systematic literature review to synthesize the current empirical evidence on psychological and physiological health effects of immersive VR-based mindfulness interventions delivered through HMDs; and (3) an experimental study to examine the potential health benefits of VR-based mindfulness breathing meditation integrating biofeedback.

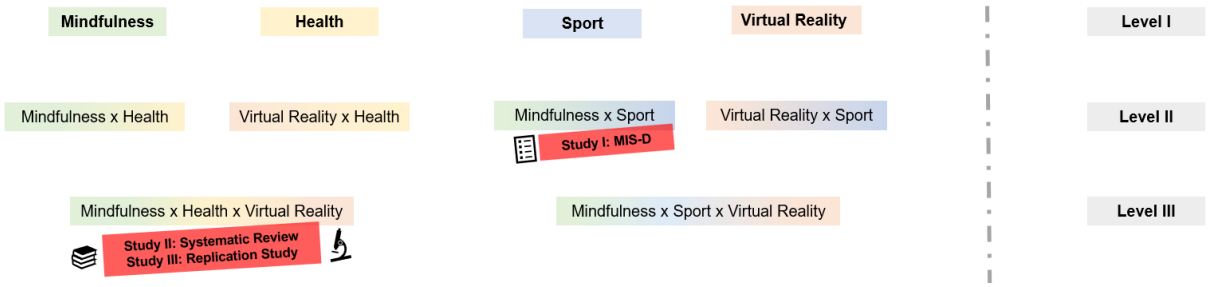


Figure 14: Positioning of the projects within the constructs and their interrelations

4 Projects

This dissertation is structured into three projects, each exploring a distinct aspect of the overarching research objective. Throughout these projects, the intersections of the key constructs introduced at the beginning, namely mindfulness, health, sport and virtual reality, are examined with varying emphasis and scope. The first project aims to develop a German-language measurement instrument for assessing athletes' mindfulness skills, the Mindfulness Inventory for Sport (MIS-D), to enable the rigorous investigation of various research questions within this field. This included evaluating its psychometric properties to ensure reliability, validity and measurement invariance.

In addition to this methodologically focused paper introducing the MIS-D, which is directly applicable in sports(-psychology) contexts, the following two projects primarily involve non-athletic participant samples. This approach reflects the close interrelation between sport psychology and general psychology as outlined by FEPSAC (1995), where sport psychology is shaped by sport practice, general psychology and other sport sciences, functioning both as an applied and empirical discipline. It not only applies psychological principles to sport-related contexts but also contributes to the broader field of psychology. In line with this integrative perspective, this dissertation draws on findings from non-sport-specific psychological research to inform the theoretical foundation, application potential and methodological considerations of VR-based mindfulness interventions in sport. The lack of a sport-specific context can, therefore, be attributed to the limited use of new technologies such as (immersive) virtual reality in sport, particularly in conjunction with mindfulness, as outlined in section 2.3.2. Given the lack of existing research in this area, we initially addressed the following two research questions using a general population. This broader approach is consistent with the reciprocal relationship between sport psychology and general psychology: insights gained outside of sport serve as a theoretical and methodological

basis that can subsequently be adapted and transferred to athletic populations. These implications are further explored in the discussion section 5.2.

Therefore, the second project aimed to investigate the psychological and physiological health effects of VR-based mindfulness interventions through a systematic review with an integrated evidence mapping. This review focused specifically on immersive VR technologies, with an emphasis on head-mounted displays (HMDs).

Building on these findings, the third project conducted an empirical replication study to assess the psychological and physiological outcomes of a mobile VR-based mindfulness breathing meditation with integrated biofeedback.

In the context of this dissertation, I served as the first author on all included papers, taking primary responsibility for the development of content, study design, data analysis and manuscript writing, while co-authors reviewed the work and provided feedback.

4.1 Psychometric Properties of the Mindfulness Inventory for Sport (German Version)

The theoretical introduction to mindfulness in sports has already emphasized the need for a context-specific measurement instrument to assess athletes' mindfulness skills respectively dispositional mindfulness. Such an instrument is essential for systematically examining the effectiveness of mindfulness-based practices and interventions on performance-related factors and overall athletic performance. In this context, Birrer et al. (2012) describe dispositional mindfulness as a mediating factor between mindfulness practices or interventions and key outcome variables, including performance and other performance-relevant parameters. The latter also includes psychological and physiological health parameters, which will play an even more pronounced role in the following two projects.

To pursue this research desideratum, the aim of the first project of this dissertation was to evaluate the psychometric properties of a German version of the Mindfulness Inventory for Sport (MIS-D) (Wieczorek et al., 2022). Originally developed by Thienot et al. (2014), the Mindfulness Inventory for Sport (MIS) assesses mindfulness skills in athletes based on the MAC approach by Gardner and Moore (2007), focusing on awareness, non-judgmental attitude and refocusing. Awareness is described as "the capacity to closely observe one's internal experiences, such as thoughts, emotions, or

bodily sensations, in the present moment." The non-judgmental attitude refers to "the openness to allow and accept one's internal experiences as they unfold, without attempting to judge or criticize oneself for having these thoughts, emotions, or bodily sensations." The final component, refocusing, is defined as "the ability to shift away from unproductive processing, such as distraction, rumination, or worry, in order to stay focused or quickly redirect attention to task-relevant cues." (Thienot et al., 2014, pp. 73–74). To validate the MIS-D, an online survey with 63 females and 165 males (*N = 228; M_{age} = 23.42 years; SD_{age} = 2.91 years*), incorporating a test-retest design to assess reliability, validity and measurement invariance across gender and competition type was incorporated.

The results demonstrated adequate reliability regarding internal consistency, with Cronbach's alpha values of 0.725 (awareness), 0.721 (non-judgmental attitude) and 0.738 (refocusing) indicating strong internal consistency. McDonald's Omega, which takes into account the fact that the items do not always capture a construct homogeneously, showed similar values, which confirms these results. Test-retest reliability over a six-week interval (n = 106) yielded intraclass correlation coefficients (ICC) of 0.58, 95% CI [0.39, 0.72], p = 0.000 (awareness), 0.77, 95% CI [0.66, 0.84], p = 0.000 (non-judgmental attitude) and 0.79, 95% CI [0.70, 0.86], p = 0.000 (refocusing), suggesting moderate to good stability over time.

In terms of factorial validity, a confirmatory factor analysis (CFA) with WLSMV estimation supported the three-factor structure, with $\chi^2(149) = 201.52$, p = 0.003, RMSEA = 0.039, SRMR = 0.069 and a χ^2/df ratio of 1.35, indicating a good model fit. However, CFI (0.898) and TLI (0.883) were slightly below the recommended threshold of 0.90. For inner-method convergent measures, all factor loadings were significantly different from zero ($p < 0.001$) and factor reliability (FR) for all three latent variables exceeded 0.60. However, none of the latent variables explained more than 50% of the variance (AVE), indicating insufficient explanatory power. Only four out of 19 items had an indicator variance (IR) higher than 40%, suggesting some critical indicators. For inner-method divergent measures, the AVE of all latent variables exceeded the maximum squared intercorrelation (MSI), with Fornell-Larcker ratios (FLR) below 1, indicating good discriminance. The scaled χ^2 test (χ^2_{scaled} = 27.651***) confirmed that the proposed model can be retained.

Measurement invariance of the 19-item three-factor MIS-D was tested across gender (female: n = 63 vs. male: n = 165) and competition type (competition: n = 92 vs. non-

competition: n = 136) using multi-group confirmatory factor analysis for ordinal data. For gender, results supported configural, metric, scalar and strict invariance, indicating that the three-factor structure was equivalent across groups and that males and females had comparable item responsiveness (ΔCFI < 0.02). For competition type, full measurement invariance was not achieved. Configural and metric models fit adequately (RMSEA ≤ 0.05, ΔCFI < 0.02), but scalar invariance was not supported. Partial invariance was tested by freeing the intercepts of items 19, 14 and 11, but this did not result in scalar invariance (ΔCFI > 0.02). Therefore, only configural and metric invariance were supported for competition type.

Convergent validity was assessed through correlations with conceptually related constructs. Significant positive correlations were found between refocusing and flow disposition (r = 0.458, p < 0.001), as well as between non-judgmental attitude and mindful traits in daily life (r = 0.207, p = 0.002). Expected negative correlations were observed between non-judgmental attitude and worry (r = -0.265, p = 0.011), refocusing and concentration disruption (r = -0.250, p = 0.016) and both non-judgmental attitude and refocusing with rumination (r = -0.236, p < 0.001 and r = -0.228, p = 0.001, respectively). However, unexpected results included a positive correlation between awareness and somatic anxiety (r = 0.306, p = 0.003).

Overall, the findings suggest that the MIS-D is a reliable and valid tool for assessing mindfulness in athletes, with strong internal consistency, moderate-to-good test-retest reliability and largely confirmed factorial structure. While the instrument shows measurement invariance across gender, further refinement is needed to ensure full invariance across competition levels. Given the increasing relevance of mindfulness-based interventions in sports, the MIS-D could serve as a valuable tool for both research and practical applications in performance enhancement and well-being and thus fills the gap of a context-specific tool in sport.

4.2 Psychological and Physiological Health Outcomes of Virtual Reality-Based Mindfulness Interventions: A Systematic Review and Evidence Mapping of Empirical Studies

Mindfulness has been widely recognized for its benefits beyond performance enhancement (Birrer et al., 2012; Bühlmayer et al., 2017; Noetel, Ciarrochi, van Zanden, & Lonsdale, 2019), particularly in promoting overall well-being and health. In

the context of sports, in addition to its role in optimizing performance, its influence on psychological and physiological health is also of significant importance (Josefsson et al., 2017; Myall et al., 2023). With a focus on integrating innovative technologies such as immersive virtual reality, the second project in this dissertation will examine the current state of research on VR-based mindfulness interventions and their effects on psychological and physiological health (Wieczorek et al., 2024). Since empirical findings in this emerging and highly specific field have rarely been applied to sports, the literature review was conducted using studies with non-athlete populations as a starting point for further potential derivation for sport.

As outlined above, different VR technologies vary in immersion, interaction and imagination, all of which can significantly shape user experience and outcomes. Given this, we have focused exclusively on HMD-based scenarios in our literature research, examining the psychological and physiological health effects of VR-based mindfulness interventions. This systematic review follows the PRISMA guidelines, screening 949 studies before selecting 22 empirical studies for final analysis. In order to integrate critical evaluation of the studies, the hermeneutic approach by Boell and Cecez-Kecmanovic (2014) was applied in combination with a evidence mapping strategy to classify and analyze research finding across distributional, methodological and content-related perspectives.

In terms of psychological outcomes, anxiety was the most frequently studied variable, appearing in 26% of selected studies. Mindfulness was examined in 17%, while emotions such as anger, happiness and vigor were also analyzed in 17%. Other notable psychological outcomes included depression, post-traumatic stress disorder (PTSD) (9%), stress (6%), mood and arousal (6%) and meditation experiences (6%). Regarding physiological health outcomes, the review identified various neurobiological markers (29%), including brain wave activity and pain-related neuromatrix activation. Heart rate and heart rate variability (HRV) were measured in 29% of studies, with significant improvements reported. Pain reduction was a key outcome in 19% of studies, while blood pressure, saliva samples (cortisol levels) and galvanic skin resistance accounted for 9%, 9% and 5% of physiological studies, respectively.

The distributional mapping examined geographical and temporal trends in VR mindfulness research. Between 2016 and 2022, research in this field has grown significantly, with the majority of studies coming from North America (45%) and South Korea (27%). The remaining 28% were distributed across Europe and other regions,

indicating that VR-based mindfulness research remains concentrated in specific areas. The selected papers were published across various channels with 64% appearing in journals, 27% in conferences and 9% in symposia. Frontiers in Psychology had the highest representation with three papers, while others were published in journals such as Pain Medicine, Virtual Reality and Digital Health.

The methodological mapping revealed differences in the study designs, with a significant proportion of the studies being pre-experimental (50%) and lacking control groups. A further 27% were quasi-experimental, while only 23% were true experimental studies (RCTs). The included studies show significant variability in the application and clarity of inclusion and exclusion criteria, while others provide a well-defined set of criteria, reflecting inconsistencies in study sampling and demographic reporting. Furthermore, many studies had small sample sizes, making it difficult to generalize the results and few included long-term follow-up measures. Another point to consider is the use of subjective versus objective measures, as 64% of studies relied on self-reported data such as anxiety and mindfulness scores, while only one study used objective physiological data exclusively.

The content mapping identified anxiety (18% large effect sizes), mindfulness (14% medium to large effect sizes) and various emotions (18% medium to large effect sizes) as the most studied psychological outcomes, with positive effects observed in clinical and non-clinical populations. Physiological outcomes focused on neurobiological markers (9% large effect sizes) and heart rate/HRV (5% large effects in heart rate/ 5% medium to large effects in HRV), with improvements seen in both healthy and pre-diseased individuals. The evidence for the internal validity of the positive effects of VR-based mindfulness interventions includes mostly statistically significant results, but lacks effect sizes to support the findings (n = 11) and four studies only provide descriptive results without engaging in statistical analysis. Furthermore, the content mapping of VR mindfulness interventions also identified attention regulation as the primary mindfulness mechanism (Hölzel et al., 2011) in 50% of studies, followed by body awareness (29%) and emotion regulation (18%). Most interventions were single-session experiences (73%), typically lasting 5 to 10 minutes, limiting the ability to assess long-term effects. Multi-session interventions accounted for only 27%, suggesting that more research is needed on sustained VR mindfulness training. Many studies utilized nature-based virtual environments, reinforcing the potential of VR to simulate calming surroundings that enhance mindfulness practices.

This systematic review provides promising initial evidence that VR-based mindfulness interventions can improve psychological and physiological health outcomes. However, due to methodological inconsistencies, further research is required to validate these findings. Future studies should focus on conducting more randomized controlled trials, increasing sample sizes, incorporating objective physiological data and examining long-term effects to fully understand the potential of VR mindfulness interventions in enhancing health and well-being.

4.3 Physiological and Psychological Health Effects of a Mobile VR-Based Mindfulness Breathing Meditation with Integrated Biofeedback: A Replication Study

Building on the insights from the previous systematic review, which highlighted the potentials of VR-based mindfulness interventions on several health parameters, this study aims to empirically investigate these effects within the framework of a replication study, ensuring the robustness and reliability of previous findings. In this case, the VR intervention is further enhanced by an integrated biofeedback component that specifically focuses on deep diaphragmatic breathing, allowing participants to gain real-time physiological feedback.

This study replicates and extends the work of Rockstroh et al. (2021) on physiological and psychological effects of a VR-based mindfulness breathing meditation with integrated biofeedback. The primary objective was to examine the effects of diaphragmatic breathing training in a fully immersive virtual reality (VR) environment using real-time biofeedback (Wieczorek et al., 2025). The study followed a within-subject longitudinal design, where 45 participants (15 women, M_{age} = 22.9, SD_{age} = 2.3) completed six consecutive days of HMD-based training. The intervention was conducted in a controlled laboratory setting and included both subjective and objective measurements of health-related parameters. The study design also incorporated two follow-up measurements to assess potential medium-term effects, distinguishing it from the original study.

The study demonstrated significant improvements in diaphragmatic breathing (H_{1a}), with the relative share of diaphragmatic breathing movements (inhalation + exhalation) increasing from 76.7% to 81.2% over six sessions, primarily due to prolonged exhalation (ηp^2 = 0.216, p < 0.001). The mean exhalation duration also increased

significantly over the training period (ηp^2 = 0.108, p < 0.001). This was accompanied by a decrease in mean respiratory rate (H_{1b}) with participants consistently breathing more slowly post-session (ηp^2 = 0.201, p < 0.001). Additionally, a reduction in heart rate (H_{1c}) was observed, with post-session values significantly lower than pre-session (ηp^2 = 0.380, p < 0.001). Subjective measures also reflected these improvements. Participants reported a significant increase in the perceived ease of diaphragmatic breathing (H_{1d}) stabilizing after session four (ηp^2 = 0.112, p < 0.001), along with a sustained enhancement in breath awareness (H_{1e}), which remained elevated even four weeks post-intervention (ηp^2 = 0.413, p < 0.001). Beyond those breathing (related) parameters, momentary relaxation (H_{2a}) significantly improved, as indicated by increased post-session HRV values (SDNN: ηp^2 = 1.000, p < 0.001), confirming greater parasympathetic activation. However, perceived stress levels (H_{2b}) did not show significant reductions (ηp^2 = 0.041, p = 0.158), likely due to the already low baseline stress of participants. Nevertheless, personal burnout symptoms (H_{2c}) significantly decreased (ηp^2 = 0.145, p < 0.001), with effects lasting up to one-week post-training. Work-related burnout symptoms remained unchanged (η_p^2 = 0.006, p = 0.900). Finally, relaxation-related self-efficacy (H_{2d}) showed a notable increase (ηp^2 = 0.213, p < 0.001), persisting over the follow-up period, suggesting long-term benefits.

This replication study largely confirms and extends the findings of Rockstroh et al. (2021), demonstrating that VR-based mindfulness breathing meditation with integrated biofeedback effectively enhances several physiological and psychological health parameters. By incorporating additional measurement time points and objective pre-post data collection, this study also addresses key limitations, providing a more comprehensive assessment of short- and mid-term effects. Furthermore, the user experience analysis reinforces the intervention's feasibility, showing high user satisfaction, minimal simulator sickness and strong perceived usefulness for relaxation and diaphragmatic breathing.

5 Discussion

This dissertation aims to advance the understanding of mindfulness in the context of health and sport by consolidating existing knowledge, generating new empirical insights and contributing to both research and applied practice. Health and sport were seen as both application areas and outcome variables. A further focus was put on the use of virtual reality, particularly immersive virtual reality via head-mounted displays

(HMDs), as an innovative medium for the delivery of mindfulness-based interventions. To contextualize the individual studies, the corresponding project overview is presented once more below. The subsequent discussion critically examines and integrates the findings of the included projects.

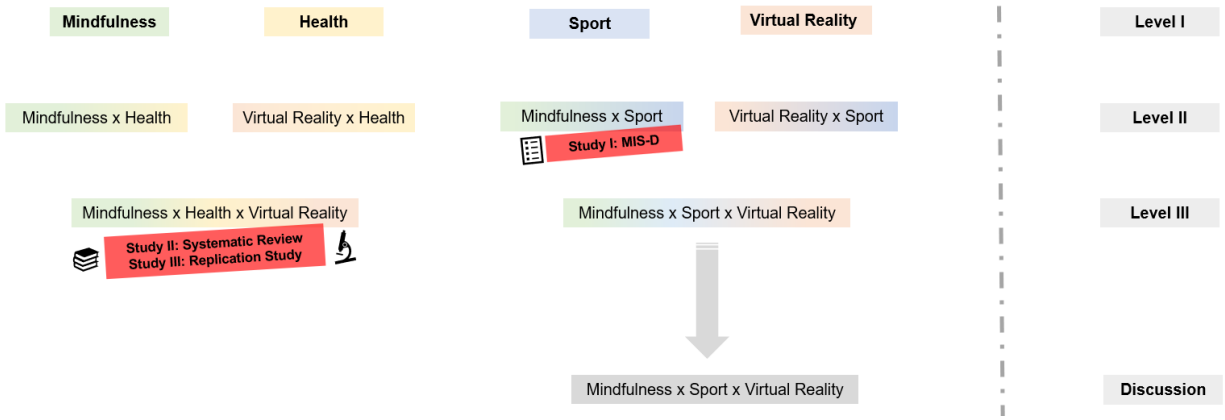


Figure 15: Positioning of the projects within the constructs and their interrelations

Building on the insights gained in the health context in the second and third project (Level III), particular attention is given to exploring the potential of VR-based mindfulness interventions for application in sport. This includes a focused discussion of the interrelation between *Mindfulness x Sport x Virtual Reality* as can be seen in Figure 15, with an emphasis on identifying transferable implications and opportunities for future research and practice in sport (section 5.2).

5.1 Summary & Discussion of the Findings

Addressing an identified research gap at the intersection of *Mindfulness x Sport* - specifically, the absence of a German-language tool to measure dispositional mindfulness in athletes - has already produced findings with direct relevance to applied sport settings, as demonstrated by the first project (Wieczorek et al., 2022). It successfully demonstrated the psychometric properties of the German-language version of the Mindfulness Inventory for Sport (MIS-D). The ability to reliably and validly measure mindfulness in athletes provides valuable insight into how they regulate their thoughts, emotions and attention. This context-specific perspective not only enhances

the scientific understanding of psychological regulation in sport but also provides practical implications for improving athletes' mental health and performance.

In order to thoroughly assess the relevance of the MIS-D within the domain of sport, it is crucial to examine whether the instrument not only meets psychometric standards, but also reflects a theoretically sound and sport-contextualized understanding of mindfulness. The MIS-D should not be viewed solely as a psychometric measurement tool, but rather as a construct model that is firmly embedded in a theoretically grounded understanding of mindfulness in sport. Its development is explicitly informed by the MAC approach developed by Gardner and Moore (2004) one of the most prominent mindfulness-based frameworks in sport as already outlined in section 2.2.2. The MAC model posits that performance dysfunction often arises from maladaptive internal control strategies, attentional lapses and static behavior patterns. In contrast, the MAC approach fosters a mindful orientation characterized by present-moment awareness, non-judgmental acceptance of internal experiences and behavioral commitment to goal-relevant actions. These three core components (1) awareness of current thoughts, emotions and bodily sensations, (2) acceptance/non-judgmental attitude toward current thoughts, emotions and bodily sensation and (3) commitment toward goal-relevant actions by maintaining goal-relevant actions for a greater behavioral flexibility are not only central to this intervention program but also theoretically underpin the structure of the MIS-D (Wieczorek et al., 2022). As such, the MIS-D operationalizes a concept of dispositional mindfulness that is both sport-specific and theory-driven, aligning directly with the mechanisms and outcomes targeted by the MAC approach. This theoretical grounding supports the interpretation of the MIS-D as a construct-valid model that captures essential psychological processes relevant to athletic functioning.

Drawing on the conceptual distinction between *dispositional mindfulness* and *mindfulness practice* proposed by Birrer et al. (2012), *dispositional mindfulness* is understood here in line with Bergomi et al. (2013) and their measurement instrument, the Comprehensive Inventory of Mindfulness Experiences (CHIME), which encompasses eight distinct subscales: (1) awareness of internal experiences, (2) awareness of external experiences, (3) acting with awareness, (4) accepting with non-judgmental attitude, (5) nonreactive decentering, (6) openness to experience, (7) awareness of thought's relativity and (8) insightful understanding. At this point, it becomes already clear that the MIS-D and the CHIME represent two theoretically related but structurally different approaches to the operationalization of mindfulness in

sport and in a general context. For instance, both models share an emphasis on awareness and acceptance aspects. However, the MIS-D differentiates itself through its goal-directed framing, aligning mindfulness processes explicitly with athletic performance outcome such as returning focus after distractions. In contrast, the CHIME adopts a broader conceptualization of mindfulness as a life disposition, without the embedded performance orientation found in the MIS-D, but this nuanced structure illustrates how further differentiation of mindfulness facets might inspire future refinements to enhance the conceptual depth and sensitivity of sport-specific assessments. Given the current state of research, the MIS-D represents a significant step toward addressing the gap identified by Birrer et al. (2012) who highlight the need for a context-specific instrument and emphasize the relevance of dispositional mindfulness in sport. Building on this foundation, future research could also investigate the development of a short form of the MIS-D like Noetel, Ciarrochi, Sahdra, and Lonsdale (2019) did using genetic algorithms to shorten the original MIS. However, careful consideration should be given to whether the theoretical integrity of the instrument can be maintained. In addition, this line of inquiry raises a further research question regarding the potential for a state-oriented version of the MIS-D that could capture fluctuations in mindfulness in response to specific sport situations. As an example, this approach was successfully applied to the Toronto Mindfulness Scale (TMS) using Generalizability Theory (GT), a robust psychometric method for distinguishing state and trait variance components. GT extends classical test theory by estimating multiple sources of measurement error, such as personal, methodological and situational factors and their interactions, thereby enhancing the precision and validity of assessments across varying contexts (Medvedev et al., 2017).

The work carried out within the MIS-D project, along with the newly identified research approaches regarding a short form or a state version of the MIS-D, clearly falls within the domain of sport science, particularly sport psychology. Sport psychology is primarily concerned with understanding human experiences and behaviors in sport-related settings. This includes describing, explaining and predicting both sporting and non-sporting behaviors, as well as exploring how targeted interventions can be designed to foster healthy and high-performance sport participation (Schüler et al., 2020). The American Psychological Association (2008) defines sports psychology as “(…) a proficiency that uses psychological knowledge and skills to address optimal performance and well-being of athletes, developmental and social aspects of sports

participation, and systemic issues associated with sports settings and organizations. (…) Sport Psychology interventions are designed to assist athletes and other sports participants (e.g., coaches, administrators, parents) from a wide array of settings, levels of competition and ages, ranging from recreational youth participants to professional and Olympic athletes to master's level performers." (American Psychological Association, 2008). Furthermore, the American Psychological Association (2008) also highlights key skills and procedures in sports psychology to address challenges faced by athletes and sports participants. These include cognitive and behavioral skills training for performance enhancement, counseling for issues like motivation, mental health or consultation for team building, sports organization development and coach education on motivation, leadership and psychological well-being. This marks a broad spectrum which sport psychology covers within the framework of both a basic and application-orientated scientific discipline - the aim should therefore be to apply the knowledge gained in practice. This understanding is based on the definition by Nitsch (1978) stating that "sport psychology is an empirical science that investigates conditions, processes and consequences of the psychological regulation of sporting activities and derives ways of influencing them." The European Federation of Sport Psychology (FEPSAC, 1995) ties in with that understanding and states that "sport psychology is concerned with the psychological foundations, processes and consequences of the psychological regulation of sport-related activities of one or several persons acting as the subject(s) of the activity. The focus may be on behaviour or on different psychological dimensions of human behaviour, i.e., affective, cognitive, motivational or sensori-motor dimensions. The physical activity can take place in competitive, educational, recreational, preventative and rehabilitation settings and includes health-related exercise. Subjects are all persons involved in the different sport and exercise settings, e.g., athletes, coaches, officials, teachers, physiotherapists, parents, spectators etc." According to the FEPSAC (1995), sport psychology as a scientific discipline as well as professional field, is shaped by three interconnected areas: (1) sport practice, (2) psychology and (3) other sport sciences. It addresses challenges from exercise and sport practice, applying psychological principles to enhance understanding and support. As a subdiscipline of psychology, it draws from various psychological fields while also contributing to a broader understanding of psychology in general. Additionally, sport psychology is part of other sport sciences, integrating empirical research and

interdisciplinary approaches to address complex questions in the field of sport and physical activity. This interdisciplinary nature of sport psychology is essential for advancing knowledge in the field. This dissertation highlights that by focusing on two projects that, while not situated within a direct sport context, generate insights outside of sport that are highly relevant to athletic performance and well-being. These projects emphasize the close connection between sport psychology and core psychological disciplines such as cognitive, clinical or organizational psychology. Many constructs central to sport, such as mindfulness, cognitive functioning or emotional regulation, are not exclusive to athletes but are widely examined across broader psychological research. By incorporating findings from these non-sport-specific studies and combining them with emerging technologies, this dissertation contributes to a deeper understanding of psychological and physiological health processes that are transferable to sport settings.

Methodologically, the second project of this dissertation was conducted in the form of a systematic review complemented by an integrated evidence mapping approach taking up on distributional, methodological as well as content aspects (Wieczorek et al., 2024). The research question addresses the efficacy of VR-based mindfulness interventions on psychological and physiological health outcomes. Through a structured synthesis using PRISMA guidelines (Liberati et al., 2009) and categorization of the existing literature by using Boell and Cecez-Kecmanovic's hermeneutic approach (2014), the study aimed to provide a comprehensive overview of current evidence, to identify research gaps and to outline implications for future investigation. Although not situated within a direct sport context, the findings offer valuable insights into the application of immersive technologies for enhancing health and regulatory processes mechanisms that are highly relevant to well-being and performance in sport settings. These potential applications within sport are discussed in greater detail in section 5.2.

The systematic review identified numerous physiological and psychological health effects associated with VR-based mindfulness interventions, such as anxiety, mindfulness, various emotions, neurobiological markers and heart rate/heart rate variability. Distributional mapping highlighted global regions, such as North America and South Korea, that contributed disproportionately to the evidence base, largely influenced by the location of the primary author. Additionally, the distribution of publication channels and the development over time were also analyzed.

Methodological mapping examined, among other things, the research design, sampling methods and study designs and highlighted various strengths and limitations of the literature included. The final content mapping further revealed dominant mindfulness mechanisms, like attention regulation and body awareness, within the VR scenarios and established an intensity profile of the implemented interventions.

In the following discussion, the theoretical foundations of this emerging field are critically examined in order to identify key issues and methodological challenges and thus provide an orientation for future research directions. The conducted systematic review implicitly assumes VR as a neutral delivery platform that adheres to the classical elements of mindfulness following the operational definition of Bishop et al. (2004), even within the virtual environment. However, it does not address whether VR might elicit a novel subjective experience or the extent to which technological mediation contributes to this experience. It remains an open question whether VR-based mindfulness may constitute a distinct psychological construct in its own right. To date, there has been little theoretical or empirical investigation into whether VR truly engages the same traditional characteristics of mindfulness. This gap highlights the need for further critical examination in future research. In response to this criticism, it is worth noting that in this second project, where an independent analysis was conducted as part of the content mapping, it was possible to demonstrate, at least to some extent, that the various VR-based mindfulness interventions included in the reviewed studies addressed central mindfulness mechanisms (Hölzel et al., 2011; Wieczorek et al., 2024). Although this insight was not derived from primary data collected within the individual studies themselves, it highlights the need for further investigation into this issue. This could, for example, inform future methodological approaches by encouraging a broader use of qualitative methods alongside quantitative ones, similar to the approach taken by Seabrook et al. (2020), whose study illustrates the value of exploring user experience in depth.

In a mixed-method study design Seabrook et al. (2020) aimed to explore how VR can support mindfulness practice and to understand user experience issues that may affect the acceptability and efficacy of VR mindfulness for users in the general population. The participants' qualitative feedback, guided by interview questions aimed at eliciting their views on the VR experience including positive and negative features of the app as well as aspects of the VR and virtual environment that supported or hindered mindfulness practice. The scenario was presented through an Oculus Go headset.

This resulted in nine thematic categories capturing the overall experience of mindfulness in VR and addressed key factors such as presence, interruptions in presence, engagement, the scope for mind-wandering, guidance and anchoring of attention, personalization and perceptions of video fidelity and headset comfort. Taken together, Seabrook et al. (2020) suggest that several design features are key to transporting mindfulness effectively into VR scenarios. These include cultivating a strong sense of presence, offering a range of attentional anchors to accommodate user preferences, supporting personalization and agency and balancing guided instruction with autonomous exploration. Additionally, maintaining a calming yet stimulating environment that avoids overstimulation is essential (Seabrook et al., 2020). These considerations, aligned with concepts from Attention Restoration Theory (Kaplan, 2001), suggest that well-designed VR environments can not only facilitate mindfulness but also promote positive emotional states and sustained engagement. ART complements mindfulness by suggesting that attentional fatigue has a negative impact on mental health and that interaction between the person and the environment helps to restore attentional resources. Restorative environments, as defined by ART, are characterized by: (1) a sense of being away, (2) effortless attention through fascination, (3) coherence and scope that support sustained engagement and (4) alignment with individual inclinations. These features were reflected in the participants' feedback, suggesting that person-VE interactions may foster a restorative experience and enhance mindfulness practice (Seabrook et al., 2020).

This study serves as an illustrative example of how qualitative analyses can be integrated into research to examine the feasibility of implementing mindfulness scenarios within immersive VR. Although the study did not explicitly address the question whether VR-based mindfulness interventions may elicit novel (mindful) experiences, it did explore how specific aspects can support the translation of traditional respectively classical mindfulness elements into VR, conceptualizing the medium as a neutral platform for such practices. Relevant aspects such as attentional anchors, mediated by visual or auditory stimuli such as forest imagery and ambient sounds, were also present in the VR scenarios of the studies included in the systematic review. Furthermore, important environmental factors, particularly natural settings, were comprehensively addressed in the discussion section of the systematic review (Wieczorek et al., 2024).

In addition to the preceding theoretical and methodological considerations, the following part of the discussion revisits the theoretical grounding of health in the context of VR, specifically mindfulness-based immersive VR, by drawing again on the Salutogenesis Model (Antonovsky, 1979), as introduced in the systematic review. The aim is to reflect on how this theoretical framework contributes to understanding the implementation of mindfulness scenarios in immersive environments, while also critically examining its potential limitations within this specific context.

The challenge of theoretically embedding VR-based mindfulness interventions within a health context was addressed in the systematic review. As a result of this specific theoretical consideration, the Salutogenesis Model by Antonovsky (1979) was adopted, framing those kind of VR interventions as generalized resistance resources (GRRs) that may contribute to a shift along the health–disease continuum (HEDE continuum) toward improved health. This classification is supported by the fact that GRRs are intentionally broad and are of different nature like social support, material resources, knowledge or identity (Antonovsky, 1979). While this inclusivity allows flexibility, it also reduces specificity when trying to map targeted VR features like immersion, interaction and presence to concrete health outcomes. Mindfulness in VR could arguably be a GRR, but whether it aligns with Antonovsky's intended meaning is debatable as GRRs refer to "phenomena that provide one with sets of life experiences characterized by consistency, participation in shaping outcomes and an underload-overload balance" (Antonovsky, 1988, p. 19). In particular, the aspect of consistency is not really present in one-time and short-term VR mindfulness interventions.

However, it is conceivable that continuous or repeated mindfulness training in VR settings could gradually develop into a solid form of GRR. With regular practice, VR-based mindfulness could promote a stable and predictable routine or consistency. In this way, the intervention would go beyond a short-term coping tool and instead become a deeper resource embedded in the individual's life experience. This would bring the practice closer to Antonovsky's (1988) concept of GRRs, particularly if the intervention is tailored to the individual and integrated into daily routines. Thus, while a single session may fall short of qualifying as a GRR, a sustained and meaningful application of VR mindfulness has the potential to meet these criteria over time. So, there remains a risk of overgeneralization, where one-time or short-term VR-based intervention with positive health outcomes might be clearly labeled as GRR without rigorous theoretical justification. Furthermore, the model does not account for the

unique capabilities of VR such as sensory immersion or simulation of natural environments, creating a conceptual gap between VR-specific mechanisms and salutogenetic constructs. Bridging this gap may require thoughtful adjustments or extensions to the model to adequately capture the emerging potentials of VR-based interventions.

Similar theoretical considerations can be applied to the third project presented in this dissertation. This project focused on a replication study investigating the psychological and physiological health effects of a mobile VR-based mindfulness breathing meditation with integrated biofeedback using a within-subject design completing six consecutive days of supervised self-guided VR-based training (Wieczorek et al., 2025). Numerous positive effects were identified in the course of the study concerning diaphragmatic breathing, breathing awareness, heart and respiratory rates, momentary relaxation, burnout symptoms and relaxation-related self-efficacy, with several benefits persisting not only short- but also medium-term (1-week/1-month post-intervention). User satisfaction ratings further confirmed the feasibility of the VR intervention.

At this point, we would like to briefly outline the possibilities for addressing the aforementioned theoretical gap in the Salutogenesis Model (SM) (Antonovsky, 1979) regarding VR-based mindfulness interventions. This approach should, on the one hand, more fully incorporate the technical and experiential characteristics of immersive VR and on the other hand, focus on developing empirical criteria to determine under what conditions a VR-based mindfulness practice may evolve into a stable GRR. Building on this, the concept of sense of coherence (SOC) offers a theoretically grounded framework for evaluating the efficacy and long-term impact of VR-based mindfulness interventions within the SM. The SOC, encompassing the dimensions of comprehensibility, manageability and meaningfulness, is a central construct in understanding how individuals interpret and respond to stressors. It reflects a global orientation that enables individuals to view life as structured, predictable and meaningful, thereby guiding them to act with confidence and inner trust when mobilizing internal and external resources (Mittelmark, 2022). Crucially, GRRs are foundational for the development of a strong SOC and act as cornerstones for cultivating a coherent orientation toward life. From this perspective, measuring SOC in the context of VR-based mindfulness interventions in future research serves providing empirical evidence of their capacity to strengthen SOC in a durable and context-

independent manner. To align more closely with Antonovsky's (1988) concept of GRRs as enduring, context-transcending resources that contribute to a stable sense of coherence over time, longitudinal studies would be particularly valuable. They allow for the examination of whether and how the salutogenetic effects of VR-based mindfulness interventions persist, accumulate or evolve across different life situations, thereby providing empirical insight into the durability and generalizability of such interventions as genuine resistance resources. Consequently, the integration of SOC measurement into future research designs holds considerable potential for the theoretical and empirical foundation of VR-based mindfulness interventions within the SM. Nevertheless, the current evidence base - including the results presented in this dissertation - does not yet provide a sufficient basis to clearly classify such interventions GRRs, underlining the need for further longitudinal and mechanism-oriented research.

The subsequent section draws on the findings, with particular emphasis on the dissertation projects 2 and 3, to delineate potential implications and domains of application within the field of sport. In addition, the intersection *between Mindfulness* × *Sport* × *Virtual Reality*, which was previously addressed in the theoretical background (Level III; Section 2.3.2) mainly with regard to its research gaps, is revisited here and discussed in more detail.

5.2 A Potential Derivation for Possible Implications in Sport

The following section outlines the potential contribution of VR-based mindfulness scenarios to the sports domain, especially based on the findings of the systematic review and the replication study, both of which were conducted as part of this dissertation. In doing so, this part of the dissertation follows up at Level III of the framework, addressing the intersection of *Mindfulness x VR x Sport* from a discussion-oriented perspective.

The primary research focus is to determine the extent to which VR-based mindfulness interventions can sustain or enhance athletes' psychological and physiological health and well-being. Due to the physiological and psychological challenges that athlete face throughout their career, health is an important asset and a prerequisite for high performance. As Gojanovic and Tercier (2020, p. 2) state that "putting complete health first is the best guarantee to mitigate the occurrence of avoidable injuries and health

issues, and to achieve sustainable performance", especially in young athletes. Consequently, in the context of sport, health and performance are inherently interconnected.

The field of sports has already undertaken an evaluation of the applicability of virtual reality technologies as shortly outlined in section 2.2.4. However, it is important to acknowledge that the concept of virtual reality extends beyond the specific scope of this dissertation, which is primarily centered on immersive VR systems, particularly head-mounted displays (HMD). A SWOT analysis conducted by Düking et al. (2018) highlight different strengths, weaknesses, opportunities and threats along with VR in sport. Strengths of VR applications in the sports context in general lie for example in the individualization of training and flexible application in everyday settings, while weaknesses might appear in the sense of immersion as a key factor to optimizing training and learning. Opportunities include, just to name a few, preparation for competitions, management of psychological stress or improvement of rehabilitation and recovery. An exemplary threat lies within the transferability of skills, tactics, creative behavior and diagnostics procedures from the virtual reality to the real world (Düking et al., 2018). More specifically, Bird (2020) delves into a more precise examination, demonstrating the prospective utility of HMD within the domain of sports psychology. Therefore, he delineates the subsequent realms of application wherein practitioners can integrate HMD: 1) perceptual-cognitive skills training, 2) relaxation and 3) injury rehabilitation. The following section outlines how VR-based mindfulness interventions can be integrated into each of these three domains to support the maintenance, recovery and ultimately optimization of athlete health and performance.

Perceptual-cognitive skills enable athletes to recognize central environmental information, thereby facilitating the anticipation of others' actions and the careful selection and execution of optimal cause of action. The benefit of employing HMD for the enhancement of athletes' perceptual-cognitive skills lies in the capacity to perform a substantial volume repetition with reduced risk of injuries. This technology is particularly suitable for sports skills with reduced range of motion like hitting in baseball or goaltending in hockey (Miles et al., 2012). VR-based mindfulness interventions have exhibited potential for enhancing cognitive processes, as exemplified by Hawes and Arya (2021) within the scope of the systematic review. Additionally, Feinberg et al. (2022) demonstrate that mindfulness-based VR guided meditation has the capacity to cultivate cognitive processes such as attention and present-focused awareness, as

measured by the CAMS-R (Feldman et al., 2007). Encouragingly, positive impacts on cognitive states were also observed by Tarrant et al. (2018). While VR-based mindfulness interventions may not directly enhance perceptual-cognitive skills in a specific sporting context, such as those required for activities like hitting or goaltending, but they do serve to stimulate fundamental cognitive processes, particularly attention and present focus, which constitute essential prerequisites for the development of those specific skills. In addition to their direct relevance in a sporting situation, perceptual-cognitive skills trained through mindfulness interventions can also play a crucial role in health. For example, mindfulness is linked to improved cognitive flexibility, attention regulation and working memory. These cognitive benefits can help individuals reduce fatigue, enhance focus and better manage stress, all of which are crucial for health (Hölzel et al., 2010; Zeidan et al., 2010).

Directly related to stress, Bird (2020) highlights *relaxation* as another domain where HMD-based training can be applied in sports psychology. Relaxation addresses several stressors athletes are exposed to like high training loads, pressure to perform or interpersonal conflict with teammates, coaches officials and opponents. Bird (2020) emphasizes the technological attributes of HMD, that facilitate immersion in diverse environmental settings. Relaxation-related outcomes resulting from VR-based mindfulness interventions, both at psychological (e.g. PSS) and physiological levels (e.g. HR, HRV), were evident in numerous studies incorporated within the analysis of the systematic review (Feinberg et al., 2022; Frewen et al., 2020; Groninger et al., 2021; Kazzi et al., 2018; Kwon et al., 2020; Navarro-Haro et al., 2019; Semertzidis et al., 2019). This clearly illustrates the potential for the sports context to assist athletes in more effectively mitigating stress and fortifying their psychological resilience. In the third project, the replication study training (Wieczorek et al., 2025), the combination of VR-based mindfulness interventions with breathing-based biofeedback showed no significant effect on subjectively measured stress levels (PSS-10), likely due to the already low baseline stress levels of the participants. However, HRV parameters, such as SDNN, demonstrated positive developments over the course of VR training, indicating its potential for promoting relaxation and enhancing physiological recovery. As HRV serves as an indicator of stress regulation by reflecting the balance between sympathetic and parasympathetic nervous system activity (Kim et al., 2018), these findings suggest that VR-based mindfulness training may positively influence autonomic regulation. A balanced autonomic nervous system is associated with better

recovery, reduced fatigue and also an improved sleep (Tekin et al., 2025). Furthermore, optimal autonomic regulation can reduce the risk of stress-related illnesses, such as cardiovascular problems and chronic stress, ultimately fostering better long-term physical and emotional health in athletes (Franklin et al., 2021).

Addressing the third domain *injury rehabilitation*, VR-based mindfulness interventions might not only be applied after an injury but also to prevent from injury. This is based on the assumption, that mindfulness can help athletes become more aware of their bodies and recognize potential signs of overload or injury early on respectively improve attention control and reduce sport anxiety (Naderi et al., 2020). The aspect of attention control underlines the interconnectedness of the areas of application of VR-based mindfulness interventions. On one hand, attention, when intertwined with perceptual-cognitive skills, empowers athletes to enhance their anticipatory abilities and make precise and goal-orientated decisions. On the other hand, attention control also assumes significance in the realm of injury prevention and has a higher health aspect in this context than in the perceptual-cognitive context. However, in the event of an athlete sustaining an injury, it typically results in an imbalance and discomfort in their life and physical inability prevents them from achieving in their sports (Reese et al., 2012). Current evidence (Arvinen-Barrow et al., 2014; Heaney, 2006; Ruddock-Hudson et al., 2014; Tatsumi & Takenouchi, 2014; Tracey, 2003; Vergeer, 2006) emphasizes the importance of psychological interventions in the rehabilitation process. One of the reasons for this is, that athletes' beliefs, emotions and cognitive processes exert a considerable influence on their physiological responses following an injury. So, there is a dynamic interplay between body and mind and this interplay can serve two main purposes. The first is to bolster the rehabilitation process for injured athletes, while the second entails enhancing the self-assurance of injured athletes in reducing the likelihood of future injuries (Joyce & Lewindon, 2016). Regarding the role of mindfulness meditation in current research, Arvinen-Barrow and Walker (2013) highlight that within the context of sports injury rehabilitation, mindfulness can serve as a valuable tool in facilitating a harmonious state of both body and mind. Furthermore, it can empower individuals to develop heightened awareness and greater acceptance of their circumstances as injured athletes. Moreover, it can help to reduce physical pain and anxiety (Mohammed et al., 2018). The extent to which VR-based mindfulness interventions can support the healing process of athletes should be investigated in future studies, particularly given their potential to offer more accessible, engaging and

standardized training experiences compared to traditional mindfulness programs delivered by therapists or in structured settings. Therefore, such interventions may serve as an effective tool for enhancing treatment adherence and increasing motivation to engage in mindfulness practice (Navarro-Haro et al., 2017; Zhang et al., 2021). The fact that VR-based mindfulness interventions can help with pain is shown, for example, by Groninger et al. (2021), Hargett et al. (2022), Min et al. (2020), Seol et al. (2017) or Wren et al. (2021). Pain in athletes has traditionally been associated with tissue damage. This one-directional perspective on pain has transitioned to a multidimensional one, in which various factors including tissue overload, nociceptive gain, cognitive, emotional, behavioral, lifestyle and many others, interact in complex ways. These interactions determine an individual's susceptibility to experiencing pain to varying degrees. Consequently, pain management increasingly takes into account psychosocial factors such as emotional stress, catastrophic thinking and pain-related fear (Alaiti & Reis, 2022; Anderson et al., 2021). Traditional mindfulness interventions are already showing promising results in reducing pain in athletes (Baghaei et al., 2021; Mohammed et al., 2018), which need to be translated into digital or virtual space. The role of anxiety in sport injury prevention, occurrence, rehabilitation and the return to sport process has already been briefly introduced. Nevertheless, anxiety can take many different forms in sports. Typically, anxiety is defined as an “an unpleasant psychological state in reaction to perceived stress concerning the performance of a task under pressure” (Cheng et al., 2009) and is a common emotional state encountered by athletes across all levels of performance. Generally, anxiety comprises cognitive elements, such as worrisome thoughts and apprehensions, as well as somatic components, including the level of physical activation. In terms of context, sport-related anxiety can be defined as a response that may manifest as a trait or state-like response to a demanding sport-related situation, which the individual subjectively interprets as potentially stressful, leading to a spectrum of cognitive assessments, behavioral reactions and/or physiological arousal (Ford et al., 2017). Given that anxiety constitutes the most extensively examined parameter within the conducted systematic review (Wieczorek et al., 2024), the presence of substantiated evidence affirming the favorable health outcomes associated with VR-based mindfulness applications necessitates an expanded integration of such interventions within the sports sector.

Besides anxiety, other emotions or emotional states and their regulation is important in order to better cope with a number of demanding challenges that occur in the career

of an athlete (Birrer et al., 2012). Emotion regulation should be regarded as the capacity to effectively manage and respond adaptively to negative emotions, rather than as a process aimed at controlling, inhibiting or entirely eliminating distressing emotions (Gratz & Roemer, 2004). In line with this view, adaptive emotion regulation was conceptualized as a multidimensional construct that encompasses the following: "(a) awareness, understanding and acceptance of emotions; (b) ability to engage in goal-directed behaviors and inhibit impulsive behaviors, when experiencing negative emotions; (c) flexible use of situationally-appropriate strategies to modulate the intensity and/or duration of emotional responses, rather than to eliminate emotions entirely and (d) willingness to experience negative emotions as part of pursuing meaningful activities in life" (Gratz & Tull, 2010, p. 111). The conceptualization of emotion regulation overlaps with facets of the mindfulness construct as both underline the acceptance of emotions and a frequently used mindfulness practice includes non-reactivity to inner experiences (Baer et al., 2006; Fink & Ruiz, 2021; Roemer et al., 2015). In summary, mindfulness in sport can help to change the way athletes deal with emotions and provide them with more effective strategies for emotion regulation, which can improve mental strength, overall well-being as well as performance. Numerous positive effects of VR-based mindfulness exercise in the area of emotions were demonstrated by the conducted systematic review (Faraj et al., 2021; Nararro-Haro et al., 2016; Navarro-Haro et al., 2017; Navarro-Haro et al., 2019; Tarrant et al., 2022), which now needs to be translated into sports.

Sleep as an essential human behavior is crucial for health and well-being, especially for professional athletes in terms of psychological and physiological recovery as well as subsequent performance (Cook & Charest, 2023; Cunha et al., 2023). The importance and awareness of cognitive interventions, besides conventional approaches like sleep hygiene practices and circadian adjustments (Bonnar et al., 2018), begins to increase. A specific need for research has been recognized, especially concerning the detrimental impacts of cognitive arousal on the night before a competition and the positive effect mindfulness interventions might have to improve sleep (Cunha et al., 2023). As shown in a study in the systematic review by Semertzidis et al. (2019) pre-sleep arousal could be positively affected on a somatic and cognitive symptom level by the so-called Inter-Dream system. This neurofeedback system controls the visuals presented in an HMD in conjunction with an interactive bed featuring haptic feedback and sound. Despite its considerable complexity and limited

ecological practicality, this system showcases the potential of VR-based mindfulness interventions and highlights the direction for future research.

The potential benefits in sports that have been observed so far are primarily focused on the psychological health outcome measures that were also identified in the systematic review (Wieczorek et al., 2024). However, it's worth noting that physiological parameters can also mirror similar constructs such as heart rate variability (HRV), galvanic skin response (GSR) or saliva samples for stress or relaxation, as well as brain-based parameters related to cognitive aspects like attention control. Consequently, there exist numerous possibilities for incorporating VR-based mindfulness training within the sports context. In contrast to traditional mindfulness programs that often involve modularized multi-week programs and the presence of a psychological expert, virtual training presents several notable advantages. These advantages encompass accessibility, flexibility in terms of timing, personalization, motivation and the capability to monitor and analyze one's progress objectively.

This overview has outlined numerous potential implications of VR-based mindfulness interventions in sport. Initial progress in this line of research is evident in the studies performed by our research group (Wagner & Wieczorek, 2024) or by Simons et al. (2024) as shown in the excursus under section 2.3.2. Building on these findings, future research should further examine the specific affordances, opportunities and limitations of virtual reality as a medium for delivering mindfulness interventions in the athletic setting.

5.3 From Findings to Potentials: A Synthesis

In summary, it can be said that the three projects presented in this dissertation have provided valuable empirical findings in various areas of application and at the same time offered meaningful theoretical developments. The development of the MIS-D, a theoretically based instrument, represents a significant step towards a reliable and valid instrument for assessing mindfulness skills in athletes in a German-speaking context. The possibility of a short form and a state-oriented version open up further promising options for future adaptation and refinement. The second and third paper, more firmly situated within the domain of health psychology yet clearly intertwined with sport psychology as a sub-discipline of sport science, demonstrate the potential of an emerging medium, respectively immersive VR via head-mounted displays, to positively

influence psychological and physiological health outcomes when combined with mindfulness-based practices. While the SM (Antonovsky, 1979) provided a valuable theoretical perspective, its integration with novel dimensions of experience introduced by immersive VR also revealed certain conceptual limitations. A definitive classification of VR-based mindfulness interventions as GRRs is not clearly conclusive at this stage. Nonetheless, several indicators identified in the studies support the assumption that such interventions can be meaningfully located within the GRR framework.

Based on the systematic review and the replication study, potential implications of VR-based mindfulness interventions for the sport context were derived, revealing a wide range of application domains. They hold the potential to strengthen perceptual-cognitive skills (Bird, 2020), such as attentional control and present-moment focus, essential for anticipation and decision-making, while also promoting broader health benefits by enhancing cognitive flexibility, attention regulation and working memory, thereby reducing fatigue, improving focus and supporting stress management (Hölzel et al., 2010; Zeidan et al., 2010). Additional domains include relaxation and stress regulation, where physiological and psychological evidence indicates benefits for recovery, resilience and autonomic balance (Wieczorek et al., 2025; Wieczorek et al., 2024). Moreover, VR-based mindfulness hold promises for supporting injury rehabilitation and prevention by fostering body awareness, alleviating pain and anxiety as well as potentially enhancing adherence to rehabilitation protocols (Arvinen-Barrow & Walker, 2013; Mohammed et al., 2018; Wieczorek et al., 2024). Emerging evidence also shows positive effects on emotion regulation and sleep quality (Wieczorek et al., 2024), both critical for athletic health and sustainable performance.

Overall, VR-based mindfulness appears to complement traditional approaches by offering accessible, engaging and scalable interventions that address both health and performance demands in sport. While the current evidence base remains preliminary, it underscores the need for future research to further examine the specific opportunities and limitations of this technological approach in applied athletic contexts.

6 Bibliograph

Wieczorek, A., Renner, K.-H., Schrank, F., Seiler, K., & Wagner, M. (2022). Psychometric Properties of the Mindfulness Inventory for Sport (German Version). *Frontiers in Psychology*, *13*, Article 864208. https://doi.org/10.3389/fpsyg.2022.864208

Wieczorek, A., Schrank, F., Renner, K.-H., & Wagner, M. (2024). Psychological and physiological health outcomes of virtual reality-based mindfulness interventions: A systematic review and evidence mapping of empirical studies. *Digital Health*, *10*, 20552076241272604. https://doi.org/10.1177/20552076241272604

Wieczorek, A., Pintz, F., & Wagner, M. (2025). Physiological and psychological health effects of a mobile VR-based mindfulness breathing meditation with integrated biofeedback: a replication study. *Virtual Reality*, *29*(4). https://doi.org/10.1007/s10055-025-01235-9

7 Appendix

I) Wieczorek, A., Renner, K. H., Schrank, F., Seiler, K., & Wagner, M. (2022). Psychometric Properties of the Mindfulness Inventory for Sport (German Version). *Frontiers in Psychology*, *13,* Article 864208. https://doi.org/10.3389/fpsyg.2022.864208

II) Wieczorek, A., Schrank, F., Renner, K. H., & Wagner, M. (2024). Psychological and physiological health outcomes of virtual reality-based mindfulness interventions: A systematic review and evidence mapping of empirical studies. *Digital Health*, *10,* 20552076241272604. https://doi.org/10.1177/20552076241272604

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frontiers | Frontiers in Psychology

ORIGINAL RESEARCH
published: 24 May 2022
doi: 10.3389/fpsyg.2022.864208



Psychometric Properties of the Mindfulness Inventory for Sport (German Version)

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Specialty section:
This article was submitted to Movement Science and Sport Psychology, a section of the journal Frontiers in Psychology

Received: *28 January 2022*
Accepted: *27 April 2022*
Published: *24 May 2022*

Citation:
Wieczorek A, Renner K-H, Schrank F, Seiler K and Wagner M (2022) Psychometric Properties of the Mindfulness Inventory for Sport (German Version). Front. Psychol. 13:864208. doi: 10.3389/fpsyg.2022.864208

Mindfulness-based training programs are highly established in competitive and recreational sports. One of the best-known approaches is the Mindfulness-Acceptance-Commitment Approach (MAC) by Gardner and Moore), which integrates mindfulness aspects of awareness, non-judgmental attitude, and focus. Based on these aspects, Thienot and colleagues developed and validated an English language sport-specific questionnaire, the so-called Mindfulness Inventory for Sport (MIS), for the assessment of mindfulness skills in athletes. The aim of this study is to psychometrically test a German language version of the MIS (MIS-D). To assess the psychometric properties, the MIS-D was examined in an online survey with an integrated test–retest design ($n = 228$) for reliability (internal consistency; test–retest reliability), validity (factorial; convergent), and measurement invariance (gender; competition type). The present results support the psychometric quality of the German language version of the MIS. Necessary replications should among others focus on checking the measurement invariance for further relevant subgroups.

Keywords: mindfulness, awareness, acceptance, focus, sports performance

INTRODUCTION

Mindfulness has gained great interest in the scientific literature, which can be seen in an exponential growth trajectory of articles since the early 2000s (van Dam et al., 2018). Publications in the field of (sports) psychology cover all kinds of areas reaching from conceptualization, psychological theories to basic and applied science of mindfulness (Schindler, 2020).

Buddhist traditions are often seen as a substantial source and inspiration to mindfulness, especially with respect to the clinical context regarding most commonly evaluated therapeutic approaches like the mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1990) or the mindfulness-based cognitive therapy (MBCT; Segal et al., 2002). Today's understanding of mindfulness, which is inevitably linked to those clinical techniques, can be described "(…) as a kind of non-elaborative, non-judgmental, present-centered awareness in which each thought, feeling, or sensation that arises in the attentional field is acknowledged and accepted as it is." (Bishop et al., 2004, 232).

Within this context, Bishop et al. (2004) proposed a two-component model of mindfulness to establish an operational definition. Those two components combine aspects of (1) self-regulation of attention and (2) orientation to experience. The first component includes the ability to sustain or switch the focus of attention and to inhibit secondary elaborative processing of thoughts, feelings, and sensations in the stream of consciousness. In addition, it is aimed to develop a so-called "beginner's mind" in order to widen the own experience and get into a state of direct observation, which is not filtered through own beliefs, assumptions, expectation, or desires (Bishop et al., 2004). The second component refers to the aspect of dispositional openness, which describes a non-judgmental attitude of curiosity and receptivity to new experiences. In adopting this stance of curiosity and acceptance less behavioral/cognitive strategies and improved affect tolerance are expected, allowing any thoughts, emotions, and sensations to occur without further elaboration (Bishop et al., 2004; Thienot et al., 2014; Jansen et al., 2019).

In the context of sports, mindfulness is often characterized as a relevant component or psychological technique, respectively, in promoting high performance (Birrer et al., 2012). Due to the fact that mindfulness is assumed to be a multifaceted concept (van Dam et al., 2018), interventions can influence psychological functioning of athletes *via* numerous impact mechanisms like attention, self-regulation, or attitude (Birrer et al., 2012). Gardner and Moore (2004, 2007) developed one of the best-known mindfulness-based intervention programs in sport called MAC (Mindfulness-Acceptance-Commitment Approach). The authors hypothesize that efforts at internal self-control, task-irrelevant focus of attention, and restrictions in behavior that often accompany performance dysfunction can be replaced by a mindful stance of awareness, attention, and acceptance of internal processes. Therefore, this intervention aims to improve quality of practice, competitive performance, and enjoyment of athletic experiences. It is based on its three components (1) awareness of current thoughts, emotions, and bodily sensations, (2) acceptance/non-judgmental attitude toward current thoughts, emotions, and bodily sensation, and (3) commitment toward goal-relevant actions by maintaining goal-relevant actions for a greater behavioral flexibility. Numerous mindfulness-based interventions were added in the past years, such as MSPE (Mindful Sports Enhancement Program) by Kaufman et al. (2009), MMTS (Meditation Training for Sport) with a focus on meditation (Baltzell and Akthar, 2014), MTC (Mindfulness Training for Coaches) with coaches as target group (Longshore and Sachs, 2015), or MAIC (Mindfulness-Acceptance-Insight-Commitment) especially for Chinese athletes (Si et al., 2016)—just to name a few.

All mentioned approaches compromise the substantial elements of mindfulness, namely, present-focused awareness and attention, non-judgmental and accepting approach to situations, physical sensations, and emotions, as well as openness and curiosity toward experience, and last compassion for self and others (Zizzi, 2017).

As a consequence of this increasing prevalence of mindfulness-based interventions in sport, a context-specific instrument is needed to assess mindfulness skills among athletes and especially, the effectiveness of the numerous interventions. In order to meet these demands, Thienot et al. (2014) developed an English questionnaire that enables to underpin those mindfulness-based programs aiming to enhance sport performance. The questionnaire is based on the above-mentioned model by Gardner and Moore (2007) and is therefore developed on the following three components: (1) awareness, (2) non-judgmental attitude, and (3) refocusing. While awareness is defined as "the ability to closely observe one's internal experience like cognitions, emotions or bodily sensations in the present moment," the non-judgmental attitude represents "the willingness to allow and accept one's internal experience as it occurs without any attempt to judge and criticize oneself for experiencing these cognitions, emotions or bodily sensations." As last component, refocusing is defined as "the ability to disengage from elaborative processing like distraction, rumination or worry in order to remain focused or to quickly refocus on task-relevant cues" (Thienot et al., 2014, 73–74).

The study design implemented by Thienot et al. (2014) to develop a respective context-specific instrument followed a three-stage approach (Netemeyer et al., 2003) to test reliability and validity. The validity aspect is grounded in Messick's (1995) classification of construct validity into content, structural, generalizability, and external aspects. Therefore, in stage 1 an initial pool of domain-specific items capturing all three components was generated and rated by six external judges in order to assess the content aspect of validity. Based on the results of the expert review, ten items for each subscale were retained (Thienot et al., 2014). In stage 2, the structural aspects of construct validity (Messick, 1995) of the 30-item measure were examined and exploratory factor analysis revealed 19 items (eight awareness, six non-judgmental, five refocusing) loading on three distinct factors. Additional reliability analyses for these remaining items in each subscale showed acceptable evidence of internal consistency (Thienot et al., 2014). In stage 3, the focus of analysis was particularly on structural, generalizability, and external aspects of construct validity (Messick, 1995). A confirmatory factor analysis was conducted to refine the structure of the instrument and to remove problematic items. A 15-item (five awareness, five non-judgmental, five refocusing), three-factor measurement model, was identified that adequately fit the data. The generalizability aspect was assessed through measurement invariance testing for gender (male vs. female) and sport types (team vs. individual sports). Results provide only partial invariance between males and females, whereas evidence of measurement consistency across sport types could be detected for metric and scalar invariance. Finally, substantial correlations between the MIS subscales and five other measures (mindful trait in daily life, flow disposition, worry and concentration disruption, perfectionism, and rumination) were found in terms of evidence for the external aspect of construct validity (Thienot et al., 2014).

Mindfulness as a construct takes over different roles in the sports context and can therefore act as a predictor as well as a mediator or moderator between performance predictors

and performance itself and in terms of this knowledge as an outcome of respective interventions (Noetel et al., 2019a). Consequently, reliable and validate assessment tools, such as the MIS, are assumed to be beneficial for a variety of different research questions in the context of mindfulness in sports. The promising work provided by Thienot et al. (2014) underpinned the request of a German version of the respective original questionnaire. Therefore, the aim of this paper is to examine the psychometric properties of the MIS-D (German translation). Regarding reliability, it is assumed that the MIS-D items reflecting the same construct will yield a strong coherence (internal consistency, hypothesis 1). Moreover, it is hypothesized that the MIS-D will provide similar results when repeated in the same sample within a six-week interval (test–retest reliability; hypothesis 2). Regarding validity, it is assumed that the postulated three-factor structure (1. awareness/2. non-judgmental/3. refocusing) can be identified (factorial validity, hypothesis 3) and that these factors will prove to be equivalent across gender and competition type (measurement invariance, hypothesis 4a/b). In terms of convergent validity (hypothesis 5), substantial correlations between the three MIS subscales and five conceptually related variables like mindfulness in daily life, flow, worry and concentration disruption, perfectionism, and rumination are expected.

MATERIALS AND METHODS

Participants

A total of 228 female and male adults (63 females, 165 males) with a mean age of $M = 23.42$ years ($SD = \pm$ 2,91 years; range: 16–33 years) participated in this study. Participants were recruited online within the author's institutional context during February and August 2021. The total sample was used for the evaluation of internal consistency (hypothesis 1), factorial validity (hypothesis 3), and measurement invariance across gender and competition type (hypothesis 4a/b). For the test–rest reliability (hypothesis 2) a subsample of 106 adults (28 females, 78 men) with a mean age of 23.31 years ($SD = \pm$ 2.84 years; range: 18–31 years) was available. For the analysis of convergent validity (hypothesis 5) the three subscales of the MIS-D (awareness, non-judgmental attitude, refocusing) were correlated with five conceptually related variables (mindful trait in daily life; flow; worry/concentration disruption; perfectionism; rumination) based on the different subsamples as not all subjects completed all questionnaires in the second survey phase after 6 weeks (*Mindful trait in daily life:* 211 participants, 59 females, 152 males; $M_{age} = 24.46$ years, $SD_{age} = \pm$ 2.99 years, range: 16–33 years; *Flow disposition:* 228 participants, 63 females, 165 males, $M_{age} = 23.42$ years, $SD_{age} = \pm$ 2.91 years, range: 16–33 years; *Worry and concentration disruption:* 92 participants, 27 females, 65 males; $M_{age} = 23.12$ years, $SD_{age} = \pm$ 2.88 years, range: 13–32 years; *Perfectionism*: 208 participants, 59 females, 149 males, $M_{age} = 24.49$ years, $SD_{age} = \pm$ 3.00 years, range: 16–33 years; *Rumination*: 221 participants, 62 females, 159 males, $M_{age} = 23.43$ years, $SD_{age} = \pm$ 2.94 years, range: 16–33 years).

Measures

Mindfulness in Sport

The 19-item MIS-D (German translation), which results from the translation of the English original version, was developed out of an independent back translation and includes eight awareness items, six non-judgmental items, and five refocusing items (see **Supplementary Material**). A 6-point Likert scale (1 = *not at all*; 6 = *very much*[1]) was used to indicate how much each statement reflects the participants' experience following the instruction: "The statements below describe a number of things that athletes may experience just before or during their sport performance. Please circle the number that best indicates how much each statement is generally reflective of your recent experience.[2]" (Thienot et al., 2014, 75) The respective format was chosen following the Mindfulness Attention and Awareness Scale (MAAS), representing the most common instrument in literature assessing mindfulness in non-athletic settings (Brown and Ryan, 2003; Grossman, 2008).

The German instruments to test for convergent validity (Campbell and Fiske, 1959) were selected in accordance with the original article by Thienot et al. (2014) and are presented in the following section as well as further refined hypotheses (hypotheses 5a−5f).

Mindful Trait in Daily Life

The German version of the Mindfulness Attention and Awareness Scale (MAAS) was used in order to assess the tendency to be mindful in daily life (Michalak et al., 2008). Therefore, the disposition to what extent internal and external conditions of the present moment are fully perceived are primarily assessed. For this purpose, 15 items formulated in a "mindless" way are rated on a 6-point Likert scale (1 = *almost always*; 6 = *almost never*[3]). According to Brown and Ryan (2003) states of low mindfulness are more perceptible and less likely to produce falsely positive responses in the sense of being attentive and therefore better suited for the assessment of mindfulness than positively formulated items. The internal consistency of the German version ($\alpha = 0.83$) is almost identical to the English scale ($\alpha = 0.82$). Like Thienot et al. (2014) already postulated, substantial positive correlations in terms of convergent validity between the MAAS and scores of the MIS awareness and refocusing scale are expected (hypothesis 5a).

Flow Disposition

The 10-item Flow Short Scale (FSS; Flow-Kurzskala) by Rheinberg et al. (2003) was used in order to assess the tendency to experience flow states while performing in sport. This questionnaire measures the components of a flow experience

[1] 1 = *gar nicht*; 6 = *sehr*.

[2] Die nachfolgenden Aussagen beschreiben einige Gedanken und Gefühle, die Sportlerinnen und Sportler kurz vor oder während einer sportlichen Leistungssituation erleben können. Bitte klicken Sie bei jeder Aussage diejenige Antwortmöglichkeit an, die am besten beschreibt, welche Gedanken und Gefühle Sie selbst kurz vor oder während einer sportlichen Leistungssituation im Allgemeinen erleben.

[3] 1 = *fast immer*; 6 = *fast nie*.

as described by Csikszentmihalyi (1975) on a 7-point Likert scale (1 = *not at all*; 7 = *very much*[4]). In general, the concept of flow represents a temporary psychological state of optimal experience, that emerges when the athlete's skill level in balance with the respective challenge (Csikszentmihalyi, 2009). The FSS is no context-specific instrument and can be applied to obtain a typical flow score for different kinds of actions or situations, such as sports performance. Three optionally items covering worry and anxiety were excluded as these items are covered by a separate questionnaire of the following reference construct *worry and concentration disruption*. In addition, the Short Dispositional Flow Scale (Short DFS-2; (Jackson et al., 2008) used by Thienot et al. (2014) includes no such items. The 10-item FSS shows high evidence of internal consistency with Cronbach's alpha around 0.90 (Rheinberg et al., 2003). As already mentioned in the original paper, mindfulness and flow share conceptual similarities as both focus on present moment focus of attention (Aherne et al., 2011; Moran, 2012). The effect of mindfulness-based approaches for performance enhancement in the sports and exercise domain is directly linked to the flow phenomenon as demonstrated by Sappington and Longshore (2015) or Noetel et al. (2019b). Additionally, Jekauc and Kittler (2015) propose an effect mechanism of mindfulness in sports, that leads to higher performance through (1) development of a flow state, (2) improved maintenance and regulation of concentration/attention, or (3) emotion regulation. Consequently, a substantial positive correlation in terms of convergent validity between all three subscales of the MIS-D and the obtained flow score with the FSS is expected (hypothesis 5b).

Worry and Concentration Disruption

The tendency to worry and be distracted just before and during competition was originally assessed by the Worry and Concentration Disruption subscales of the Sport Anxiety Scale 2 (SAS-2, (Smith et al., 2006). A German equivalent to this questionnaire is the so-called Wettkampfangstinventar-Trait (WAI-T) by Brand et al. (2009) which captures the following three components: (1) somatic anxiety, (2) worry, and (3) concentration disruption. Each component has four items and is rated on a 4-point Likert scale (1 = *not at all*; 4 = *very much so*[5]). Using an athletes sample, Brand et al. (2009) reported internal consistencies reaching from $\alpha = 0.811$ (somatic anxiety), $\alpha = 0.826$ (worry) to $\alpha = 0.768$ (concentration disruption). As part of the operational definition by Bishop et al. (2004), the component *self-regulation of attention* emphasizes that mindfulness practices aim to improve cognitive inhibition, especially at the level of stimulus selection. This means that secondary elaborative processing of thoughts, feelings, and sensations that arise in the stream of consciousness should be inhibited. The positive promotion effect of mindfulness-based interventions on performance-related psychological parameters like sport anxiety-related worry or task-related worries could be shown in several studies (de Petrillo et al., 2009; Thompson et al., 2011). As a consequence, a substantial negative correlation in terms of convergent validity between the MIS-D subscales and the worry and concentration disruption subscale of the WAI-T is expected (hypothesis 5c).

Perfectionism

According to Hewitt and Flett (1991), central determinants of perfectionism are setting unrealistically high standards, selective attention to mistakes and their overgeneralization, constant evaluation of one's own actions, and the tendency to "all-or-nothing thinking" in the sense that only absolute success or total failure is possible. Within the original paper a brief version of the Hewitt and Flett (1991) Multidimensional Perfectionism Scale (HF-MPS) and the Frost et al. (1990) Multidimensional Perfectionism Scale (F-MPS) by Cox et al. (2002) was used to measure perfectionism. In reference to that, the German version of the F-MPS by Altstötter-Gleich and Bergemann (2006) with six subscales and 35 items rated on a 6-point Likert scale (1 = *strongly disagree*; 6 = *strongly agree*[6]) was used. In a sample of 1,170 participants, the internal consistency of the subscales ranged from $\alpha = 0.70$ (Doubts about Action) to $\alpha = 0.90$ (Organization). For several multidimensional instruments assessing perfectionism, second-order factors like *positive striving* vs. *maladaptive evaluation concerns* (Frost et al., 1993; Slaney et al., 1995), *adaptive* vs. *maladaptive perfectionism* (Rice et al., 1998) or *healthy* vs. *unhealthy perfectionism* (Stumpf and Parker, 2000) were identified and labeled as *functional* vs. *dysfunctional components* (Altstötter-Gleich and Bergemann, 2006). Based on these findings, a substantial negative correlation in terms of convergent validity between all MIS-D subscales and the dysfunctional components (Concern Over Mistakes, Doubts About Action, Parental Expectations, Parental Criticism) is expected (hypothesis 5d) due to the fact that higher mindfulness skills are associated with lower maladaptive perfectionism (Hinterman et al., 2012). Further, Hinterman et al. (2012) found a negative correlation between functional/positive perfectionism and the subscale *Accept without judgment* of the Kentucky inventory of mindfulness skills (KIMS; Baer et al., 2004). Consequently, a substantial negative correlation in terms of convergent validity between the non-judgmental subscale of the MIS-D and the functional/positive perfectionism items of the German F-MPS (Personal Standards, Organization) is expected (hypothesis 5e).

Rumination

Rumination pertains to self-attentiveness motivated by perceived threats, losses, or injustices to the self (Trapnell and Campbell, 1999). The tendency to ruminate was assessed by the German Rumination Scale (König, 2012) of the original Rumination Reflection Questionnaire (RRQ) by Trapnell and Campbell (1999). This questionnaire uses a 5-point Likert scale (1 = *strongly disagree*; 5 = *strongly agree*[7]). Contrarily, Thienot et al. (2014) used the Rumination subscale of the Emotion Control

[4] 1 = *trifft nicht zu*; 7 = *trifft zu*.
[5] 1 = *gar nicht*; 4 = *sehr*.
[6] 1 = *trifft überhaupt nicht zu*; 6 = *trifft sehr gut zu*.
[7] 1 = *stimme überhaupt nicht zu*; 5 = *stimme voll und ganz zu*.

Questionnaire-2 (Roger and Najarian, 1989) which was developed with a True/False response format. Psychometric analyses of the German Rumination Scale of the RRQ showed an internal consistency of $\alpha = 0.904$ based on sample of 577 subjects with different mental impairments (D. König-Teshnizi, personal communication, January 20, 2021). Like Hinterman et al. (2012) could already establish a negative correlation between mindfulness and perfectionism, a similar finding emerged for the correlation between mindfulness and rumination (Josefsson et al., 2017). Therefore, a substantial negative correlation in terms of convergent validity was particularly expected between the German Rumination Scale and the MIS-D refocusing and non-judgmental scale in our study (hypothesis 5f).

Procedure

Participants completed the 19-item German version of the Mindfulness Inventory for Sport (MIS-D), that was developed in stage 2 of the respective validation process by Thienot et al. (2014). The protocol was approved by the institutional review board prior to data collection. The questionnaire package was completed online *via* Social Science Survey (SoSci) consisting of an upstream information about the nature of the study, the right to withdraw, the storage and confidentiality of collected data, and a digital declaration of consent as obligatory requirement for participation, followed by selected questions on personal and sporting data in accordance to the Motorik-Modul Physical Activity Questionnaire (MoMo-PAQ; Woll et al., 2011), the MIS-D and the five conceptually related variables.

Statistical Analysis

Subsequent results on reliability, validity, and measurement invariance of the MIS-D (German translation) were calculated using SPSS 27.0 (IBM Corp., Released 2020) and R 4.1.1 (R Core Team, 2021). The significance level for all statistical tests (two-tailed) was set *a priori* to $\alpha = 0.05$.

For the evaluation of internal consistency of all three MIS-D subscales (hypothesis 1), Cronbach's Alpha as well as McDonald's Omega were calculated (Briggs and Cheek, 1986; Streiner, 2003; Berger, 2019). Intraclass correlation coefficient (ICC) was used to evaluate test–retest reliability (hypothesis 2) using a mean of multiple measurement, absolute agreement 2-way mixed-effects model (Koo and Li, 2016).

To examine factorial validity of the three MIS-D subscales (hypothesis 3), a confirmatory factor analysis (CFA, reflective model) was conducted. Considering the given discrete response categories of the MIS-D, the WLSMV discrepancy function (Weighted Least Squares Mean and Variance adjusted) was chosen as an appropriate and robust estimation method (DiStefano and Morgan, 2014; Li, 2016). To evaluate global model fit, fit indices including Root Mean Square Error of Approximation (RMSEA; ≤0.06), Standardized Root Mean Residual (SRMR; ≤0.08), Comparative Fit Index (CFI; ≥0.90), and Tucker–Lewis Index (TLI; ≥0.90) were calculated, based on recommendations by Hu and Bentler (1999) and Schermelleh-Engel et al. (2003). RMSEA is attributed with a salient meaning in confirmatory context and therefore plays a superordinate role in assessing global model fit (Bentler and Bonett, 1980; Hu and Bentler, 1999; Schermelleh-Engel et al., 2003; Bühner, 2011). As structural equation models and their substructures can be problematic despite a good global fit, the model's local fit was assessed additionally. Therefore, inner-method convergent and divergent measures like indicator reliability (IR), factor reliability (FR), average variance extracted (AVE), Fornell–Larcker ratios (FLR), and a scaled χ^2 difference test statistic (Satorra, 2000; Satorra and Bentler, 2001) for robust estimation methods were applied, based on recommendations by Kline (2016).

Measurement invariance across gender and competition type of the MIS-D (hypothesis 4a/b) were examined by testing and comparing nested models using multiple-group analysis with each successive model including the previous model restrictions. As nested models are not independent of each other, the decision whether to accept or reject a model was initially based on the χ^2 difference test (Hu and Bentler, 1999), respectively the Satorra–Bentler scaled χ^2 (Satorra, 2000; Satorra and Bentler, 2001). However, since the χ^2 value depends on the sample size, Cheung and Rensvold (2002) and Meade et al. (2008) suggest using the CFI difference test instead. According to this test, if a difference in CFI of 0.02 between the base model and the respective model is exceeded, no significant difference between those two models can be detected. Common fit statistics like RMSEA (Root Mean Square Error of Approximation; ≤ 0.06), CFI (Comparative Fit Index; ≥ 0.90), and TLI (Tucker–Lewis Index; ≥ 0.90) were used for further indications of model validity (Hu and Bentler, 1999; Schermelleh-Engel et al., 2003).

For the evaluation of convergent validity (hypothesis 5), we calculated Bravais–Pearson correlation coefficients between the MIS-D subscales awareness, non-judgmental attitude, and refocusing and the five conceptually related variables (one's tendency to be mindful in daily life, flow, worry/concentration disruption, perfectionism, and rumination).

RESULTS

Reliability

All three MIS-D subscales ($N = 228$) showed adequate internal consistency according to Cronbach's alpha (hypothesis 1; awareness: 0.725; non-judgmental: 0.721; refocusing: 0.738). This goes along with an optimal level of homogeneity represented by mean interitem correlations ranging from 0.250 to 0.371. To address the fact that items do not always capture a construct homogeneously, McDonald's Omega was calculated as a complement to Cronbach's Alpha (awareness: 0.729; non-judgmental: 0.726; refocusing: 0.745), even though both measures show only marginal estimate differences. The MIS-D (German translation) provides moderate to good test–retest reliability (hypothesis 2; interval: 6 weeks; $n = 106$; $ICC_{awareness} = 0.58$, 95% CI [0.39, 0.72], $p = 0.000$; $ICC_{nonjudgmental} = 0.77$, 95% CI [0.66, 0.84], $p = 0.000$; $ICC_{refocusing} = 0.79$, 95% CI [0.70, 0.86], $p = 0.000$). In summary, results provide good evidence for the reliability of the MIS-D (German translation).

Factorial Validity

To assess factorial validity (hypothesis 3), WLSMV estimation was applied with regard to discrete response categories. The proposed three-factor structure encompassing eight indicators for awareness, six indicators for refocusing and five indicators for refocusing (see **Figure 1**) reached good global model fit with χ^2 (149) = 201.520, $p = 0.003$, RMSEA = 0.039 with 90% CI [0.024, 0.053] and SRMR = 0.069. While the χ^2/df ratio of 1.35 supports this assumption, CFI and TLI values of 0.898, respectively, 0.883 show marginal deviations from an adequate fit (≥0.90).

For inner-method convergent measures (see **Table 1**), each estimated factor loading differed significantly from zero ($p < 0.001$) and the factor reliability (FR) for all three latent variables clearly exceeded the required minimum of 0.60. By contrast, none of the latent variables could explain more than 50% of the variance (AVE) of its subordinated indicators and therefore no sufficient explanatory power could be identified. In addition, in only four out of 19 items, the variance that was assessed by the respective superordinate latent variable (IR) was higher than 40% and therefore a few indicators were proven to be particularly critical at this point.

For inner-method divergent measures (see **Table 1**), the AVE of all three latent variables was higher than the maximum squared intercorrelation (MSI) resulting in FLRs lower than 1, which can be interpreted as an indication for good inner-method discriminance. Furthermore, the scaled difference χ^2 test statistic proved that the proposed model can be retained ($\chi^2_{scaled} = 27.651^{***}$).

Measurement Invariance Across Gender and Competition Type

Analyses of measurement invariance across gender and sports type of the MIS-D were conducted with the 19-item three-factor model. To test for measurement invariance of the MIS-D (hypothesis 4a/b), a multi-group comparison within the framework of confirmatory factor analysis for ordinal data was applied. The restricted models were compared with the basic model after gradually equating more and more parameters in an iterative manner (configural/metric/scalar/strict invariance) across gender (female, $n = 63$ vs. male, $n = 165$) and competition type (competition, $n = 92$ vs. non-competition athletes, $n = 136$).

Results on measurement invariance across gender of the MIS-D (hypothesis 4a; see **Table 2**) support the assumption of configural, metric, scalar, and strict invariance across gender, which means that the postulated three-factor structure displays equivalent in both groups and that males and females show a comparable item responsiveness (ΔCFI < 0.02).

Results on measurement invariance across competition type of the MIS-D (hypothesis 4b; see **Table 2**) could not provide strong evidence of complete measurement invariance for the three-factor model across competition and non-competition athletes. Indices for the configural and metric model reflect an adequate fit (RMSEA ≤0.05) as well as ΔCFI less than 0.02 (metric model). As this pattern of ΔCFI (<0.02) could not be transferred to scalar invariance level, it is tested for partial invariance by freeing one item at a time (van de Schoot et al., 2012). In this case, a maximum of three items can be freed according to Dimitrov's (2010) guidelines stating that less than 20% free parameters are acceptable. The following model modification was carried out on the basis of the largest improvement in the CFI by freeing the intercepts of item 19 ("When I become aware that some of my muscles are sore, I quickly refocus on what I have to do"), item 14 ("When I become aware that I am angry at myself for making a mistake, I criticize myself for having this reaction") and item 11 ("When I become aware that I am really excited because I am winning, I think that is bad to have this feeling of excitement"). Although the intercepts of those three items were freed, no partial measurement invariance at scalar level could be shown as the CFI difference remains larger than 0.02. Therefore, findings of measurement invariance across the two competition type groups only support the assumption of configural and metric invariance.

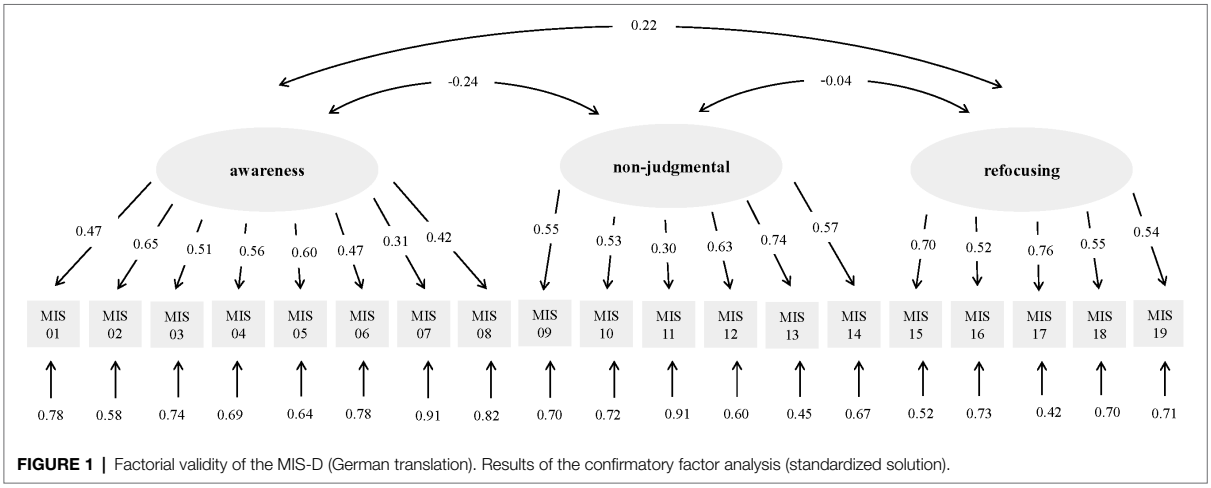


FIGURE 1 | Factorial validity of the MIS-D (German translation). Results of the confirmatory factor analysis (standardized solution).

TABLE 1 | Inner-method convergent and divergent measures within MIS-D (German translation).

Subscales	Item No.	IR	*t*-value loading	FR	AVE	FLR	Scaled χ^2 difference test statistics
Awareness	1	0.216	–	0.99	0.28	0.21	27.651***
	2	0.424	6.046***				
	3	0.264	5.750***				
	4	0.313	5.161***				
	5	0.357	7.499***				
	6	0.222	5.125***				
	7	0.094	3.117***				
	8	0.179	4.214***				
Non-judgmental	9	0.301	–	0.96	0.32	0.18	
	10	0.278	5.695***				
	11	0.091	3.415***				
	12	0.395	6.060***				
	13	0.553	7.143***				
	14	0.328	6.290***				
Refocusing	15	0.484	–	0.93	0.37	0.13	
	16	0.268	5.962***				
	17	0.582	8.995***				
	18	0.302	6.436***				
	19	0.289	6.870***				

****= p < 0.001; IR, indicator reliability; FR, factor reliability; AVE, average variance extracted; FLR, Fornell–Larcker ratio.*

TABLE 2 | Results of multi-group comparing within MIS-D (German translation).

	χ^2	df	*p*	$\Delta\chi^2$	Δdf	p($\Delta\chi^2$)	CFI	ΔCFI	TLI	RMSEA
Gender										
Baseline males	190.808	149	0.012	-	-	-	0.876	–	0.858	0.041
Baseline females	151.575	149	0.426	-	-	-	0.977	–	0.973	0.017
Configural invariance	339.131	298	0.051	-	-	-	0.903	–	0.889	0.035
Metric invariance	350.692	314	0.075	15.199	16	0.510	0.914	|0.011|	0.906	0.032
Scalar invariance	369.959	330	0.064	33.082	32	0.414	0.906	|0.003|	0.903	0.033
Strict invariance	388.369	349	0.072	52.342	51	0.422	0.908	|0.005|	0.909	0.032
Competition type										
Baseline competition	183.887	149	0.027	–	–	–	0.860	–	0.839	0.051
Baseline non-competition	177.547	149	0.055	–	–	–	0.877	–	0.859	0.038
Configural invariance	361.104	298	0.007	–	–	–	0.869	–	0.850	0.043
Metric invariance	378.321	314	0.007	18.259	16	0.309	0.866	0.003	0.855	0.043
Scalar invariance	420.564	330	0.001	52.818	32	0.012	0.812	0.057	0.805	0.049
Scalar invariance MIS19 ~ 1	414.664	329	0.001	48.397	31	0.024	0.822	0.047	0.815	0.048
Scalar invariance MIS19 ~ 1 + MIS14 ~ 1	409.574	328	0.001	44.439	30	0.043	0.831	0.038	0.823	0.047
Scalar invariance MS19 ~ 1 + MIS14 ~ 1 + MIS11 ~ 1	405.490	327	0.002	41.067	29	0.068	0.837	0.032	0.830	0.046

χ^2 = chi square; df = degrees of freedom; p = level of significance of χ^2 test; Δdf = changes in degrees of freedom; p($\Delta\chi^2$) = level of significance of scaled χ^2 test; CFI = Comparative Fit Index; ΔCFI = CFI difference test; TLI = Tucker–Lewis Index; RMSEA = Root Mean Square Error of Approximation.

Convergent Validity

The following correlations of the MIS-D (German translation) subscales of awareness, non-judgmental attitude, and refocusing with the above-mentioned reference constructs emerged (see **Table 3**).

Mindful Trait in Daily Life

The theoretically expected correlation between the MIS-D refocusing subscale and the MAAS ($r = 0.213$, $p = 0.002$, hypothesis 5a) was similar to Thienot et al. (2014). In accordance with Thienot et al. (2014), there was no significant positive correlation between the MIS-D awareness subscale and the MAAS ($r = 0.108$, $p = 0.117$; hypothesis 5a). In addition, the positive correlation between the MIS-D non-judgmental subscale and the MAAS was unexpected, as no attitudinal component of acceptance is covered by the MAAS ($r = 0.207$, $p = 0.002$).

Flow Disposition

The positive correlation between the MIS-D refocusing subscale and the FSS ($r = 0.458$, $p = 0.000$; hypothesis 5b) corresponds to the results of the original paper ($r = 0.43$, $p < 0.001$). Contrary

TABLE 3 | Bivariate correlations (Bravais–Pearson correlation) between the MIS-D (German translation) and the subscales of five conceptually related constructs.

Subscales	*n*	*M*	*SD*	Skewness	Kurtosis	α	MIS-D	MIS-D Non-judgmental	MIS-D refocusing
MAAS	211	60.06	11.12	−0.34	−0.26	0.83	0.108	0.207**	0.213**
FSS	228	5.37	0.85	−0.36	−0.17	0.90	0.110	0.095	0.458**
WAI-T somatic anxiety	92	10.53	2.87	−0.02	−0.68	0.81	0.306**	−0.099	−0.147
WAI-T worry		9.62	2.80	0.13	−0.22	0.83	0.111	−0.265*	−0.059
WAI-T concentration disruption		6.12	1.93	1.16	2.09	0.77	0.076	−0.139	−0.250*
F-MPS functional	208	59.29	10.44	−0.71	0.29	–	0.126	−0.180**	0.142*
F-MPS dysfunctional		57.80	19.18	0.50	−0.43	–	0.076	−0.229**	−0.132
RRQ	221	41.23	9.44	−0.32	−0.72	0.90	0.088	−0.236**	−0.228**

**=p<0.05, two-tailed. **=p<0.01, two-tailed. MAAS=Mindful Attention and Awareness Scale; FSS=Flow Short Scale; WAI-T=Wettkampfangstinventar-Trait; F-MPS=Frost et al. Multidimensional Perfectionism Scale; RRQ=Rumination Reflection Questionnaire; MIS-D=Mindfulness Inventory for Sport (German version).*

to our hypotheses, no further significant positive correlations could be shown in the MIS-D awareness, respectively, non-judgmental subscale and the FSS ($r=0.110$, $p=0.099$; $r=0.095$, $p=0.152$; hypothesis 5b). Whereas Thienot et al. (2014) found a positive correlation between the awareness subscale and the FSS ($p<0.001$; $r=0.34$).

Worry and Concentration Disruption

As expected, a negative correlation between the MIS-D non-judgmental subscale and the WAI-T worry subscale could be identified ($r=-0.265$, $p=0.011$; hypothesis 5c). The same association could be shown between the MIS-D refocusing subscale and the WAI-T concentration disruption subscale ($r=-0.250$, $p=0.016$; hypothesis 5c). In contrast to Thienot et al. (2014), theoretically expected significant negative correlations between the MIS-D awareness/non-judgmental subscale and the WAI-T concentrations disruption subscale ($r=0.076$, $p=0.472$; $r=-0.139$, $p=0.187$; hypothesis 5c) as well as between the MIS-D awareness/refocusing subscale and the WAI-T worry subscale ($r=0.111$, $p=0.293$; $r=-0.059$, $p=0.577$; hypothesis 5c) could not be shown. In addition, the MIS-D awareness did show an unexpected positive correlation with the WAI-T somatic anxiety subscale ($r=0.306$, $p=0.003$).

Perfectionism

The theoretically expected negative correlation between the MIS-D non-judgmental subscale and the functional aspect of perfectionism could be supported ($r=-0.180$, $p=0.009$; hypothesis 5d) as with Thienot et al. (2014), as well as the negative correlation between the MIS-D non-judgmental subscale and the dysfunctional aspect of perfectionism ($r=-0.229$, $p=0.001$; hypothesis 5d). The expected negative correlation between the MIS-D refocusing subscale and the dysfunctional aspect of perfectionism was only marginally significant ($r=-0.132$, $p=0.058$; hypothesis 5d).

Rumination

Both theoretically expected negative correlations between the two MIS-D subscales non-judgmental, respectively, and refocusing and the RRQ were found ($r=-0.236$, $p=0.000$; $r=-0.228$, $p=0.001$; hypothesis 5e).

DISCUSSION

The purpose of this study was to initially test the reliability (internal consistency: hypothesis 1/test–retest reliability: hypothesis 2), validity (factorial validity: hypothesis 3/convergent validity: hypothesis 5), and measurement invariance across gender and competition type (hypothesis 4a/b) of the MIS-D (German translation) using a total sample of 228 female and male adults out of the authors institutional context.

Reliability

Adequate reliability estimates of internal consistency (hypothesis 1) were obtained for each subscale of the MIS-D (German version). Although item 7 (awareness) and item 11 (non-judgmental) narrowly missed the critical item-total correlation of 0.30, those items were not excluded (Fisseni, 1997) from further analysis procedures. If we excluded those items, there would have been marginal to no improvement in internal consistency of the MIS-D. In addition, the aim was to preserve the content heterogeneity for substantial convergent constructs. A particularly high reliability and therefore mostly homogeneous tests are often only slightly valid against more complex external criteria. Thus, the primary aim was not to improve the reliability of the test at any cost, but rather to keep the content heterogeneity high (Amelang and Schmidt-Atzert, 2006; Furr, 2021). This proceeding was affirmed by item difficulty indexes of 76.4 (item 7) and 65.3 (item 11), thus, both items were answered in the sense of the characteristic to be measured (Kelava and Moosbrugger, 2011). Results also provide preliminary evidence for test–retest reliability (hypothesis 2) of the MIS-D, which extends the reliability analyses of the original paper by Thienot et al. (2014).

Factorial Validity

Concerning factorial validity, no one-to-one comparison to the original paper is possible as Thienot et al. (2014) defined a different model in their validation process. In our confirmatory context, the given 19-item MIS-D global model fit was evaluated with particular attention to the absolute fit index RMSEA following Rigdon's (1996) recommendations to provide a basis for further theory development. In addition, the construction

of confidence intervals around particular point estimates allows for a higher informative content and can also prevent freeing additional parameters in a model for the sake of marginal improvements in fit (Browne and Cudeck, 1992). As a consequence, the three-factor model structure was confirmed in the CFA with good model fit (RMSEA ≤0.05, SRMR ≤0.08; hypothesis 3). Therefore, conspicuous regression weights (<0.40) in item 7 and item 11 were no sufficient indication for the removal of these items as well as taking possible suppression effects into account. This potential explanation, which we did not pursue further, indicates that both items can increase the predictive contribution of one or even more other variable(s) by suppressing irrelevant variance components for the prediction (MacKinnon et al., 2000). Due to the salient meaning of the RMSEA, CFI and TLI values, that are marginal below a sufficiently acceptable fit, played only a subordinate role in the evaluation and adjustment of the model, as well as the fact, that the CFI has proven to be appropriate in more exploratory contexts (Rigdon, 1996).

The detailed inner-method convergent analysis showed deviating values in the average variance extracted (AVE) and the indicator reliability (IR) exceeding cutoff values of 0.50 and 0.40, respectively. AVE values below 0.50 do not convey sufficient variance for the items to converge into a single construct, which means that items do not adequately measure the latent construct. There seems to be more error variance than explained variance. Nevertheless, Fornell and Larcker (1981) state, that an AVE less than 0.50 can still be adequate with a composite reliability higher than 0.60. Reliability estimators based on structural equation modeling are typically referred to as composite reliability like the estimated McDonald's Omega. In contrast to Cronbach's alpha, this approach claims to include larger estimates of true reliability as construct loadings or weights are allowed to vary (Peterson and Kim, 2013). Composite reliability values (McDonald's Omega) of all three subscales are higher than 0.60 and therefore confirm adequate AVE values in our study (Fornell and Larcker, 1981). Generally, the indicator reliability (IR) reflects the degree of explanation of the indicator variance by a construct. Even if the IR is not sufficient (<0.40), more indicators improve reliability and validity as there is more information to estimate the latent construct's shared variance. In order to keep any additional information to the model and in view of a good overall quality measured by composite reliability, there is no cogent reason to exclude any indicators.

Considering options of further modifications of the MIS-D, especially to meet the demand of briefer versions in order to decrease response burden and increase the number of constructs to be measured in parallel, we would like to point out the option of genetic algorithms like Noetel et al. (2019a) applied to the original MIS (Thienot et al., 2014). This approach represents an innovative method to abbreviate questionnaires, but as large modifications could effect the theoretical integrity of a model resulting in a new instrument, an independent sample is required and should therefore be taken under consideration for future research.

Measurement Invariance Across Gender and Competition Type

Based on the locally confirmed three-factor model, nested model comparisons provide weak evidence for the measurement invariance of the MIS-D (German translation) across competition type (hypothesis 4b) and strong evidence across gender (hypothesis 4a). Consequently, on a construct level, it can be assumed that there is no difference between female and male, which could not be shown in the original paper. Nevertheless, results should be treated with caution since sample size is partially unbalanced between groups, as well as sample size is rather small (<100) in two subgroups (male: $n = 63$/competition: $n = 92$). This might lead to over-rejection of correct models in some measures of absolute model fit, like the RMSEA. Fit indices less-sensitive to sample size like the alternative fit indices (AFIs) should be considered for further instrument refinements. Nevertheless, partial invariance or non-invariance can be also quite informative as given in the grouping variable competition type (Putnick and Bornstein, 2016). Competitive athletes usually have a certain sport-specific expertise and get in touch with psychological training during their career. Thus, some athletes might have already developed skills like goal setting, positive self-talk, or imagery which in consequence may result in a different understanding and interpretation of the items (Grossman, 2008). In order to get to the bottom of this result, exploring mean differences and intercorrelations of the individual items can be helpful to inform development of a refined measure in future research. To evaluate measurement invariance in future studies and to maintain that dynamic and informative aspect of the functioning of a construct across groups, we propose an enlarged and representative sample with the option of the additional grouping variable *sports type* (individual vs. team sport athletes; see Thienot et al., 2014) as well as taking invariance across measurement occasions into account. In doing so, it would also be possible to construct an additional state measure of the MIS-D that could be used in evaluating momentary effects of mindfulness trainings in sports. Furthermore, and according to latent state–trait theory (Steyer et al., 1999, 2015), the consistency and specificity of the proposed State and the existing Trait MIS scales could be determined and thus the extent to which trait and state variance are measured with the respective instruments (see, e.g., Renner et al., 2018; Hock et al. submitted for current empirical demonstrations regarding anxiety and depression).

Convergent Validity

Concerning convergent validity, it should be kept in mind, that possible deviations reported in this and the original Thienot et al. (2014) paper may be ascribed to mostly different German questionnaires compared to those used by Thienot et al. (2014). There is one exception, namely, the tendency to be mindful in daily life, which was assessed by the MAAS in both versions. In addition, not each instrument measuring the reference constructs was explicitly validated using an athlete population, which might explain different distributions.

Mindful Trait in Daily Life

A non-judgmental and open attitude toward upcoming experiences is not specifically part of the MAAS; thus, the positive correlation with the MIS-D non-judgmental subscale was theoretically unexpected. Nevertheless, higher MAAS scores are associated with a higher level of mindful attitude which may also lead in a reduced evaluative attitude toward any occurring experience (Michalak et al., 2008). This mediating effect might be a possible explanation for the positive correlation, as it was also found by Thienot et al. (2014). The less prevailing result in the relationship between the MIS-D awareness subscale and the MAAS (hypothesis 5a) might be due to different content domains of awareness. The MAAS puts stronger emphasize on the cognition and perceiving part of the present moment, whereas items of the MIS-D subscale cover awareness mostly with regard to emotions and bodily sensations.

Flow Disposition

Mindfulness is often suggested as a catalyst for flow consisting of a feeling of enhanced physical and psychological functioning with an absence of negative thoughts and self-conscious evaluating, as well as the ability to be absorbed in the present moment task (Csikszentmihalyi, 1978; Jackson and Csikszentmihalyi, 1999; Scott-Hamilton et al., 2016). Anchored in the requirement profile of endurance athletes, a mindful skill like refocusing and acceptance may be especially relevant for this target group as they tend to experience prolonged exposure to sensations of discomfort (Scott-Hamilton et al., 2016). As only a quarter of our total sample ($N = 228$) can be clearly attributed to endurance sports, this might have caused ambiguous results in the MIS-D awareness and non-judgmental subscale (hypothesis 5b). Instead, the strong expected correlation between the MIS-D refocusing subscale and the FSS (hypothesis 5b) illustrates the importance of an attention regulation component in the MIS-D as described by Bishop et al. (2004) in the beginning.

Worry and Concentration Disruption

The unexpected positive correlation between the MIS-D awareness subscale and the WAI-T somatic anxiety subscale might be explained by the strong physical reference in their items. Whereas the somatic anxiety subscale describes the physically noticeable component of anxiety, which manifests itself in signs of anxiety, such as palpitations, clammy hands, or a sinking feeling in the stomach (Brand et al., 2009), the MIS-D awareness subscale is defined as "the ability to closely observe one's internal experience like cognitions, emotions or bodily sensations in the present moment" (Thienot et al., 2014, 73–74). Additionally, mindful awareness implies a higher level of processing, a so-called meta-awareness, to reach a state of distant observation from the self, which may help the athletes to perceive their current state and internal events without responding with sustained evaluation and to detach from non-targeted sensations (Wells, 2005). In consequence, this correlation might be caused by semantic confusion while assessing mindfulness processes as Thienot et al. (2014) already elaborated. Therefore, some items rely on the reader's experience in mindfulness training to understand the item in its deeper meaning (Grossman, 2008). This phenomenon can also be attributed to the unexpected correlations between the MIS-D awareness and the WAI-T worry/concentration disruption subscales. Nevertheless, the importance of an attention regulation component is clearly shown by the correlations between the MIS-D non-judgmental subscale and the WAI-T worry subscale (hypothesis 5c) and between the MIS-D refocusing subscale and the WAI-T concentration disruption subscale, respectively, (hypothesis 5c). This pattern was also confirmed by Thienot et al. (2014). Contrary to the results in this paper, Thienot et al. (2014) found correlations between the MIS-D non-judgmental subscale and the SAS-2 concentration disruption subscale and between the MIS-D refocusing and SAS-2 worry subscale. At this point, however, it should be mentioned that the concentration disruption subscale showed in both papers (SAS-2/WAI-T) skewness and kurtosis outside of the normality values. Therefore, the interpretation of the given results should be taken with caution.

Perfectionism

Within the sports setting, there is still a lack of research integrating the relationship between mindfulness and perfectionism. Hill et al. (2018) showed in their meta-analytical review of multidimensional perfectionism evidence for a maladaptive effect for athletes in the dysfunctional aspect, whereas the functional aspect seems to be more complex and ambiguous. A recent study by van Dyke et al. (2021) claims for a person-centered approach in the context of mindfulness and perfectionism as high-performance quality came along with varying mindfulness and perfectionism techniques. The current findings in the sporting setting underline the complexity of integrating both constructs. The aforementioned ambiguous effects of the functional perfectionism on athletes also seem to be reflected in the results within mindfulness skills in athletes among all subscales of the MIS-D. Nevertheless, the expected negative correlation between the MIS-D non-judgmental subscale and the F-MPS functional component (hypothesis 5e) could be confirmed, even though the basis for this assumption lies outside the sporting context (Hinterman et al., 2012). The theoretically expected negative correlations between the MIS-D subscales and the dysfunctional component of perfectionism could only be confirmed in the non-judgmental subscale (hypothesis 5d). The absence of self-critical and evaluative thinking representing the non-judgmental subscale might explain the negative correlation with the dysfunctional component characterized by concerns over mistake, fear of negative social evaluation, or negative reaction to imperfection (Hill et al., 2018). However, this interpretation must be taken cautiously in both perfectionism components as they also display skewness outside the normality values considered as acceptable.

Rumination

The convergent validity results in this reference construct align with theoretically expected negative correlations (hypothesis 5f), as well as with the results of the original paper by Thienot et al.

(2014), highlighting again the importance of the attention regulation component and the ability to inhibit elaborative processes in the context of mindfulness in sports (Bishop et al., 2004).

CONCLUSION

Mindfulness plays an increasingly important role in sport, whether as a mediator, moderator, or predictor of sport performance as well as the fact, that mindfulness-based training programs are meanwhile highly established in the sports performance setting. Consequently, a reliable and valid instrument to pursue the variety of research questions, for example to test the effectiveness of these interventions, is needed for different languages. The results of this study show that the German version of the Mindfulness Inventory for Sport (MIS-D) is sufficiently reliable. Factorial validity and invariance of measurement across gender and competition type could be largely shown. In addition, the MIS-D subscales correlate with five conceptually related constructs and thus initial evidence for convergent validity is provided. However, current results should be interpreted with caution in terms of preliminary evidence since corresponding data were assessed using partially rather small subsamples. Thus, replications should primarily focus on a larger sample size. In addition, for measurement invariance analyses further relevant subgroups as well as taking invariance across measurement occasions (e.g., invariance across time) should be taken into consideration as a construct can also change over time. On an applied level, the MIS-D can contribute to evaluate mindfulness-based interventions as well as accompany and document the development process of mindfulness-based skills in athletes. By assessing the athletes' use of mindfulness as a self-regulatory skill when facing disruptive stimuli, the MIS-D offers the possibility to get a better insight into mindfulness-based interventions in the sports context than other common instruments devised for use in clinical settings.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethikkommission UniBw (Institutional Review Board of the Universität der Bundeswehr). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.864208/full#supplementary-material

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Review Article

DIGITAL HEALTH

DIGITAL HEALTH
Volume 10: 1–48
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Article reuse guidelines:
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DOI: 10.1177/20552076241272604
journals.sagepub.com/home/dhj

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Psychological and physiological health outcomes of virtual reality-based mindfulness interventions: A systematic review and evidence mapping of empirical studies

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Abstract

Objective: In the past two decades, mindfulness, rooted in Buddhist traditions, has gained considerable scientific interest. Virtual reality (VR) technology, in particular head-mounted displays, offers immersive experiences and is examined in this systematic review in terms of VR-based mindfulness interventions and their effects on psychological and physiological health outcomes.

Methods: Using the Preferred Reporting Items for Systematic Review and Meta Analyses guidelines, a systematic search was conducted with the following search terms: [(mindful* OR "meditat*") AND ("virtual reality" OR "VR") AND (health OR physio* OR psycho* OR mental OR physical)]. Considering critiques of methodological quality in existing systematic reviews, this study adopts Boell and Cecez-Kecmanovic's hermeneutic approach, critically evaluating research outcomes.

Results: Psychological benefits include improved anxiety, mindfulness, emotions, disease patterns, affect, stress, (presleep) arousal, meditation and others. Physiological effects focus on neurobiological markers, heart rate/heart rate variability, pain, blood pressure, cortisol and galvanic skin resistance. Evidence mapping shows that more research has been conducted in the last 6 years, particularly by North American and South Korean authors, and points to gaps in study methodology. In addition, attention regulation is identified as a primary mindfulness mechanism in VR scenarios, often in nature-based virtual environments, with mainly single-session studies lasting 5 or 10 minutes.

Discussion: Critical mapping reveals the need for additional studies to support and extend initial findings in this emerging research field. Methodologically, there is a call for more true-experimental studies to enhance rigor. From a content perspective, VR protocols are currently still strongly characterized by single-session interventions, which makes it especially difficult to make a dose–response statement regarding long-term effects.

Conclusion: In summary, the studies provide important initial findings on psychological and physiological effects of VR-based mindfulness interventions on health. In addition, the need for more methodologically rigorous studies was emphasized, along with other methodological adjustments that must be carefully considered in the planning of future studies.

Keywords

Virtual reality, head-mounted display, mindfulness, health, meditation

Submission date: 2 February 2024; Acceptance date: 16 July 2024

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Introduction

Mindfulness and health

In the past 20 years, the scientific interest in mindfulness has surged covering different kinds of areas reaching from conceptualization to basic and applied science.[1,2] Although the concept of mindfulness has been defined in different ways in the literature, Buddhist traditions are often seen as a substantial source and inspiration and has been described as a process of bringing a certain quality of attention to moment-by-moment experience.[3] Bishop[4] adopted an operational definition of mindfulness in order to specify testable theoretical predictions for the purpose of validation and refinement. This two-component model of mindfulness covers today's general understanding of mindfulness, which can be described as a kind of nonelaborative, nonjudgmental, present-centered awareness in which each thought, feeling or sensation that arises in the attentional field is acknowledged and accepted as it is.[3,5–8] In detail, the two components combine aspects of (a) self-regulation of attention and (b) orientation to experience by including the ability to sustain or switch the focus of attention and to inhibit secondary elaborative processing of thoughts feelings and sensations in the stream of consciousness. The first component also addresses the so-called "beginner's mind" in order to widen the own experience and get into a state of direct observation, which is not filtered through own beliefs, assumptions, expectations or desires. The second component focuses on the aspect of dispositional openness, which describes a nonjudgmental attitude of curiosity and receptivity to new experiences. In adopting this stance of curiosity and acceptance less behavioral/cognitive strategies and improved affect tolerance are expected, allowing any thoughts, emotions and sensations to occur without further elaboration.[5]

Mindfulness has been introduced to the field of psychology, especially with respect to the clinical context, by commonly evaluated therapeutic approaches like the mindfulness-based stress reduction,[3] the mindfulness-based cognitive therapy[8,9] or the acceptance and commitment therapy.[10] Each of these mindfulness-based interventions (MBIs) has originally been conceptualized for different target groups like patients in pain, with depression or social anxiety. Nevertheless, these approaches are constantly adapted for further populations, respectively focus on different contents like acceptance, mindfulness, emotion regulation or meditation techniques.[11] These MBIs have been theoretically and empirically associated with psychological and physiological health outcomes showing the important contribution mindfulness can provide to one person's health. Concerning psychological health outcomes, beneficial effects of MBIs could be found for example in the improvement of well-being and behavioral regulation,[12] positive affect[13,14] as well as in reductions of anxiety and depressive symptoms,[15–18] stress[19,20] and burnout.[21] Concerning physiological health outcomes, MBIs show varying positive bodily changes like reductions in heart and respiratory rates, hypertension symptoms,[22,23] skin conductance[24] and pain levels[25,26] or an increase in heart rate variability (HRV).[27]

To theoretically frame these positive effects of MBIs on health, we apply Antonovsky's salutogenic model of health.[28] This model views health as a continuum ranging from ease to dis-ease,[29] reflecting a paradigm shift from pathogenesis to salutogenesis. This shift signifies a fundamental change in healthcare, emphasizing the promotion and maintenance of health and well-being rather than merely treating disease. This reorientation of healthcare toward a resource-orientated, salutogenic paradigm has been advocated by the Word Health Organization for several decades, as highlighted in the Ottawa Charter.[30] With the mentioned continuum, Antonovsky[28] wants to break away from the traditional medical dichotomy of sick/healthy in the pathogenic paradigm and views people from the perspective of heterostasis and entropy in the course of their lives as partly healthy and partly sick. Therefore, the salutogenesis approach stems from the idea of understanding health and disease not as alternative, dichotomous states, but as conceptual endpoints in a common continuum of health-ease (HE) and dis-ease (DE).

The primary objective in both life and research is to determine how individuals can progress toward the healthy end of the continuum, given the constant exposure to changes and events that may be considered as stressors. At this point, two key concepts of the salutogenesis model will be introduced. First, we will look at the generalized resistance resources (GRRs). This term was also shaped by Antonovsky[31] and refers to the resources that facilitate the individual's abilities to cope effectively with stressors in avoiding disease. They can be of genetic, constitutional, psychosocial, cultural, spiritual and material nature and exist at the individual, group (family), subcultural and societal levels. GRRs are fundamental to developing a strong sense of coherence (SOC), the second key concept of the salutogenesis model we wanted to introduce. SOC reflects a person's view of life and capacity to respond to stressful situations, embodying a global orientation that perceives life as comprehensible, manageable and meaningful, guiding individuals to think, act and live with an inner trust that enables them to identify, benefit from, utilize and reuse available resources.[32] The connection between GRRs and the SOC with its three elements comprehensibility, manageability and meaningfulness could be shown by a thematic analysis by Griffiths et al.,[33] in which various general resistant resource themes such as coping strategies, challenges worth investing time and effort or solution focused outlook fit the SOC concept. Thus, GRRs act as a kind of cornerstone for the development of a strong SOC.

Incorporating mindfulness into this framework as a "way of being," which emphasizes living in an open and highly engaged manner, facilitates responding rather than merely reacting to life's challenges.[3] Mindfulness may function as a GRR, e.g., as a kind of coping strategy, that strengthens

the SOC. For instance, mindfulness can enhance the sense of manageability by promoting more adaptive responses to life's challenges and moment-to-moment awareness, which facilitates openness and understanding of experiences. In addition, mindfulness can foster a sense of purpose in life simply by allowing space to explore meaning. These are all aspects with which a SOC is associated, namely seeing the world as comprehensible, manageable and meaningful. In this theoretical framework, mindfulness can therefore help a person to move along the HEDE continuum towards the ease-pole.

Close to this is the concept of resilience which describes an individual's capacity for dealing with adversity, whether that adversity originates internally or externally.[34] In this context, mindfulness is a crucial resource for building individual resilience in the face of adversity. Practicing mindfulness fosters traits such as emotional control, healthy coping mechanisms and a strong sense of self-worth, which are essential for navigating life challenges and environmental stressors. This practice can also help individuals recognize that the psychological distress caused by adverse events is merely a natural and temporary mental reaction. This awareness can enhance their ability to tolerate and cope positively with such challenges. Both the theoretical classification of mindfulness in the salutogenesis model and with regard to resilience, mindfulness plays a mediating role in improving mental and physical health.

Mindfulness, health and virtual reality

As the possibilities for using different technologies are constantly evolving, virtual reality (VR) exhibits particularly favorable features respectively components that make the VR experience compelling, known as the "three Is" of VR[35]: interaction, immersion and imagination. First, an interaction with the VR environment is actively possible. Second, immersion is the system's capability to adequately stimulate all human perceptual channels (sensory, vestibular, proprioceptive, interoceptive) whose level depends on the extension of the perceptual domains involved (multisensory integration) and on the accuracy, resolution and reactivity in production of the stimuli.[36] Therefore, VR is intentionally designed to give participants a heightened sense of presence, characterized by the "illusion of being immersed in the computer-generated world as if it were a place they are visiting."[37] This powerful experience of psychological presence describes a state, where users are immersed to the point where they momentarily disregard the physical world and perceive themselves as truly "in" the virtual environment.[38] Third, the imagination aspect refers to the mind's ability to create and perceive experiences, objects and environments that are not physically present, thereby convincing users to believe something even if their representation is unreal.[35] In other words, this allows users to freely explore the simulated world with their imagination, enabling them to see, touch, move and experience things in new ways and from different perspectives.[39] Imagination is defined as the extent to belief a user feels within a virtual environment, despite knowing he or she is physically situated in another environment[35,40] in contrast to immersion defined by the degree a user associates being within a virtual environment.[41] Moreover, it is important to mention, that immersion and interaction have a direct effect on a user's level of imagination, which is dependent on the VR's input devices, graphics and objectives as not all VR setups attempt to emphasize all three features. For example, full immersion is achieved with a head-mounted display (HMD), semi-immersion with large projection or LCD screens and non-immersion with standard desktop setups using keyboards and mice.[40–42]

Due to these technologies, interventions, especially for the mental health domain, are getting more accessible to the broader public.[43] The benefits of different VR technologies (VR, augmented reality (AR), mixed reality (MR) and extended reality (XR)) for improving mindfulness practices and health-related outcomes in adults were demonstrated in two systematic reviews that addressed similar research questions or foci as intended in our review, published in 2021 and 2022. On the one hand, key findings from the systematic review of Zhang and colleagues[44] indicate that both mindfulness interventions and the interactive experience of VR alone can alleviate a broad range of physical and psychological symptoms. However, the results do not show that a VR condition enhances the effectiveness of MBIs. Although, the MBI + VR condition retained more participants than the MBI alone, which might be an important aspect for improving treatment adherence and motivation to practice mindfulness. On the other hand, Arpaia and colleagues'[45] narrative review aimed to verify scientific evidence that VR technology improves mindfulness practice and therapeutic effectiveness of mindfulness respectively. Special focus was set on mindfulness mechanisms like decentering and interoceptive awareness.[46] From the literature review, it can be concluded that VR enhances relaxation and self-efficacy, reduces mind wandering and preserves attention resources. The authors also presented a design proposal for upcoming trends in VR-supported mindfulness with special focus on the integration of bio-/neurofeedback data. In addition to the two aforementioned papers, other researchers have also explored this topic through different reviews. However, they typically focus more specifically on particular settings, specific health outcomes or targeted populations. For this reason, we will not go into details of the individual reviews below, but instead provide an overview of the current range of research in this area. For example, Mitsea et al.[47] showed in their review that mindfulness training supported by immersive technology can significantly improve a wide range of cognitive/socio-emotional meta-skills, emotional regulation and outcomes related to mental/physical health, academic performance and well-being in the special education setting. Moreover, a scoping review by O'Connor

et al.[48] on the management of chronic pain found preliminary evidence suggesting that VR may enhance aspects of mindfulness practice, such as inducing relaxation, centeredness or distraction. These effects could potentially alleviate pain and improve sleep and mobility for some individuals. Reviews that focus on a specific target group, such as that by Mitsea et al.[49] show that mindfulness training supported by immersive technology significantly improves a wide range of cognitive and socio-emotional meta-skills in people with various mental disorders. In contrast, Failla et al.[50] concentrated on a nonclinical population and were able to show that mindfulness interventions mediated by VR systems were able to induce a significant reduction in negative mood states combined with increased mindfulness skills. This is not a complete summary of current reviews, but merely offers an overview. Based on these findings, especially by Zhang et al.[44] and Arpaia et al.,[45] the purpose of this paper is to clarify the effectiveness of immersive VR-based mindfulness practice on psychological and physiological health outcomes through an updated and adapted systematic review. After almost 2 years, it can be assumed that sufficient new research has accumulated, especially in fast-moving areas such as (VR-based) technology, to justify updating the review and incorporating new findings as Zhang et al.[44] included studies until 2020 and Arpaia et al.[45] until January 2021. In addition to the valuable insights gained by both research groups, narrative reviews, such as the one by Arpaia et al.,[45] always entail certain limitations. Those can be found for example in the nonprotocol-based search method or data extraction, which might lead to a subjective selection bias. Moreover, the inclusion of studies can be guided by the author's intuition and research experience and is not clearly predefined by selection criteria.[51] Although Arpaia et al.[45] have counteracted with the formulation of eligibility criteria following Preferred Reporting Items for Systematic Review and Meta Analyses (PRISMA) recommendations, the narrative character is particularly evident in the derivation of design proposals for the integration of biofeedback or neurofeedback. Zhang et al.[44] gave a comprehensive insight into this research topic by including all types of XR (xReality) technologies such as AR, VR and MR. In addition to various definitional approaches, Rauschnabel et al.[52] specifically distinguish AR from VR. The clear distinguishing feature is that in AR, the physical environment is at least partially part of the experience, whereas in VR it is not. Furthermore, a nuanced differentiation is established between the continuums of AR and VR, delineated by local presence (AR), denoting the degree to which virtual entities are perceived as authentically present and telepresence (VR), reflecting the extent to which an individual perceives themselves to be situated within the virtual environment. Taking these technological differences into account, it becomes clear that a differentiated view of possible health effects is required and will be addressed in our systematic review.

Derived from this and from a content point of view, our interest lies solely on immersive VR technology, especially HMDs as they provide a deeply immersive experience by completely filling the user's field of vision and enabling free movement within the virtual environment, distinguishing them from stationary VR rooms or cave systems. They offer portability, personalized use, potential cost-effectiveness and ongoing technological advancements in display quality, resolution, ergonomics and tracking systems, contributing to the creation of highly realistic and immersive VR experiences. Previous reviews define the concept of VR much more broadly[44] and/or focus on specific aspects of mindfulness like decentering and interoceptive awareness[45] as just outlined.

On a methodological level, this paper will address the growing criticism that systematic reviews receive. Those points of criticism include "a set of methodologies characterized by tight focus, exhaustive search, high rejection-to-inclusion ratio and an emphasis on technical rather than interpretive synthesis methods."[53] Other authors criticize that systematic reviews are often poorly conducted[54] or not suitably written for policy decision making[55] as well as they often fail to adequately capture the complexity of real-world phenomena and influential contextual factors.[56] At the center of the criticism is the often-mechanistic approach of the process, which is accompanied by a lack of intellectual contribution. This means that the highly structured approach to searching for and obtaining original studies sometimes comes at the expense of intellectual analysis and interpretation of the studies. To pick up on these points, Boell and Cecez-Kecmanovic's[57] hermeneutic approach for conducting literature reviews and literature research puts an additional focus on describing, classifying and critically assessing the totality of research results. Evidence mapping is employed to enhance the visualization of key findings. Therefore, this systematic review integrates an intellectual analysis and interpretation of the studies into the protocol-based PRISMA approach in order to conduct a methodological review of high quality identifying the effectiveness of those interventions.

Systematic literature review methodology

Eligibility criteria

In accordance with the PICOS approach [population (P), intervention (I), control/comparators (C), main outcome (O) and study design (S)] the following inclusion/exclusion criteria were used.[58]

Inclusion criteria:

IC1. Human participants of any gender and age
IC2. Immersive VR-based interventions that promote mindful content like awareness, commitment, acceptance, nonjudgmental attitude, (re-)focus or meditation

IC3. Passive-inactive control, alternative-active control following another psychological training or no control at all
IC4. Psychological/mental health outcomes (e.g., anxiety, pain, emotions, stress or mindfulness), physiological/physical health outcomes (i.e., cortisol, HRV, heart rate or lactate response)
IC5. Empirical studies of any design

Exclusion criteria:

EC1. Papers not written in neither English nor German
EC2. Papers published in the form of a review, meta-analysis, abstract (one or two pages) or posters
EC3. Papers dealing with technical configuration of VR-based mindfulness interventions

Information sources and search strategy

We conducted the systematic review according to the PRISMA guidelines.[59] To identify potentially relevant articles, a comprehensive search was conducted by the authors including a variety of study types covering randomized controlled studies as well as pilot and case studies. The study design intentionally encompassed more than just randomized controlled trials (RCTs) due to the early stage of research in this field. Nonrandomized trials, simple before–after comparisons or case–control designs hold significance for a systematic review, particularly in uncovering unexplored advantages and drawbacks and supplementing evidence derived from RCTs.[60] Six databases, IEEE (Institute of Electrical and Electronics Engineers), ACM (Association for Computing), Scopus, PubMed, Base and EBSCO (PsycArticles, PsycInfo, PsyIndex, Medline), with a link to health psychology and human–computer interaction themes were screened from the earliest available evidence to September 22nd, 2022. Relevant search terms were combined with Boolean conjunctions (OR/AND) and applied as follows: [(mindful* OR meditat*) AND ("virtual reality" OR "VR") AND (health OR physio* OR psycho* OR mental OR physical)]. Depending on the settings options in the database, the language and document/study type filters were preset.

Article selection, data collection and extraction strategy

Search results ($n = 949$) were checked for duplicates ($n = 541$) with Citavi®[61] and were then imported and processed in the Covidence systematic review management online system.[62] During the selection process at Covidence additional duplicates ($n = 12$) were found and removed. The remaining articles were first identified for further review by screening the titles and abstracts. In case of insufficient information in title and abstract, a full article was required. Titles, abstracts and full texts were strictly screened according to the inclusion and exclusion criteria by the two reviewers (AW and FS). Any disagreements were always resolved through discussion between the two reviewers; a third reviewer would have been consulted if the discrepancy could no bet settled. The identification process in this systematic review is illustrated in Figure 1.

Study risk of bias assessment

To assess risk of bias, different standardized tools were used in accordance with their study type and design respectively. For pre–post studies with no control group a checklist by the National Heart, Lung and Blood Institute[63] was applied. This checklist is one of the few available tools in this study category. For case-series,[64] quasi-experimental[65] and RCT studies[66] different Joanna Briggs Institute (JBI) checklists were chosen. The general choice of appraisal tools, especially for nonrandomized studies (NRSs), is complicated by the heterogeneity of this study category. It is often used as an umbrella term that encompasses a variety of designs such as experimental studies, quasi-experimental studies and traditional observational studies.[67] Since there is no gold standard for NRSs, we have attempted to identify the most common and practical assessment tools for NRS types, preferably from one organization. Farrah and colleagues[67] found that JBI checklists are one of the most commonly used in systematic reviews when multiple instruments are used according to different study designs. This prompted us to apply the three instruments mentioned. Any discrepancies that arose between the two raters (AW and FS) were identified and resolved through discussion. The full risk of bias assessment is provided in the Online Supplementary materials. Extracted data were used for the evidence mapping in order to describe, classify and critically assess the totality of research results.

Results

Literature search

The literature search resulted in 949 citations. After a first removal of duplicates by Citavi ($n = 541$), 408 documents were imported to Covidence[62] and an additional 12 duplicates were found and removed before screening. In total, 22 studies were included in the systematic review. Reasons for exclusions are listed in the flowchart (Figure 1). Tables 1 and 2 provide a summary of the selected studies.

In the following, we offer a concise overview of the psychological and physiological effects from VR-based mindfulness interventions as identified in the studies included. These studies are then subject to a further and deeper analysis employing the hermeneutic approach proposed by Boell and Cecez-Kecmanovic,[57] wherein we categorize and map them across distributional, methodological and content-related perspectives.

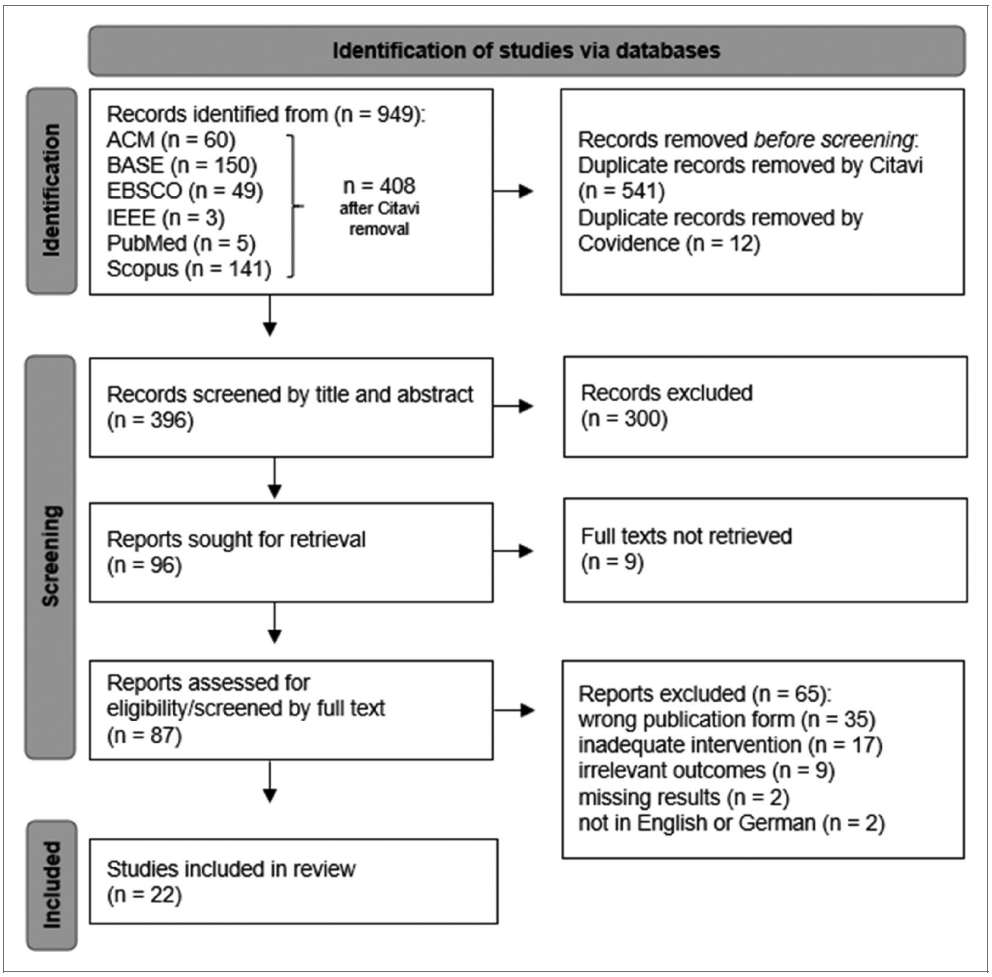


Figure 1. PRISMA flow chart (full texts not retrieved = no classic journal full text available, e.g., only as abstract format).

Psychological effects. The selected studies showed a broad spectrum of psychological effects of VR-based mindfulness interventions. These effects were observed among both healthy individuals and those in a prediseased state. In general, the following positive effects on psychological variables could be found: anxiety,[69–76] mindfulness,[74,77–81] various emotions or emotional states like anger, happiness or vigor,[70,74,79,80,82,83] different disease patterns like depression or posttraumatic disorder,[70,72,74,75,83,84] affect,[84–86] stress and distress respectively,[78,84,87] (presleep) arousal,[82,88] meditation experience[78,84,86] and others like quality of life or opioid craving.[70,87] It's worth noting that among the 22 studies, four only assessed their findings concerning psychological outcome variables descriptively.[75,79,84,85]

Effect sizes overall, including psychological and physiological outcomes, are only represented in half of the included studies. Looking into psychological outcome categories seven studies reported their results with effect sizes.

Concerning anxiety, as the most addressed physiological outcome, large effect sizes in reference to Cohen's guidelines[89] with $d > |.96|$ are represented in the studies by Navarro-Haro et al.[74] and Tarrant et al.[76] respectively with $\eta_p^2 = .60$. Furthermore, Min et al.[73] reported small to medium effects with $d = 2.31$, while Tarrant et al.[76] observed effect sizes ranging from $\eta_p^2 = .02$ to $\eta_p^2 = .07$. Large correlation effects between anxiety and depression questionnaires ($r = .73$) respectively between two anxiety scales ($r > .53$), a self-report scale and a visual-analog scale, are reported by Kwon et al.[72] Mindfulness effects exhibit substantial magnitudes, ranging from $d = .96$ to $d = 1.07$, as indicated by research conducted by Feinberg et al.[78] and Navarro-Haro et al.[74,80] In addition, small ($d = |.02|$) and medium to large ($d = .26$) effects are present in Navarro-Haro et al.[74] Emotions and emotional states show a wide range of effect sizes, reaching from small ($d = .02/\eta_p^2 = .01$) to large ($d = |.89|/\eta_p^2 = .52$), depending on the ones examined by Navarro-Haro et al.,[74,80]

Table 1. Summary of included studies.

			Population			Intervention		
No.	Reference	Study type	EXP	CON	Target group, clinical condition/gender/age	VR/HMD technology	VR content	Length
1	Chandrasiri et al. (2020)	RCT	$n = 16$	$n = 16$	General population 16♀, 16♂ Age (years): $M = 27.25 \pm 6.04$, range = 18–64	EXP: Oculus rift CON: –	A walk on the beach/360° landscape video of Australia's coast	EXP/CON: 1 × 20 minutes
2	Faraj et al. (2021)	Pre-post study with no control group	$n = 15$	–	MMT patients 11♀, 5♂ Age (years): 2 × 19–29, 5 × 30–49, 8 × 50 +	Windows mixed reality headset	Different VR-guided meditations (a.o. KKC techniques)	12 weeks, 2 × 15 minutes/week
3	Feinberg et al. (2022)	Pre-post study with no control group	$n = 15$	–	Novice meditators Age (years): range = 18–34, median = 21	Oculus Quest	Zen VR interaction: progressive lessons to teach technical/philosophical foundations of meditation	4 weeks, 2 × 25 minutes/week
4	Frewen et al. (2020)	Case series	$n = 10$	–	Veterans 2♀, 8♂ PTSD self-reported symptom severity: $M = 41.70 \pm 6.55$, range = 31–54	Dell Visor headset	Guided meditation VR	10 minutes introduction (choice of environment) + 5 minutes guided meditation (loving kindness vs. focused attention) + freely exploring VR environment using VR blink teleport functionality

(continued)

Table 1. Continued.

			Population			Intervention		
No.	Reference	Study type	EXP	CON	Target group, clinical condition/gender/age	VR/HMD technology	VR content	Length
5	Groninger et al. (2021)	RCT	$n = 52$	$n = 36$	Hospitalized participants with advanced heart failure 35♀, 53♂ Age (years): $M = 56.1 \pm 13.2$	EXP: Oculus Go + over-the-ear headphones or device speakers CON: tablet + over-the-ear headphones or tablet speaker	EXP: forest of serenity (Holosphere VR®, Birmingham, UK) CON: meditation with instrumental background music + 2D imagery of a peaceful lakeside view	EXP/CON: 1 × 10 minutes
6	Hargett et al. (2022)	Pre-post study with no control group	$n = 11$	-	Hospitalized participants with preexisting opioid tolerance or opioid use disorder 6♀, 5♂	Oculus Go	Calm® application (guided meditations incl. gratitude, impermanence, choice, grief etc.) 7	1 × 10 minutes
7	Hawes and Arya (2021)	RCT	$n_{meditation} = 26$ 2nd condition: primed vs. no-primed	$n_{game} = 30$	(Non) students 30♀, 26♂ Age (years): range = 17–48	Oculus Quest	EXP: Calm® application (VR-guided meditation) CON: Beat Saber Demo (VR game)	EXP: 1 × 5 minutes CON: 2 × 2 minutes 35 seconds
8	Kazzi et al. (2018)	Quasi-experimental study	$N = 16$ (two experiments)		Healthy participants 9♀, 7♂ Age (years): $M = 34 \pm 13$, range: 20–68	Samsung Gear VR	EXP: VR 3D HMD active CON: VE 2D via phone passive CG: seated rest	EXP/active CON: 1 × 5 minutes guided relaxation/breathing passive CON: 1 × 5 minutes rest

(continued)

Table 1. Continued.

			Population			Intervention		
No.	Reference	Study type	EXP	CON	Target group, clinical condition/gender/age	VR/HMD technology	VR content	Length
9	Kim et al. (2022)	Pre-post study with no control group	$N = 5$	-	3♀, 2♂ Age (years): range = 21-35	Oculus Quest 2	Melody of the Mysterious Stones (mini games with the focus to create a flow experience)	Not specified
10	Kwon et al. (2020)	Pre-post study with no control group	$N = 22$	-	Typically developing children, no history of psychiatric illnesses Age (years): $M = 11.59 \pm 1.84$, range = 9-16	Samsung Gear VR	VR scene day before exam (Exam1) → VR at-home meditation (Med1) → VR scene exam day (Exam2) → VR at-school meditation (Med2)	Exam1: approx. 3 minutes Med1: approx. 3 minutes Exam2: approx. 2 minutes Med2: approx. 4 minutes
11	Min et al. (2020)	Quasi-experimental study	$N = 25$		Paid subjects, 16♀, 9♂ Age (years): $M = 23 \pm 3.485$, range = 19-35	Oculus CV1	"Drop the (heart) beat (rate)" → VR scenario + haptic device which gives simulated kinesthetic feedback of a beating heart VR (POS): calm, soothing content–haptic device with fluffy cover VR (NEG): disturbing, unnerving content–haptic device with wet cover	3 minutes 30 seconds. VR NEG or POS → 3 minutes rest → 3 minutes 30 seconds. VR NEG or POS (counter-balanced order)
12	Mistry et al. (2020)	Quasi-experimental study	$N = 96$ 8 between groups conditions participants were randomized with counterbalancing (12 participants in each condition)		Undergraduate university students with different experience in meditation 54♀, 42♂ Age (years): range = 17-22	Dell Visor Windows mixed reality headset + headphones	Guided meditation VR	10 minutes introduction: choice of environment + music → 5 minutes VR/non-VR (randomized order + randomized content: FAM or LKM + randomized completion of meditation in non-VR group: eyes open or closed) → 5 minutes VR/non-VR
13	Nararro-Haro et al. (2016)	Case series	$N = 1$	-	32 years female with diagnosed borderline	Kaiser Electro-Optics goggles	1 month of standard DBT® → 4 sessions of VR + DBT®: VR scenario with an illusion of floating down a	4 × 8-10 minutes (one session per week for 4 weeks)

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Table 1. Continued.

			Population		Intervention			
No.	Reference	Study type	EXP	CON	Target group, clinical condition/gender/age	VR/HMD technology	VR content	Length
					personality disorder and substance use disorder/ polysubstance dependence/ multiple hospitalizations due to drug overdose, suicide attempt, nonsuicidal self-injuries		3-D-computer generated river + audio tracks (observing sounds, observing visuals, wise mind)	
14	Navarro-Haro et al. (2017)	Pre-post study with no control group	$N = 44$	-	Attendees of an international meeting with varying experience using computers and VR systems 28♀, 16♂ Age (years): $M = 45.32 \pm 13.20$, range = 21-69	Oculus Rift DK2	VR + DBT® mindfulness skills training: VR scenario with an illusion of floating down a 3-D-computer generated river + audio tracks (observing sounds, observing visuals, wise mind)	1 × 10 minutes (randomly assigned audio track)
15	Navarro-Haro et al. (2019)	RCT	MBI + VR: $n = 19$	MBI: $n = 20$	GAD diagnosed participants 30♀, 9♂ Age (years): $M = 45.23 \pm 11.23$	Oculus Rift DK2	MBI: mindfulness -based program developed by García Campayo and Demarzo for both conditions together MBI + VR: VR + DBT® mindfulness skills training	MBI: 7 × 90 minutes group sessions MBI + VR: 6 × 90 minutes group sessions + 6 × 15 minutes (10 minutes VR + DBT®/5 minutes measures)
16	Roo et al. (2017)	Quasi-experimental study	VR/SAR: $N = 12$ counterbalanced order of conditions		Participants interested in meditation and varying practical exercise 12♀ Age, years: 45 ± 11	Oculus Rift	VR: meditation with focus on breathing SAR: a sandbox is connected to physiological sensors to create a mindful interactive experience where the user can shape her own	1st condition: VR → SAR 2nd condition: SAR → VR VR/SAR: 1 × 10 minutes

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Table 1. Continued.

			Population			Intervention		
No.	Reference	Study type	EXP	CON	Target group, clinical condition/gender/age	VR/HMD technology	VR content	Length
							world that evolves according to breathing/heart rate	
17	Semertzidis et al. (2019)	Pre-post study with no control group	$N = 12$	-	Nonclinical, healthy participants 3♀, 9♂ Age (years): $M = 33 \pm 11.86$	VR headset (no specification)	Inter-dream system: neurofeedback modulating visuals (displayed in VR headset) + interactive bed with haptic feedback + sound	1×10 minutes
18	Seol et al. (2017)	Pre-post study with no control group	$N = 5$	-	Panic disorder patients	Oculus CV1	VR scenario: 1. neutral/peaceful state, 2. panic exposure/escape button, 3. "drop the beat"	2 sessions with 1-2 week break
19	Tarrant et al. (2018)	Quasi-experimental study	$n = 14$ Nonrandomized assignment	$n = 12$	GAD diagnosed participants 11♀, 3♂ (EXP) 9♀, 3♂ (CON) Age (years): $M = 46.21 \pm 10.77$ (EXP), $M = 48.17 \pm 20.11$ (CON)	Gear VR powered by Samsung Android S7 smartphone	EXP (VR): mindfulness in nature experience incl. 360° video photography + guided meditation CON: eyes-open resting period	EXP (VR): 1×5 minutes 41 seconds CON (rest): 1×5 minutes

(continued)

Table 1. Continued.

			Population			Intervention		
No.	Reference	Study type	EXP	CON	Target group, clinical condition/gender/age	VR/HMD technology	VR content	Length
20	Tarrant et al. (2022)	RCT	VR + neurofeedback: $n = 50$ Alternately assignment	Audio: $n = 50$	Frontline healthcare workers 43♀, 7♂ (EXP) 48♀, 2♂ (CON) Age (years): $M = 42.16 \pm 14.4$ (EXP), $M = 40.9 \pm 13.9$ (CON)	EXP: Oculus VR goggles (+Brainlink Lite EEG headband integrating high beta brainwaves as visual biofeedback) CON: over the ear headphones + iPad	VR: VR Healium scenario "relaxation beach" = body-scan/relaxation mindfulness meditation Audio: audio track of "relaxation beach"	EXP/CON: 1 × 1 minute warm up + approx. 5 minutes intervention
21	Wren et al. (2021)	Pre-post study with no control group	$n = 61$	/	Children + young adults diagnosed with inflammatory bowel disease (ulcerative colitis or Chron's disease) 26♀, 35♂ Age (years): $M = 15.6 \pm 3.29$, range = 10–25	Samsung Gear VR + Samsung Galaxy S8 smartphone	MBVR = mindfulness-based VR intervention "MediMindfulness-Transitions" → aim: cultivating focused-attention + present moment awareness (breathing/natural environment)	1 × 6 minutes

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Table 1. Continued.

			Population		Intervention			
No.	Reference	Study type	EXP	CON	Target group, clinical condition/gender/age	VR/HMD technology	VR content	Length
22	Zambotti et al. (2022)	Quasi-experimental study	Good sleepers (SLE): $n = 34$ Insomnia sufferers (INS): $n = 18$ Counterbalanced order of intervention/control session		Junior and senior high-school students with/without insomnia disorder according to DSM-5 12♀, 6♂ (INS) 20♀, 14♂ (SLE) Age (years): $M = 18.4 \pm 0.7$ (INS), $M = 18.4 \pm 0.8$ (SLE)	Oculus Rift	Nature-based VR-guided meditation + paced breathing meditation (Nature Treks VR images of Greener Games)	EXP: 1×20 minutes VR meditation scenario CON: 1×20 minutes quiet activity of choice (e.g., watching TV, reading)

Note. VR: virtual reality; HMD: head-mounted display; RCT: randomized controlled trial; PTSD: posttraumatic stress disorder; MBI: mindfulness-based intervention; MMT: methadone maintenance treatment; KKC: Kids Kicking Cancer; FAM: focused attention meditation; LKM: loving kindness meditation; SAR: Spatial Augmented Reality; DSM: Diagnostic and Statistical Manual of Mental Disorders; PCG: postcentral gyrus.

Table 2. Measures and results of included studies.

		Outcomes	
Number	Reference	Measurement	Variables
1	Chandrasiri et al. (2020)	Toronto Mindfulness Scale (TMS)	• Total mindfulness: $p < .05$ ↑ (within-group, VR/non-VR); $p = 1.95$ (between-group, VR vs. non-VR) • Decentering: $p < .05$ ↑ (within-group, VR/non-VR); $p < .05$ (between-group, VR > non-VR) • Curiosity: $p = .102$ (within-group, VR); $p = .152$ (within-group, non-VR); $p = .932$ (between-group, VR vs. non-VR)
2	Faraj et al. (2021)	1. Visual analogue scales (VAS) 2. Saliva samples 3. MRI scanning	1. Pain: $p = .042$, $\eta^2 = 0.265$ (session × week rm-ANOVA, main effect of session) opioid craving/anxiety/depression: $p < .005$ (session × week rm-ANOVA, main effect of session) craving: $p = .022$ week 1–6 ↑/$p < .05$ week 7–9 ↓ (session × week rm-ANOVA, main effect of week) anger: $p > .05$, n.s. (no main or interaction effect) 2. Cortisol: $p < .001$, $\eta^2 = 0.62$ ↓ (session × week rm-ANOVA, main effect of session) c-reactive protein (CRP): $p > .05$ (no main or interaction effect) 3. Pain neuromatrix activation • Positive activation at baseline (from zero) in left/right PCG (postcentral gyrus): $p < .001$/$p = .0123$ • Left PCG pain-related activity: $p = 0.23$ ↓ (baseline vs. post) • Higher self-reported pain functional interference at baseline associated with higher pain-related activation in left PCG at baseline: $p = .03$, $r(15) = .56$ • Higher baseline presession cortisol associated with higher pain-related activation in left PCG at baseline: $p = .02$, $r(15) = .591$ • Higher baseline pre-/postsession cortisol levels associated with higher pain-related activation in right/left anterior insula (AI) at post-intervention: $p < .05$, $r = .56$ to $.70$ • Higher baseline presession CRP associated with higher pain-related activation left PCG at baseline: $p = .037$, $r(14) = .557$ • Higher baseline postsession CRP associated with higher pain-related activation in the right PCG and left AI: $p = .021$, $r(12) = .652$; $p = .025$, $r(12) = .640$Pain neuromatrix functional connectivity • Positive/negative functional connectivity between left/right PCG and other pain neuromatrix regions like dorsal posterior insula or cerebellum: $p < .001$ (baseline) • Changes in functional connectivity between left/right PCG and other pain neuromatrix regions like left caudate or left inferior parietal lobe: $p < .001$ (pre vs. post) • Higher baseline pain severity associated with higher functional connectivity: $p < .001$

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Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
			• Higher baseline pain functional interference associated with higher functional connectivity: n.s. • Higher baseline pain severity associated with higher functional connectivity at the postintervention time point: $p < .001$ • Higher baseline functional interference associated with higher functional connectivity at the postintervention time point: $p < .001$ • Higher baseline pain severity associated with changes in functional connectivity from pre- to postintervention: $p < .001$
3	Feinberg et al. (2022)	1. Mindfulness Awareness Attention Scale (MAAS) 2. Cognitive and Affective Mindfulness Scale-Revised (CAMS-R) 3. Perceived Stress Scale (PSS) 4. Meditation questionnaire (10-point Likert scale)	1. MAAS scores: $p = .011$, Cohen's $d = .96$ ↑ (pre vs. post) 2. CAMS-R scores: $p < .01$, Cohen's $d = .89$ ↑ (pre vs. post) 3. PSS-scores: $p = .059$, Cohen's $d = .55$ ↓ 4. Ability to meditate during the lesson: $p < .001$, Cohen's $d = 1.43$ ↑ (1st vs. 8th lesson) Overall ability to meditate: $p < .0001$, Cohen's $d = 2.03$ ↑ (1st vs. 8th lesson) Confidence in meditating on their own: $p < .001$, Cohen's $d = 1.76$ ↑ (1st vs. 8th lesson)
4	Frewen et al. (2020)	1. Modified Differential Emotional Scale (mDES) 2. Buddhist Affective States Scale (BASS) 3. Meditative Experience Questionnaire (MEQ) 4. Symptom Checklist 10-Revised (SCL-10R) 5. Self-report of symptoms of PTSD (PCL-5)	1. Positive/negative affect ratings: high degree of positive affect, very little negative affect 2. Buddhist affective state: high level of certain affective states 3. Meditative experience: lower "normative" meditative experiences 4. Psychological distress: very rarely experienced psychological symptoms 5. PTSD symptoms: very rarely experienced psychological symptoms → postintervention data; results are only at descriptive level!
5	Groninger et al. (2021)	1. Self-reported pain scores (Likert scale 0–10) 2. Functional Assessment of in Chronic Illness Therapy in Palliative Care 14 item scale (FACIT-Pal 14) 3. National Comprehensive Cancer Network Distress Thermometer	1. Pain (primary outcome) • $p < .0001$ ↓ (within-group, VR pre–post); $p = .0001$ ↓ (within-group, guided imagery pre–post) • $p < .0001/p = .0012$ ↓ (rm-ANOVA mixed model, time effect, VR/guided imagery) • $p = .0153$ (postintervention comparison, VR scores < guided imagery scores) • $p = .0011$ (post–pre comparison, VR score decrease > guided imagery score decrease) • $p = .0002/p = .0966$ ↓ (24 hours postintervention compared to baseline, VR/guided imagery) • $p < .0001/p = .0019$ ↓ (intention-to-treat analysis, within-group, pre vs. post, VR/guided imagery)

(continued)

Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
			• $p < .0001/p = .0628$ ↓ (intention-to-treat analysis, within-group, pre vs. post, incl. originally assigned groups, VR/guided imagery) 2. Quality of life (secondary outcome) • *Total FACIT-Pal 14 score:* $p = .0255$ ↑ (pre vs. post, VR); $p = .0060$ ↑ (pre vs. post; guided imagery) • *Total FACIT-Pal 14 score*: $p = .0863$, n.s. (postintervention comparison, VR vs. guided imagery) • *Total FACIT-Pal 14 score:* $p = .05615$, n.s. (post-pre comparison, VR vs. guided imagery) • "*I have been short of breath*": $p = .0272$ ↑ (pre vs. post, VR); $p = .6889$, n.s. (pre vs. post, guided imagery) • "*I have been short of breath*": $p = .7066$, n.s. (postintervention comparison, VR vs. guided imagery) • "*I have been short of breath*": $p = .2095$, n.s. (post-pre comparison, VR vs. guided imagery) • "*I am content with the quality of life right now*": $p = .12342$, n.s. (pre vs. post, VR); $p = .0416$ ↑ (pre vs. post; guided imagery) • "*I am content with the quality of life right now*": $p = .5475$, n.s. (postintervention comparison, VR vs. guided imagery) • "*I am content with the quality of life right now*": $p = .6859$, n.s. (post-pre comparison, VR vs. guided imagery) 3. distress (secondary outcome) • *Total distress score*: $p = .0255$ ↑ (pre vs. post, VR); $p = .0060$ ↑ (pre vs. post; guided imagery) • *Total distress score*: $p = .6314$, n.s. (postintervention comparison, VR vs. guided imagery) • *Total distress score*: $p = .9943$, n.s. (post-pre comparison, VR vs. guided imagery)
6	Hargett et al. (2022)	Self-reported pain scores (Likert scale 0–10)	• Pain: $p = .03$ ↓ (pre vs. post)
7	Hawes and Arya (2021)	1. Shortened version of State and Anxiety Inventory (STAI) 2. University of California Matrix Reasoning Task (UCMRT)	1. Anxiety • $p = .021$ (between-subjects, game > meditation)

(continued)

Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
			• $p < .0001$ (within-subjects, primed vs. no-primed) • $p = .824$ n.s. (within-subjects, primed/no-primed × game/meditation) • $p = .0003$ (VR game priming, posthoc); $p = .000007$ (VR meditation priming, posthoc) • $p = .41$, n.s. (Δ prime vs. no-primed: VR meditation vs. VR gaming) 2. Cognitive bandwidth • $p = .232$ n.s. (between-subjects, game vs. meditation) • $p = .009$ (within-subjects, primed vs. no-primed) • $p = .061$ n.s. (within-subjects, primed/no-primed × game/meditation) • $p = .0007$ (VR game priming, posthoc); $p = .34$ (VR meditation priming, posthoc) • $p = .03$ (Δ prime vs. no-primed: VR meditation vs. VR gaming)
8	Kazzi et al. (2018)	1. Finger blood pressure (SphygomoCor XCEL, ATCor Medical) 2. Electrocardiogram (ECG; Nexfin, Edwards Life Sciences)	1. Blood pressure • *Systolic blood pressure (SBP, mmHg):* $p = .0238$; *diastolic blood pressure (DBP, mmHg):* $p = .966$ (rm-ANOVA; seated rest vs. 2D vs. VE) • *SBP:* $p = .767$ (following handgrip: rest vs. VE); $p = .172$ (following serial events: rest vs. VE) • *DBP*: $p = .794$ (following handgrip: rest vs. VE); $p = .769$ (following serial events: rest vs. VE) • *Mean arterial pressure (MAP):* n.s. (following handgrip: rest vs. VE); n.s. (following serial events: rest vs. VE) • *Pulse pressure (PP):* n.s. (following handgrip: rest vs. VE); n.s. (following serial events: rest vs. VE) 2. Heart rate (HR) • $p = .092$ (rm-ANOVA; seated rest vs. 2D vs. VE) • $p = .448$ (following handgrip: rest vs. VE); $p = .775$ (following serial events: rest vs. VE)Heart rate variability (HRV) • *Total power (10^3 ms^2):* $p = .364$ (rm-ANOVA; seated rest vs. 2D vs. VE); n.s. (following handgrip: rest vs. VE); n.s. (following serial events: rest vs. VE) • *LF power (nu):* $p = .585$ (rm-ANOVA; seated rest vs. 2D vs. VE); n.s. (following handgrip: rest vs. VE); $p < .01$ (following serial events: rest < VE) • *HF power (nu):* $p = .526$ (rm-ANOVA; seated rest vs. 2D vs. VE); n.s. (following handgrip: rest vs. VE); $p < .05$ (following serial events: rest > VE) • *LF/HF ratio:* $p = .117$ (rm-ANOVA; seated rest vs. 2D vs. VE); n.s. (following handgrip: rest vs. VE); $p < .05$ (following serial events: rest < VE)
9	Kim et al. (2022)	Positive and Negative Affect Schedule (PANAS)	• Positive affect schedule: $M_{pre} = 20.2$, $SD_{pre} = 7.96$; $M_{post} = 14.2$, $SD_{post} = 5.02$ ↓

(continued)

Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
			• Negative affect schedule: $M_{pre} = 12.4$, $SD_{pre} = 6.28$; $M_{post} = 4.8$, $SD_{post} = 3.19$ ↓ → Results are only at descriptive level!
10	Kwon et al. (2020)	1. Physiological measures, BIOPAC MP 160 system 2. VAS anxiety, 0–10 scale 3. Clinical scales: Korean Test Anxiety Inventors (K-TAI), Children's Depression Inventory (CDI), Korean State-Trait Anxiety Inventory (STAI-C)	1. Physiological measures (heart rate = HR; heart rate variability = HRV) • *Heart rate* (see VAS anxiety results) • *Root mean square of the successive differences (RMSSD, HRV):* $p = .036$ (mixed ANOVA; main time effect) • *Average of NN (AVNN, HRV):* $p = .05$ (mixed ANOVA; main time effect); $p < .05$ (posthoc analysis, Session A vs. Session B) • *Standard deviation of NN (SDNN, HRV):* $p = .002$ (mixed ANOVA; main time effect); $p < .05$ (posthoc analysis; Exam1−Med1/Exam2−Med2) • *Proportion of NN50 (pNN50, HRV):* $p = .199$, n.s. (mixed ANOVA) 2. VAS anxiety • $p = .0012$ ↑ (rm-ANOVA posthoc; after Exam1); $p = .001$ ↓ (rm-ANOVA posthoc; after Med1); $p = .006$ (rm-ANOVA posthoc; after Exam2); $p = .015$ (rm-ANOVA posthoc, after Med2) • VAS anxiety changes* ↔ average heart rate (AVHR): $r(19) = .62$, $p = .003$ (Session A); n.s. (Session B); $r(19) = -.66$, $p = .001$ (during Med1); $r(19) = -.54$, $p = .011$ (during Med2) 3. Clinical scales • *K-TAI ↔ CDI:* $r(20) = .73$, $p < .001$ (correlation) • *VAS anxiety ↔ K-TAI:* $r(20) = .53$, $p = .01$ (correlation; pre-Med1); $r(20) = .69$, $p < .001$ (correlation; pre-Med2);*Session A: pre-Med1−baseline/Session B: pre-Med2−post-Med1
11	Min et al. (2020)	1. State and Anxiety Inventory (STAI) 2. Physiological measures, ECG sensor (PSL-iECG2, PhysioLab)	1. (Mental) anxiety • *POS:* $p < .001$, $d = 1.404$ ↓ (ANOVA, pre vs. post); $p = .001$, $d = .231$ (ANOVA, pre vs. post2/retrospective) • *NEG:* $p < .001$, $d = 2.635$ ↑ (ANOVA, pre vs. post); $p < .001$, $d = 1.089$ (ANOVA, pre vs. post2/retrospective) 2. Heart rate (HR) • *POS:* $p < .001$ ↓ (ANOVA; pre vs. post) • *NEG:* $p = .0829$, n.s. (ANOVA, pre vs. post)Blood pressure (BP) • *POS: systolic BP with $p < .001$ ↓; diastolic BP with $p = .002$ ↓ (ANOVA, pre v. post)* • *NEG: systolic P with $p = .831$, n.s.; diastolic BP with $p = .564$, n.s. (ANOVA, pre v. post)*Galvanic skin resistance (GSR) • *POS: n.s. (ANOVA, pre v. post)* • *NEG: $p = .001$ ↑ (ANOVA, pre v. post)*

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Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
12	Mistry et al. (2020)	1. Modified Differential Emotional Scale positive/negative affect (mDES-PA/NA) 2. Buddhist Affective States Scale (BASS) 3. Meditative Experience Questionnaire (MEQ)	1. Positive affect • *TYPE* (VR vs. non-VR): $p < .001$, $\eta^2 = .472$ (multivariate level) • *TYPE* × *ORDER* (VR first/second vs. non-VR second/first): $p < .001$, $\eta^2 = .338$ (univariate level) → significant for all positive affective states besides "grateful, appreciative, thankful" ($p = .173$) + "love, closeness, trust" ($p = .071$) • VR meditation first reported greater positive affect (follow-up within-group *t*-tests)negative affect: TYPE n.s.; TYPE × ORDER n.s. 2. Buddhist affective states • *TYPE*: $p < .001$, $\eta^2 = .402$ (multivariate level) • *TYPE*: all BASS are significant (univariate level) besides "confusion, uncertainty, doubt" ($p = .026$, n.s.) • *TYPE* × *ORDER*: $p = .004$, $\eta^2 = .402$ (multivariate level) • *TYPE* × *ORDER*: significant for "absorption, immersion, engrossment" + "oneness, unity, connectedness" + "ecstasy, rapture, bliss" (univariate level) • VR meditation first is associated with higher BASS (follow-up test within-group *t*-tests) 3. Meditative experiences • *TYPE*: $p = .003$, $\eta^2 = .323$ (multivariate level) → e.g., "less awareness of the presence of others in the room" • *TYPE* × *ORDER*: $p < .001$, $\eta^2 = .323$ (multivariate level) → e.g., "feeling relaxed and calm"; n.s. (univariate level) • VR meditation first is associated with e.g., greater "pleasant or happy thoughts or memories"; no differences for those who completed VR meditation second (follow-up within-group *t*-test) • Group differences are restricted to response to the non-VR meditation, e.g., less "feeling relaxed an calm" by those participants receiving the VR meditation first ($p = .001$, follow-up between-group *t*-test)
13	Nararro-Haro et al. (2016)	1. Adapted DBT® diary card to assess urges (0–5 scale) and emotions (0–100 scale) 2. Adapted KIMS-short version	1. Urge to commit … *suicide/self-harm/quit therapy/use substances:* reduced after VR mindfulness exercise ↓ Emotions–*fear/anger/guilt/shame/disgust*: reduced after VR mindfulness exercise ↓ Emotions–*joy*: session 1 ↑, session 2 ↔, session 3 ↑, session 4 ↓ 2. Mindfulness scores • *Wised mind/observing sounds VR scenario*: increase in mindfulness scores ↑

(continued)

Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
			• *Observing visuals VR scenario:* slight decrease in mindfulness scores ↓→ Results are only at descriptive level!
14	Navarro-Haro et al. (2017)	1. Emotional State Scale (VAS) 2. Mindfulness Awareness Attention Scale (MAAS)	1. Emotional state • *Joy*: n.s., $d = .06$ (paired *t*-test, pre vs. post) • *Sadness:* $p < .01$, $d = .44$ ↓ (paired *t*-test, pre vs. post) • *Anger*: $p < .05$, $d = .28$ ↓ (paired *t*-test, pre vs. post) • *Surprise*: n.s., $d = .24$ (paired *t*-test, pre vs. post) • *Anxiety*: $p < .01$, $d = .51$ ↓ (paired *t*-test, pre vs. post • *Relax:* $p < .01$, $d = .68$ ↑ (paired *t*-test, pre vs. post) • *Vigor*: n.s., $d = .02$ (paired *t*-test, pre vs. post) 2. State of mindfulness: $p < .001$, $d = .75$ ↑ (paired *t*-test, pre vs. post)
15	Navarro-Haro et al. (2019)	1. General Anxiety Disorder 7 Items (GAD-7) 2. Hospital Anxiety and Depression Scale (HADS) 3. Five Facets of Mindfulness Questionnaire (FFMQ) 4. Difficulties of Emotion Regulation Scale (DERS) 5. Multidimensional Assessment of Interoceptive Awareness (MAIA) 6. Emotional state scale (7-point Likert scale)	1. GAD-7 (primary outcome): $p < .001$, $d = -1.33$ ↑ (within-group MBI + VR, pre vs. post); $p < .001$, $d = -1.36$ ↑ (within-group MBI, pre vs. post) 2. HADS, anxiety and depression • *Anxiety*: $p < .001$, $d = -.96$ ↓ (within-group MBI + VR, pre vs. post); $p < .001$, $d = -1.27$ ↓ (within-group MBI, pre vs. post) • *Depression*: $p = .027$, $d = -.54$ ↓ (within-group MBI + VR, pre vs. post); $p < .001$, $d = -1.33$ ↓ (within-group MBI, pre vs. post) 3. FFMQ, mindfulness aspects • *Observing:* $p = .244$, n.s., $d = .26$ ↑ (within-group MBI + VR, pre vs. post); $p = .133$, n.s., $d = .34$ ↑ (within-group MBI, pre vs. post) • *Describing*: $p = .001$, $d = .85$ ↑ (within-group MBI + VR, pre vs. post); $p = .016$, $d = .73$ ↑ (within-group MBI, pre vs. post) • *Awareness*: $p = .003$, $d = .66$ ↑ (within-group MBI + VR, pre vs. post); $p < .001$, $d = 1.07$ ↑ (within-group MBI, pre vs. post) • *Nonjudging:* $p = .024$, $d = .55$ ↑ (within-group MBI + VR, pre vs. post); $p = .222$, n.s. $d = .65$ ↑ (within-group MBI, pre vs. post) • *Nonreactivity:* $p = .152$, n.s., $d = .58$ ↑ (within-group MBI + VR, pre vs. post); $p = .383$, n.s. $d = .39$ ↑ (within-group MBI, pre vs. post) 4. DERS, emotion regulation • *Inattention*: $p = .172$, n.s., $d = -.30$ ↓ (within-group MBI + VR, pre vs. post); $p = .016$, $d = -.67$ ↓ (within-group MBI, pre vs. post) • *Confusion:* $p = .014$, $d = -.59$ ↓ (within-group MBI + VR, pre vs. post); $p = .045$, $d = -.11$ ↓ (within-group MBI, pre vs. post) • *Nonacceptance:* $p = .202$, n.s., $d = -.28$ ↓ (within-group MBI + VR, pre vs. post); $p = .011$, $d = -.76$ ↓ (within-group MBI, pre vs. post)

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Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
			• *Interference:* $p < .001$, $d = -.84$ ↓ (within-group MBI + VR, pre vs. post); $p = .090$, n.s., $d = -.31$ ↓ (within-group MBI, pre vs. post) • *Impulse*: $p = .001$, $d = -.89$ ↓ (within-group MBI + VR, pre vs. post); $p = .004$, $d = -.88$ ↓ (within-group MBI, pre vs. post) 5. Interoceptive awareness • *Noticing*: $p = .419$, n.s., $d = .29$ ↑ (within-group MBI + VR, pre vs. post); $p = .080$, n.s., $d = .37$ ↑ (within-group MBI, pre vs. post) • *Distraction*: $p = .802$, n.s., $d = -.31$ ↓ (within-group MBI + VR, pre vs. post); $p = .892$, n.s., $d = -.02$ ↓ (within-group MBI, pre vs. post) • *Nonworrying*: $p = .534$, n.s., $d = .21$ ↑ (within-group MBI + VR, pre vs. post); $p = .220$, n.s., $d = .28$ ↑ (within-group MBI, pre vs. post) • *Attention regulation*: $p = .150$, n.s., $d = .29$ ↑ (within-group MBI + VR, pre vs. post); $p < .001$, $d = .72$ ↑ (within-group MBI, pre vs. post) • Emotional awareness: $p = .534$, n.s., $d = .12$ ↑ (within-group MBI + VR, pre vs. post); $p = .582$, n.s., $d = -.17$ ↑ (within-group MBI, pre vs. post) • *Self-regulation:* $p < .001$, $d = .98$ ↑ (within-group MBI + VR, pre vs. post); $p < .001$, $d = .89$ ↑ (within-group MBI, pre vs. post) • *Body-listening:* $p = .016$, $d = .54$ ↑ (within-group MBI + VR, pre vs. post); $p < .001$, $d = .92$ ↑ (within-group MBI, pre vs. post) • Trusting: $p = .005$, $d = .63$ ↑ (within-group MBI + VR, pre vs. post); $p = .002$, $d = .70$ ↑ (within-group MBI, pre vs. post) 6. Emotional state • *Happiness* ↑*:* $p = .083$, n.s. (session 1, pre vs. post); $p = .248$, n.s. (session 2, pre vs. post); $p = .160$, n.s. (session 3, pre vs. post); $p = .097$, n.s. (session 4, pre vs. post); $p = .361$, n.s. (session 5, pre vs. post); $p = .248$, n.s. (session 6, pre vs. post) • *Sadness* ↓*:* $p = .018$ (session 1, pre vs. post); $p = .001$ (session 2, pre vs. post); $p = .046$ (session 3, pre vs. post); $p = .032$ (session 4, pre vs. post); $p = .046$ (session 5, pre vs. post); $p = .265$, n.s. (session 6, pre vs. post) • *Anger* ↓*:* $p = .025$ (session 1, pre vs. post); $p = .091$, n.s. (session 2, pre vs. post); $p = .033$ (session 3, pre vs. post); $p = .164$, n.s. (session 4, pre vs. post); $p = .041$ (session 5, pre vs. post); $p = .212$, n.s. (session 6, pre vs. post) • *Surprise*↓/↑*:* $p = .009$ (session 1, pre vs. post); $p = .086$, n.s. (session 2, pre vs. post); $p = .399$, n.s. (session 3, pre vs. post); $p = .285$, n.s. (session 4, pre vs. post); $p = .040$ (session 5, pre vs. post); $p = .714$, n.s. (session 6, pre vs. post) • *Anxiety* ↓*:* $p = .002$ (session 1, pre vs. post); $p = .005$ (session 2, pre vs. post); p

(continued)

Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
			= .067, n.s. (session 3, pre vs. post); p = .065, n.s. (session 4, pre vs. post); p = .001 (session 5, pre vs. post); p = .049 (session 6, pre vs. post) • *Relaxation* ↑: p = .001 (session 1, pre vs. post); p = .001 (session 2, pre vs. post); p = .022 (session 3, pre vs. post); p = .003 (session 4, pre vs. post); p = .006 (session 5, pre vs. post); p = .015 (session 6, pre vs. post) • *Vigor* ↓/↑: p = .166, n.s. (session 1, pre vs. post); p = .295, n.s. (session 2, pre vs. post); p = .763, n.s. (session 3, pre vs. post); p = .999, n.s. (session 4, pre vs. post); p = .033 (session 5, pre vs. post); p = .248, n.s. (session 6, pre vs. post)
16	Roo et al. (2017)	Toronto Mindfulness Scale (TMS)	• TMS score: p = .13, n.s. (VR vs. SAR)
17	Semertzidis et al. (2019)	1. Pre-Sleep Arousal Scale (PSAS) 2. Positive and Negative Affect Schedule Extended (PANAS-X) 3. Muse® EEG headset	1. PSAS, pre-sleep arousal • *Somatic symptoms:* p = .25, n.s., d = .35 ↓ (paired t-test, pre vs. post) • *Cognitive symptoms:* p = .01, d = .28 ↓ (paired t-test, pre vs. post) 2. PANAS-X, emotion and affect • *General negative emotion:* p = .008, d = .90 ↓ (t-test, pre vs. post) • *General positive emotion*: p = .07, n.s., d = .30 ↑ (t-test, pre vs. post) • *Basic negative affect:* p = .004, d = .90 ↓ (t-test, pre vs. post) • *Basic positive affect:* p = .47, n.s., d = .15 ↑ (t-test, pre vs. post 3. EEG data (frequency bandwidth most prevalent by measure of absolute power): • *Delta (1–4 Hz):* M = .61, SD = .52 • *Theta (4–8 Hz):* M = .10, SD = .35 • *Alpha (7.5–13 Hz):* M = .29, SD = .16 • *Beta (13–30 Hz):* M = .21, SD = .24 • *Gamma (30–44 Hz):* M = .01, SD = .29
18	Seol et al. (2017)	1. Hamilton Anxiety Rating Scale (HAM-A) 2. Beck Anxiety Inventory (BAI) 3. Korean Version of the Montgomery-Asberg Depression Scale (K-MADRS) 4. State and Anxiety Inventory (STAI)	1. HAM-A, anxiety: scores ↓/↑ (pre vs. post, 2 sessions) 2. BAI, anxiety: scores ↓/↑ (pre vs. post, 2 sessions) 3. K-MADRS, depression: scores ↓/↑ (pre vs. post, 2 sessions) 4. STAI • *State:* scores ↓/↑ (pre vs. post, 2 sessions) • *Trait:* scores ↓/↑ (pre vs. post, 2 sessions)→ Results are only at descriptive level
19	Tarrant et al. (2018)	1. State and Anxiety Inventory (STAI, form Y/state portion) 2. EEG eyes-closed recordings with 19 electrodes in the standard 10–20 international placement 3. General Anxiety Disorder 7 Items (GAD-7)	1. STAI • *Scores:* p < 0.001, η_p^2 = .60 ↓ (2 × 3 ANOVA, group × time, main effect for time); p = .202, n.s., η_p^2 = .07 (2 × 3 ANOVA, no group effect); p = .54, n.s., η_p^2 = .02 (2 × 3 ANOVA, no interaction effect)

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Table 2. Continued.

	Outcomes	
Number Reference	Measurement	Variables
		• *Correlation analyses: STAI vs. High-Beta (T3-2):* $r = .456$, $p = .019$ 2. Mean power, cognitive state • *Alpha*: $p = .002$, $\eta_p^2 = .23$ ↑ (ANOVA, time effect); $p = .039$, $\eta_p^2 = .17$ (ANOVA, group effect, VR meditation > quiet rest); no interaction effect; $p = .058$, n.s., $p = .036$, $p = .033$ (follow-up ANOVA; T1: VR meditation ≈ quiet rest, T2/T3: VR meditation > quiet rest); $p = .998$, n.s. (T1-2, after rest interval, VR intervention); $p = .369$, n.s. (T1-2, after rest interval, quiet rest); $p = .302$, n.s. (T2-3, after VR meditation); $p = .149$, n.s. (T2-3, after quiet rest) • *Alpha1:* $p = .004$, $\eta_p^2 = .20$ ↑ (ANOVA, time effect); no interaction effect • *Alpha2*: $p = .006$, $\eta_p^2 = .004$ ↑/↓ (ANOVA, time effect); no interaction effect • *Beta:* $p = .005$, $\eta_p^2 = .20$ ↑ (ANOVA, time effect); no interaction effect • *Low beta:* $p = .001$, $\eta_p^2 = .26$ ↑ (ANOVA, time effect); $p = .032$, $\eta_p^2 = .18$ (ANOVA, group effect, EXP > CON); no interaction effect; $p = .036$, $p = .040$, $p = .025$ (follow-up ANOVA, T1/T2/T3: VR meditation > quiet rest); $p = .582$, n.s. (T1-2, after rest interval, VR meditation); $p = .205$, n.s. (T1-2, after rest interval, quiet rest); $p = .021$ (T2-3, after VR mediation); $p = .137$ (T2-3, after quiet rest) • *High beta:* $p = .085$, n.s., $\eta_p^2 = .098$ (ANOVA, no time effect); no interaction effectPower ratios, spectral power shifts from the perspective of relative power changes • *Alpha/Sum:* $p = .015$, $\eta_p^2 = .16$ (time effect); no group-differences or interaction effects • *Alpha1/Sum:* $p = .025$, $\eta_p^2 = .14$ (time effect); no group-difference effect; $p = .031$ ↑ (T2-3; after VR meditation/quiet rest) • *Alpha2/Sum:* $p = .093$, n.s., $\eta_p^2 = .09$ (no time effect), no group-difference effect • *Alpha1/Alpha2:* $p = .375$, n.s., $\eta_p^2 = .04$ (no time effect), no group-difference effect • *Alpha/Beta:* $p = .009$, $\eta_p^2 = .18$ (time effect); no group-differences or interaction effects • *Beta/Sum:* $p = .523$, n.s., $\eta_p^2 = .03$ (no time effect); no group-differences or interaction effects • *High-Beta/Sum:* $p = .009$, $\eta_p^2 = .18$ (time effect); no group-difference effect; $p = .009$ ↓ (T1-3; VR meditation > quiet rest) • *Low-Beta/Sum:* $p = .660$, n.s., $\eta_p^2 = .02$ (no time effect), no group-difference effect

(continued)

Table 2. Continued.

	Outcomes	
Number Reference	Measurement	Variables
		• *High-Beta/Alpha:* $p < .001$, $\eta_p^2 = .28$ (time effect); no group-difference effect; $p = .002$ ↓ (T2-3, VR meditation/quiet rest) • *Low-Beta/Alpha:* $p = .008$, $\eta_p^2 = .18$ (time effect); no group-difference effect; $p = .028$ ↓ (T2-3, VR meditation/quiet rest) • *Low-Beta/High-Beta:* $p < .001$, $\eta_p^2 = .36$ (time effect), no group-difference effect; $p = .032$, $\eta_p^2 = .13$ (interaction effect); $p = .053$, n.s., $p = .089$, n.s., $p = .040$ (follow-up ANOVA, T1/T2: VR meditation ≈ quiet rest, T3: VR meditation ≠ quiet rest); $p = .998$, n.s. (T1-2, after rest interval, VR meditation); $p = .578$, n.s. (T1-2, after rest interval, quiet rest); $p = .005$ (T2-3, after VR meditation); $p = .463$, n.s. (T2-3, after quiet rest)sLORETA, specific anterior and posterior cortical regions of interest for changes in regional activity across spectral bands • *ACC (anterior cingulate cortex):* • *Alpha*: $p = .649$, n.s., $\eta_p^2 = .02$ (no time effect); no group-difference effect • *Beta:* $p = .054$, $\eta_p^2 = .11$ (time effect); $p = .038$, $\eta_p^2 = .13$ (time × group effect); $p = .795$, n.s. (T1-2, after rest interval, VR meditation); $p = .171$, n.s. (T1-2, after rest interval, quiet rest); $p = .048$ ↓ (T2-3, after VR meditation); $p = .998$, n.s. (T2-3, after quiet rest) • *Theta:* $p = .664$, n.s., $\eta_p^2 = .02$ (no time effect); no group-difference effect • *PCC (posterior cingulate cortex)* • *Alpha*: $p = .017$, $\eta_p^2 = .16$ (time effect); $p = .042$ ↑ (T1-3, VR meditation/quiet rest); $p = .045$, $\eta_p^2 = .16$ (VR meditation > quiet rest) • Beta: $p = .006$, $\eta_p^2 = .19$ (time effect); $p = .015$ ↑ (T1-3, VR meditation/quiet rest); $p = .049$, $\eta_p^2 = .15$ (VR meditation > quiet rest) • Theta: $p = .106$, n.s., $\eta_p^2 = .09$ (no time effect) • CSD (current source density): linear increase over time for both groups 3. GAD-7, correlation analyses • *GAD scores vs. Alpha/Sum:* $r = -.47$, $p = .019$ (T1); $r = -.35$, $p = .080$ (T2); $r = -.43$, $p = .027$ (T3) • *GAD scores vs. Alpha1/Sum:* $r = -.46$, $p = .018$ (T1); $r = -.35$, $p = .078$ (T2); $r = -.43$, $p = .029$ (T3) • *GAD scores vs. Alpha2/Sum:* $r = -.12$ to $r = -.13$, $p > .20$ (T1/T2/T3) • *GAD scores vs. Low-Beta/High-Beta:* $r = -.45$, $p = .023$ (T1); $r = -.43$, $p = .030$ (T2); $r = -.39$, $p = .048$ (T3) • *GAD scores vs. High-Beta/Sum:* $r = .48$, $p = .013$ (T1); $r = .45$, $p = .022$ (T2); $r = .44$, $p = .025$ (T3) • *GAD scores vs. Low-Beta/Sum:* $r = .10–.12$, $p > .50$ (T1/T2/T3)

(continued)

Table 2. Continued.

		Outcomes	
Number	Reference	Measurement	Variables
20	Tarrant et al. (2022)	Brunel Mood Scale	• Anger: $p = .268$, n.s., $\eta_p^2 = .01$ (no group × time interaction) $p = .001$, $\eta_p^2 = .29$ (time effect, VR/meditation↓) $p < .001$, $\eta_p^2 = .29$ (group effect, audio > VR) • Tension $p = .248$, n.s., $\eta_p^2 = .01$ (no group × time interaction) $p < .001$, $\eta_p^2 = .52$ (main time effect, VR/meditation↓) $p = .365$, n.s., $\eta_p^2 = .01$ (no group effect) • Depression $p = .299$, n.s., $\eta_p^2 = .01$ (group × time interaction) $p < .001$, $\eta_p^2 = .42$ (time effect, VR/meditation↓) $p = .254$, n.s., $\eta_p^2 = .01$ (no group effect) • Vigor $p < .001$, $\eta_p^2 = .18$ (group × time interaction, VR↓/audio↑) $p = .190$, n.s., $\eta_p^2 = .02$ (no time effect) $p < .001$, $\eta_p^2 = .24$ (group effect, audio < VR) • Fatigue $p = .002$, $\eta_p^2 = .10$ (group × time interaction, VR↓/audio↑) $p = .076$, n.s., $\eta_p^2 = .03$ (no time effect) $p = .001$, $\eta_p^2 = .10$ (group effect) • Confusion $p = .003$, $\eta_p^2 = .08$ (group × time interaction, VR↓/audio ↔) $p = .038$, $\eta_p^2 = .04$ (time effect, VR↑/audio ↔) $p < .001$, $\eta_p^2 = .14$ (group effect) • Happiness $p < .001$, $\eta_p^2 = .18$ (group × time interaction, VR↑/audio ↔) $p < .001$, $\eta_p^2 = .15$ (main time effect, VR/meditation ↑) $p = .408$, n.s., $\eta_p^2 = .01$ (no group effect) • Calmness $p < .001$, $\eta_p^2 = .32$ (group × time interaction, VR↑/audio↓) $p < .001$, $\eta_p^2 = .22$ (main time effect, VR/meditation ↑) $p = .164$, n.s., $\eta_p^2 = .02$ (no group effect)
21	Wren et al. (2021)	1. Anxiety VAS scale 2. Pain VAS scale	1. Anxiety • *Preliminary efficacy:* $p = .001$ ↓ (pre vs. post) • *Exploratory analyses:* < 18 years ($n = 42$): $p < .001$ ↓ (pre vs. post) > 18 years ($n =$

(continued)

Table 2. Continued.

Number	Reference	Outcomes	
		Measurement	Variables
			19): $p = .41$ ↓ (pre vs. post)Diagnostic subgroups: $p > .05$, n.s. (Crohn's disease vs. ulcerative colitis following the intervention) 2. Pain • *Preliminary efficacy:* $p < .001$. ↓ (pre vs. post) • *Exploratory analyses:*< 18 years ($n = 42$): $p = .001$ ↓ (pre vs. post)> 18 years ($n = 19$): $p = .16$, n.s. (pre vs. post)Diagnostic subgroups: $p > .05$, n.s. (Crohn's disease vs. ulcerative colitis following the intervention)
22	Zambotti et al. (2022)	1. Pre-Sleep Arousal Scale (PSAS) 2. Daytime Insomnia Symptom Scale, VAS (DISS) 3. Physiological measures, EEG + ECG via Compumedics Grael® system 4. Saliva samples 5. Automatic sphygmomanometers	1. PSAS, cognitive arousal: no group (between, insomnia sufferers vs. good sleepers), condition (within, VR intervention vs. control) or group × condition effects 2. DISS, cognitive alertness/positive and negative mood/sleepiness: no group (between, insomnia sufferers vs. good sleepers), condition (within, intervention vs. control) or group × condition effects 3. Physiological measures • *EEG data:* No differences between resting state and following 20 minutes intervention/control in cortical activity Alpha power (occipital): $p < .001$, $\eta_p^2 = .08$ ↓ (time main effect, pre vs. 20 VR intervention) Sigma power (central/occipital): $p = .005$, $\eta_p^2 = .06$/$p = .002$, $\eta_p^2 = .07$↑ (time main effect, pre vs. 20 VR intervention) Beta power (frontal/central/occipital): $p = .002$, $\eta_p^2 = .07$/$p < .001$, $\eta_p^2 = .09$/$p < .001$, $\eta_p^2 = 16$ ↑ (time main effect, pre vs. 20 VR intervention) Gamma power (occipital): $p < .001$, $\eta_p^2 = .12$ ↑ (time main effect, pre vs. 20 VR intervention) No further group, time or group × time effects • *Heart rate (HR):* $p < .001$ ↓ (pre vs. post, VR meditation) → as well as levels preceding and following quiet activities (condition × time interaction: $p = .004$, $\eta_p^2 = 0.19$) No HR difference in baseline periods preceding the intervention and quiet activities No between-group differences • *Heart rate variability (HRV):* HF power: $p = 0.039$, $\eta_p^2 = 0.10$ (group main effect, insomnia sufferers < good sleepers); no condition/time effect; $p < .001$, $\eta_p^2 = 0.18$ (baseline vs. minutes 0-20 of VR meditation) LF power: no group difference; $p < .001$, $\eta_p^2 = 0.57$ ↑ (baseline vs. minutes 0–20 of VR

(continued)

Table 2. Continued.

Outcomes	
Number Reference	Measurement
	Variables
	intervention) VLF power: $p < .001$, $\eta_p^2 = 0.14$ ↑ (baseline vs. minutes 4–6, 8–10 of VR intervention) Total power: no group difference 4. Saliva, cortisol: $p < .001$, $\eta_p^2 = 0.25$ ↓ (condition main effect) 5. Blood pressure (BP): no significant effects for SBP/DBP

Semertzidis et al.[82] or Tarrant et al.[83] Concerning disease patterns, Navarro-Haro et al.[74] are the only ones reporting an effect size with medium to large effect ($d = -.54$) for depression. Large effect sizes in affect variables are present in the study by Mistry et al.[86] ($\eta^2 = .338–.472$) and Semertzidis et al.[82] ($d = .90$). However, the latter study also records small effects in the area of affect variables with $d = .15$. Positive effects in the area of stress and distress are solely reported with a medium to large effect ($d = .55$) in Feinberg et al.[78] Moreover, small to medium effects could be detected in presleep arousal by Semertzidis et al.[82] Concerning meditation experiences, large effects ($d > 1.43/\eta^2 = .323$) could be found in the studies by Feinberg et al.[78] and Mistry et al.[86] In the studies from our category "others," no effect sizes were provided by Faraj et al.[70] or Groninger et al.[87]

Physiological effects. The range of positive effects of VR-based mindfulness interventions on physiological variables is less diverse, the following outcome variables were identified: neurobiological markers including electroencephalogram (EEG) data of different brain waves, pain neuromatrix activation or cognitive bandwidth,[70,71,76,82,88] heart rate and HRV,[72,73,88,90] pain,[69,70,87,91] blood pressure,[73,88,90] cortisol respectively saliva samples[70,88] and galvanic skin resistance.[73]

Looking at the results within these categories, three studies supported them by reporting effect sizes, which are also categorized in reference to Cohen's guidelines.[89] For example, neurobiological markers, primarily including EEG data, reached effect sizes from small ($\eta_p^2 = .004$) to large ($\eta_p^2 = .57$) as provided by the studies from Tarrant et al.[83] and Zambotti et al.[88] In addition, Faraj et al.[70] showed different pain neuromatrix correlations, based on magnetic resonance imaging scans, with large effects ($r > .56$). The same study reported large effects regarding pain with $\eta^2 = .265$. Large effects in heart rate ($\eta_p^2 = .19$) and medium to large effects in HRV ($\eta_p^2 > .10$) were also detected in Zambotti et al.[88] Positive effects on cortisol, respectively saliva samples, were shown by Faraj et al.[70] and Zambotti et al.[88] with a large effect sizes of $\eta^2 = .265$ and $\eta_p^2 = .25$. Variables like blood pressure and galvanic skin resistance were presented without information on effect sizes.

Study risk of bias assessment

Figure 2 summarizes the results of the risk of bias assessment of methodological study quality using four standardized instruments. For this purpose, the respective ratings of the studies (see Online Supplementary materials) were used for an overall assessment and converted into the categories "yes," "no" and "some concerns." Pre–post studies with no control groups ($n = 9$) mostly lack in categories concerning sample size, blinding of outcome assessors and multiple outcome measures. Therefore, sample size was sometimes not sufficiently large enough to provide deep confidence as a priori analyses were largely nonexistent or the information whether outcome assessors were blinded was not given. In addition, outcome measures were mostly only recorded before and immediately after the intervention and no further or multiple measurements and especially no follow-up measurement to determine the stability of the effects was carried out. Nevertheless, 50% of the studies were rated with a good overall quality, 30% with fair and 20% with poor overall quality. The remaining studies were assessed through different JBI checklists. One of the case series ($n = 2$) studies was rated with poor quality due to a few unclear and not reported aspects like participants inclusion criteria, demographics of participants or appropriate statistical analyses. Reaching higher methodological study types, more than 60% of the quasi-experimental studies ($n = 6$) and 100% of the RCTs ($n = 5$) were rated with good overall quality even though some RCTs lacked in clearly reporting facts like allocation of groups or the blinding process. Some quasi-experimental studies revealed gaps in implementing a control group, multiple measurements and a follow-up in their study design.

Critical assessment of results

In the subsequent section, a critical assessment of the studies and their outcomes is provided based on evidence mapping with different analysis aspects. The distributional analysis includes an examination of the diverse publication platforms featuring articles on VR-based mindfulness interventions and their potential health implications. Furthermore, an exploration of the temporal and geographical trends in the publication of studies within this domain is undertaken. The methodological analysis aims to recognize the principal research methodologies used in our studies on VR-based mindfulness interventions and their psychological and physiological effects. This involves a comprehensive examination of applied sampling methodologies and study designs including aspects like randomization techniques and the constitution of control groups. Concurrently, the content mapping seeks to identify psychological and physiological variables considered in these studies, especially those with a more robust evidential foundation concerning the research query. This analysis also attempts to evaluate previous VR protocols in terms of their intensity, duration and the integration of mindfulness elements within the VR scenarios.

In summary, this section encompasses a comprehensive analysis and classification of studies, covering their distribution across various publication channels, temporal and geographical trends, methodological approaches and content perspectives, thereby contributing to a holistic understanding of VR-based mindfulness interventions and their associated effects on health outcomes.

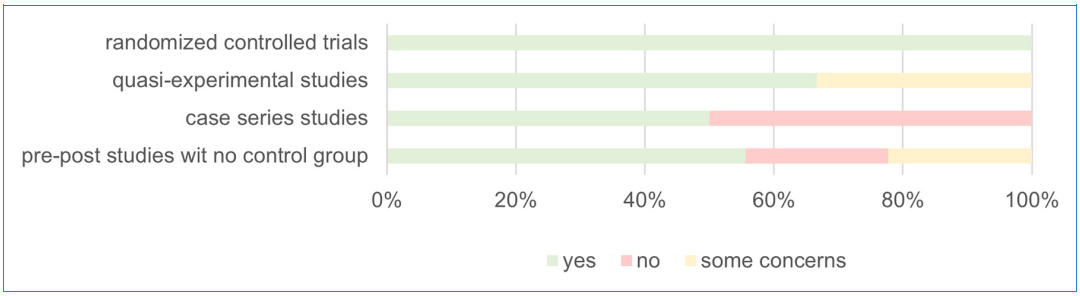


Figure 2. Summary of risk of bias assessment.

Distributional mapping of space, time and publication. Figure 3 uses a world map to show the nationality of the first author of each of the selected papers. This figure provides information on the geographical/spatial and temporal distribution of the studies addressing VR-based mindfulness interventions on health outcomes. A total of six nationalities were identified, of which North American and South Korean researchers show the largest output concerning VR-based mindfulness interventions. European interest in this field of research has so far been limited to Spanish and French researchers. Figure 4 provides insights on the publication evolution of the selected papers between 2016 and 2022; most of the research was published during the past 3 years (2020–2022; $n = 9$).

The selected papers are distributed through a variety of different publication channels. Among the identified publication sources, *Frontiers in Psychology* is represented three times.[74,76,79] Another 11 papers were published through different journals like *Pain Medicine*, *Virtual Reality* or *Digital Health* (see Table 3). Four papers were published through the ACM (Association for Computing Machinery) Conference on Human Factors in Computing Systems (CHI) between 2017 and 2022.[78,81,82,85] Two additional papers were drawn from IEEE (Institute of Electrical and Electronics Engineers) Conferences, one from the Conference on Engineering in Medicine and Biology Society in 2018 and another one from the Conference on Virtual Reality and 3D User Interfaces in 2021.[71,90] Moreover, two more papers were published through the ACM Symposium on Virtual Reality Software and Technology in 2017 and 2020.[73,75] Around 64% were published in journals, 27% were presented in conferences and only 9% in symposia. Consequently, journals appear to be the primary source where articles on VR-based mindfulness interventions and their effects on psychological and physiological outcomes are published.

Methodological mapping

Research design, sampling and study design. The aim of experimental research is to analyze and understand the effect of a program, treatment or intervention. Three types of experimental research designs are being distinguished in our studies: preexperimental, quasi-experimental and true experimental.[92,93] In total, 50% preexperimental (pre–post studies with no control group: $n = 9$; case series: $n = 2$), 27% quasi-experimental ($n = 6$) and 23% true-experimental studies (RCTs: $n = 5$) were identified in our selected papers. A methodological gain of quasi- and true-experimental studies can be explained through the addition of a control group. The following section takes a closer look at the sampling process of participants as well as to design specific aspects like sample size, randomization and control group conception (see Table 4) in all selected quasi- and true-experimental studies ($n = 11$).

As part of the sampling process, the application and clear formulation of inclusion and exclusion criteria strongly differ between those 11 selected studies. For example, Hawes and Arya[71] or Min et al.[73] do not mention any inclusion or exclusion criteria at all and although Roo et al.[81] or Mistry et al.[86] do cite inclusion criteria, exclusion criteria are not discussed further. However, a whole set of clear inclusion and exclusion criteria for participation is present in studies like Groninger et al.,[87] Kazzi et al.,[90] Tarrant et al.[76,83] or Zambotti et al.[88] as can be seen in Table 4. A similar diverse pattern can be observed in a comprehensive and clear presentation of the demographic characteristics of the study cohort.

Regarding study design, total sample size varies widely ($M = 34$, SD = ±34, minimum = 1, maximum = 100) in all 22 selected studies (see Figure 5).

Furthermore, the control group design consists of different combinations of active/passive or (non) randomized/counterbalanced/alternating group allocations: (a) active + randomized ($n = 5$), (b) active + counterbalanced ($n = 4$), (c) active + alternating ($n = 1$), and (d) passive + nonrandomized ($n = 1$). Out of 11 quasi- and true-experimental studies, 10 out of 11 studies choose an active control group and so only one study had a passive, resting, control group.[76] The active control group conditions predominantly comprised audio-based interventions, such as guided meditations.[77,86,87,90] However, alternative interventions using VR/AR applications,[71,73,81,83] a quiet activity[88] or a traditional MBI-intervention[74] were also administered.

In addition, a closer look was taken at the implementation of multiple measurement time points, which was also a rarely fulfilled criterion in the risk of bias assessment. Broadly, within this systematic review, most quasi- and true-experimental

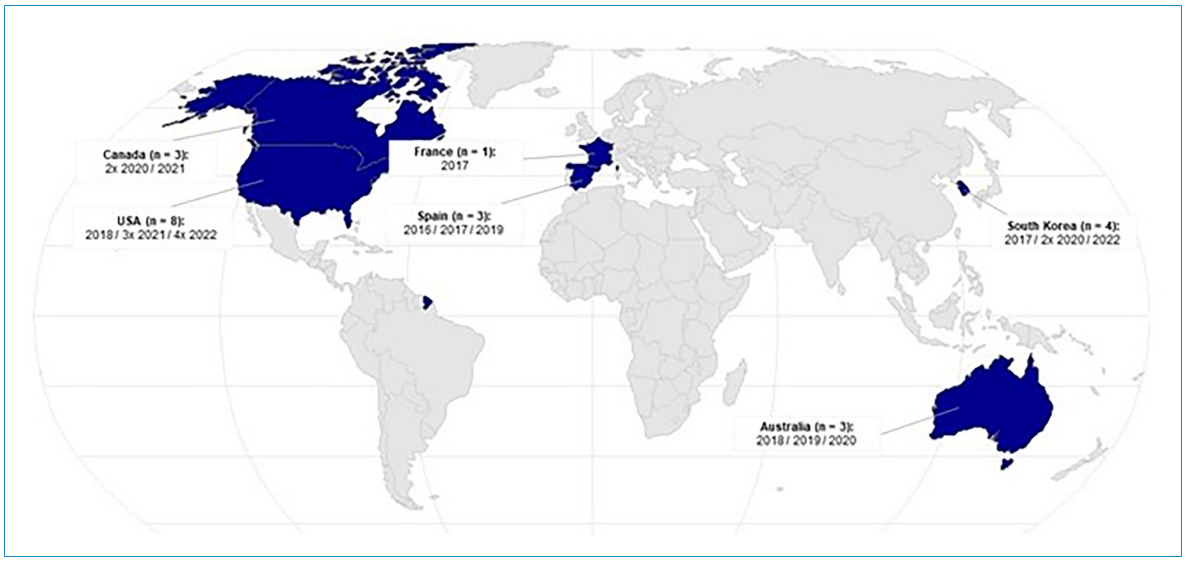


Figure 3. Geographical distribution.

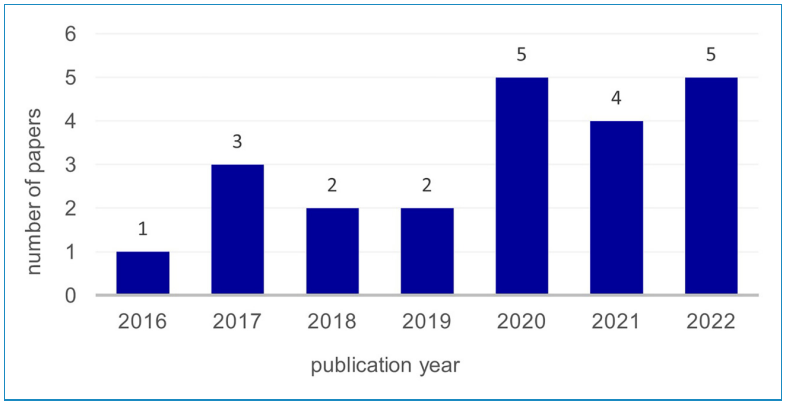


Figure 4. Temporal distribution.

studies primarily measure their variables before and after the intervention, with some additionally measuring physiological variables during the intervention.[73,88,90] However, the inclusion of baseline measurements as an initial status[76] and follow-up measurements[73] is remarkably rare.

Subjective vs. objective methods. In our selected studies, 14 papers[69,74,75,77–81,83–87,91] relied exclusively on subjective data (64%), while seven studies[70–73,76,82,88] used a combination of subjective and objective data collection methodologies (32%) and a single study[90] exclusively utilized objective data, representing 4% of the total studies. Subjective data primarily encompass psychological health outcomes such as anxiety, various emotions and mindfulness, while objective data predominantly pertain to the recording of physiological health outcomes, including blood pressure, saliva composition and HRV. A comprehensive outline of all employed subjective instruments and their respective objectives is provided in the Online Supplementary materials, with certain instruments being utilized across multiple studies.

Content mapping

Outcome variables. Directly linked to the measuring instruments are the respective outcomes representing psychological and physiological health variables. To identify possible outcomes of higher empirical evidence, especially psychological outcomes are classified and assigned

Table 3. Publication source of the selected studies.

Publication source	Type	Paper no.	Number	%
ACM Conference on Human Factors in Computing Systems	Conference	3,9,16,17	4	18.18
Frontiers in Psychology	Journal	13,15,20	3	13.64
ACM Symposium on Virtual Reality Software and Technology	Symposium	11,18	2	9.09
IEEE Engineering in Medicine and Biology Society	Conference	8	1	4.55
IEEE Virtual Reality and 3D User Interfaces	Conference	7	1	4.55
Children	Journal	21	1	4.55
Cyberpsychology, Behavior and Social Networking	Journal	10	1	4.55
Digital Health	Journal	22	1	4.55
Frontiers in Virtual Reality	Journal	19	1	4.55
Journal of Military, Veteran and Family Health	Journal	4	1	4.55
Pain Medicine	Journal	2	1	4.55
Pain Management Nursing	Journal	6	1	4.55
Palliative Medicine	Journal	5	1	4.55
PLoS One	Journal	14	1	4.55
Psychological trauma: theory, research, practice and policy	Journal	12	1	4.55
Virtual Reality	Journal	1	1	4.55

to their respective underlying construct, in case only dimensions were measured.

As shown in Figure 6 anxiety (26%), mindfulness (17%) and various emotions (e.g., anger, surprise or happiness; 17%) are those three types of psychological variables that are addressed the most in the selected papers. Positive effects on anxiety were found in methadone maintenance treatment (MMT) patients,[70] (non)students,[71] children,[72] general anxiety disorder (GAD) diagnosed patients,[74,76] children and young adults with inflammatory bowel disease[69] as well as panic disorder patients.[75] The target group and the setting are strongly clinical, but there is also an application example from a school setting.[72] Improved mindfulness was found in a general population[77,78,80,81] as well as in a prediseased population.[74,79] The positive influence of VR-based mindfulness application on various emotions were mainly found in prediseased participants,[70,74,79] but also in attendees of an international meeting and frontline healthcare workers.[80,83] Those three major psychological outcome categories are followed by disease patterns (e.g., depression, posttraumatic stress disorder [PTSD]: 9%), affect (9%), stress (6%), mood/arousal/sleep (6%), meditation experiences (6%) and other (e.g., quality of life, opioid craving; 4%).

In the area of physiological health variables (see Figure 7) neurobiological markers (brain-waves, pain neuromatrix activation, resting-state connectivity, cognitive bandwidth; 29%) and heat rate/HRV (29%) were primarily assessed, followed by pain (19%), blood pressure (9%), saliva samples (9%) and galvanic skin resistance (5%). Positive effects on neurobiological markers were found in healthy[71,82,88,90] and prediseased participants.[70,76,88] Participants who improved from a VR-based mindfulness application in HR and HRV can be mainly allocated to a healthy collective.[72,73,88,90]

VR scenario: content and intensity. Ultimately, the focus will be on VR scenarios from a content-oriented perspective. This will involve an initial analysis of the incorporation of mindfulness within the VR scenarios, followed

Table 4. Control group design and sampling of quasi- and true experimental studies.

Study	Control group design	Sampling	Measurement time points
Chandrasiri et al. (2019)	Random assignment; active control group (mindfulness audio track)	• No inclusion criteria • Exclusion criteria e.g., psychiatric disorders or psychological treatment • Few demographic characteristics	• Pre-post
Groninger et al. (2021)	Random assignment; active control group (guided imagery session)	• Inclusion criteria e.g., ≥ 18 years, diagnosed with ACC/AHA stage C or D heart failure • Exclusion criteria e.g., familiarity with VR, history of motion sickness/ seizures/epilepsy • Demographic characteristics	• Primary outcome: pre-post-24 hour post • secondary outcomes: pre-post
Hawes and Arya (2021)	Random assignment; active control group (VR game)	• No inclusion/exclusion criteria • Few demographic characteristics	• Before/after priming
Kazzi et al. (2018)	Randomized order; passive/active control group (seated rest/ audio)	• Inclusion criteria: healthy • Exclusion criteria: predisposition to motion sickness • Few demographic characteristics	• Study 1: continuously measurement + at 3 minutes within each condition (rest/ audio/VR) • Study 2: continuously measurement + at 2 minutes (during stress test) + at 6 minutes (during recovery)
Min et al. (2020)	counterbalanced order; active control group (VR scenario)	• No inclusion/exclusion criteria • Few demographic characteristics • No information on sampling	• Pretest, during + right after VR simulation, retrospective (after a day)
Mistry et al. (2020)	8 counterbalanced between group conditions; active control group (guided meditation)	• Inclusion criteria: 17–22 years • No exclusion criteria • Information about ethnicity + regularity/familiarity with meditation practice	• After VR-/non-VR meditation
Navarro-Harro et al. (2019)	Random assignment; active control group (mindfulness-based intervention group sessions)	• Inclusion criteria e.g., 18–65 years, diagnosis of GAD • Exclusion criteria e.g., pregnancy, receiving other psychological treatment • Demographic characteristics	• Pretreatment-posttreatment • MBI + VR group: before/after each session
Roo et al. (2017)	Counterbalanced order; active control group (spatial augmented reality)	• Inclusion criteria: interest in meditation • No clear exclusion criteria • Information about regularity with meditation practice	• After VR/SAR session
Tarrant et al. (2018)	Nonrandom assignment; passive control group (resting)	• Inclusion criteria: ≥18 years, moderate level of generalized anxiety • Exclusion: e.g., history of head	• Baseline-pre-post

(continued)

Table 4. Continued.

Study	Control group design	Sampling	Measurement time points
		injury, seizure activity or major mental health concerns • Two independent rounds of sampling (1st pool: intervention group, 2nd pool: control group) • Demographic characteristics	
Tarrant et al. (2022)	Alternately assignment; active control group (guided audio meditation)	• Inclusion criteria: ≥ 18 years • Exclusion criteria e.g., any history of seizure, current blindness or severe eye impairment or history of motion sickness • Demographic characteristics	• Pre-post
Zambotti et al. (2022)	Counterbalanced order; active control *condition* (quiet activity)	• Inclusion criteria: DSM-5 (with/without insomnia) • Exclusion criteria: e.g., severe medical condition • Demographic characteristics	• Before-during-after intervention/control

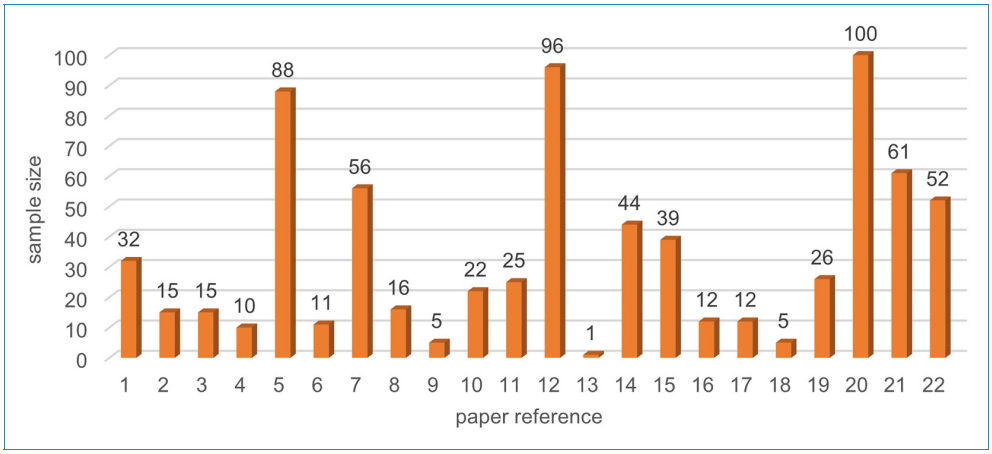


Figure 5. Total sample size of selected studies.

by an investigation into the structural aspects of the VR protocol concerning its duration and intensity.

Mindfulness is typically cultivated in formal meditation practices like sitting and walking meditation, loving kindness meditation or mindful movements.[3] Meditation is often used as an umbrella term, under which a number of diverse practices are summarized, but three main criteria have been defined as essential to any meditation practice: (a) the use of defined techniques, (b) logic relaxation meaning not intending to analyze, judge or expect and (c) a self-induced state or mode.[94] In accordance with the two-component model by Bishop et al.,[5] Hölzel et al.[95] identified an array of distinct but interacting mechanisms that are at play in producing the benefits of mindfulness meditation practice. The first mechanism is the attention regulation, seen as a building block for practitioners to also benefit from the other mechanisms of mindfulness practice. It comprises a sustaining attention on the chosen object and whenever attention is distracted, one is able to return attention to the object. The second mechanism, body awareness, includes the focus on an object of internal experience like sensory experiences of breathing, emotions or other body sensations. The third mechanism emotion regulation is divided in the aspect of reappraisal and the

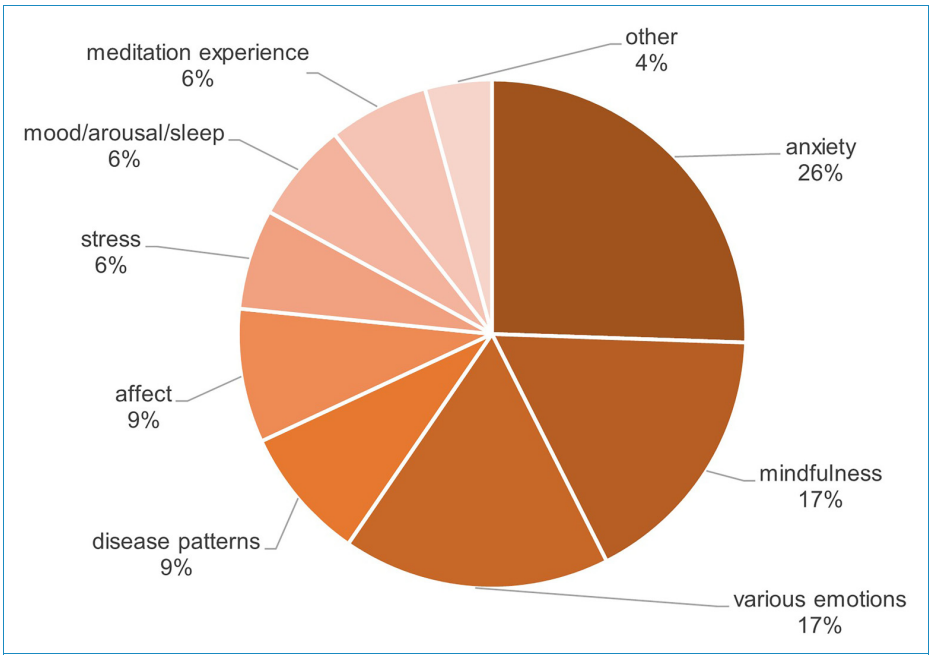


Figure 6. Psychological outcomes.

aspect of exposure, extinction and reconsolidation. Reappraisal means that one is approaching ongoing emotional reactions in a different way, with acceptance and no judgment. Exposure, extinction and reconsolidation are about exposing oneself to whatever is present in the field of awareness, letting oneself be affected by it and refraining from internal reactivity. The last mechanism, change in perspective on the self, includes the detachment from identification with a static sense of self.[95] The components might interact very closely with one another, so that a distinction between each component might seem artificial, but at this point we try to identify which components are mostly addressed in the implemented VR scenarios in our selected papers as one of the mechanisms might move into the foreground, while others become less relevant.

A comprehensive list of the VR contents within the included studies, alongside our identified predominant mindfulness mechanisms, is available in the Online Supplementary materials. Among the VR scenarios investigated, attention regulation emerges as the most prevalent mindfulness mechanism, observed in 50% of the included studies, followed by body awareness at 29%, emotion regulation encompassing both facets at 18% and exposure, extinction and reconsolidation at 3%. Notably, mindfulness mechanisms such as "reappraisal" and "change in perspective on the self" were not clearly identifiable in the studies (see Figure 8).

Regarding the VR protocol, the majority of the selected papers (see Figure 9) conduct only a one-session intervention program (73%) while only a handful run a multiple-session intervention program (27%). The latter is found in the study by Hargett and colleagues,[91] who include two VR sessions in their study protocol, but do not provide any further details on the specific duration of the individual sessions. In addition, there are no inferential statistical results available, only descriptive data are presented (two sessions with 1–2-week break). In the area of single-session studies, durations of 5[71,76,83,84,86,90] and 10 minutes[76,80–82,91] per session are the most common ones. Significant effects on one's health differ from outcomes like pain, emotions/emotional state, mindfulness and presleep arousal in the 5-minute intervention studies. Studies that used a duration of 10 minutes have recorded significant results in health-related variables such as anxiety, HRV, affect/affective states, meditation experience, brain waves and mood.

Discussion

The following section discusses the results that emerged from the comprehensive evidence mapping of the included studies and highlights the resulting implications for practical application as well as the prospects for further research in the field of VR-based mindfulness interventions and their effects on psychological and physiological health outcomes. It is important to note that a meta-analysis was not performed as the included studies were very heterogeneous in terms of methodological design and contents and therefore could not be compared with each other. Attempting a meta-analysis

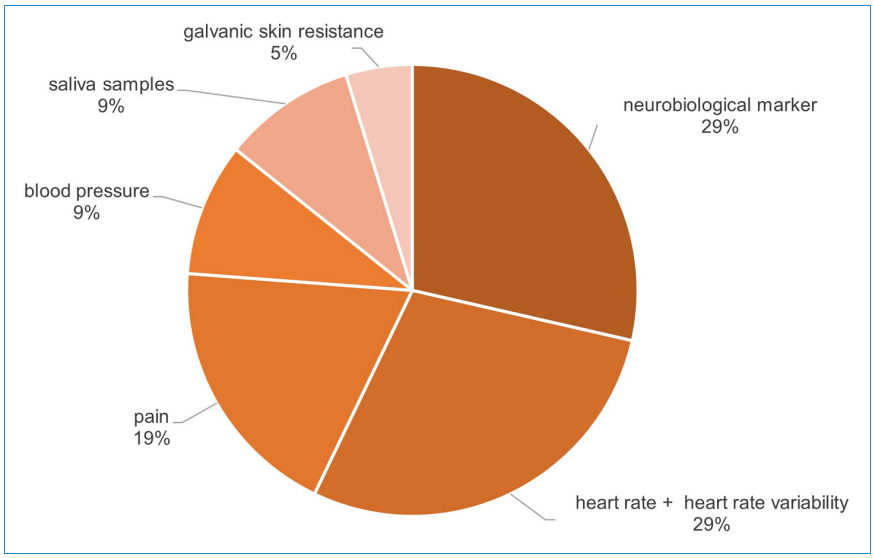


Figure 7. Physiological outcomes.

under these circumstances would likely lead to results with limited power and could potentially mask true effects.

Distributional mapping of time, space and publication

Although we planned to include studies published from the earliest available, we have only captured those published in the last 6 years (2016–2022). However, immersive reality like HMDs may be seen to have reached a period of high popularity in 2016 and wireless HMDs mainly have been developed in 2017.[96] The early stage of this technology and its accessibility are reflected in the small number of published research papers, particularly in the area of methodologically rigorous studies. This scarcity clearly underlines the need for additional research efforts in this area.

Regarding regional expertise in VR-based mindfulness interventions and their impact on health variables, this can be particularly found in the North American and South Korean regions judging by the first author's countries of origin. Implementing new technologies, like immersive VR, into all kinds of settings like medicine, education, sports or rehabilitation can be a valuable tool for mental health and physical well-being as their decreasing costs lead to more popularity and accessibility.[90,97] Expertise and evaluation of such new multidisciplinary tools are warranted, as for example the need for therapy places in the therapeutic area strongly indicates.[98] Therefore, research groups, especially in the European area, are needed to build on these initial promising results to pave the way for innovative technologies such as VR in the healthcare sector.

According to the findings reported, a valuable insight has been gained as regards to VR-based mindfulness interventions and their effect on psychological and physiological health outcomes, as it was investigated in different publication channels including journals, conferences and symposia. The majority of the papers (64%) selected in this systematic review have already been published in journals focusing on medicine, psychology or virtual/digital topics. Nevertheless, nearly 40% are published through conferences and symposia, which might be explained by the strong preexperimental characteristics around half of the studies have. In addition, among the papers published through conferences and symposia there was only one RCT.[71] According to our subsequent research, none of these studies were subsequently published in journals.

Methodological mapping

Research design, sampling and study design. With 50% preexperimental studies, 27% quasi-experimental studies and only 23% true-experimental studies, it is imperative to strengthen the basis of empirical evidence by increasing the conduct of quasi- and true-experimental studies.

Within the scope of sampling, both quasi- and true-experimental studies undergo an evaluation of applied inclusion and exclusion criteria. As a full set of clear inclusion and exclusion criteria was not always available in our selected studies, we recommend for future studies to distinctly define their target demographic and precisely articulate the criteria for inclusion and exclusion. Even if this may have happened in the background, transparent sharing of this information is important. This approach aims to facilitate the identification of the study's

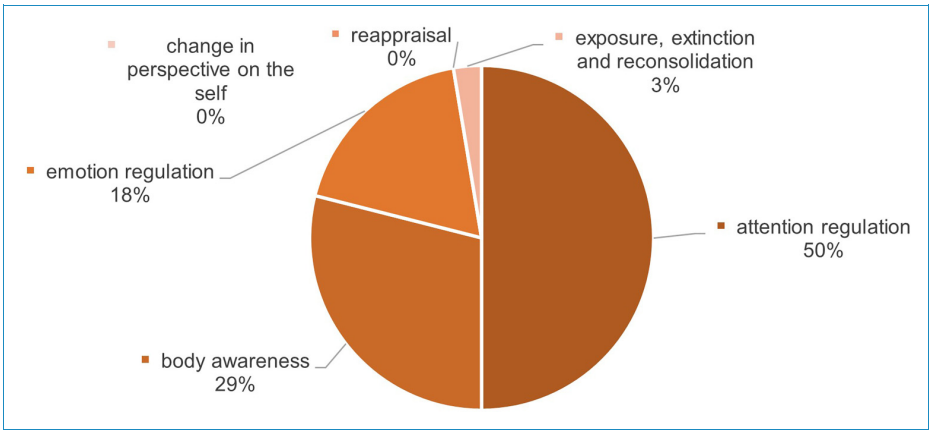


Figure 8. Mindfulness mechanism in virtual reality (VR) scenarios.

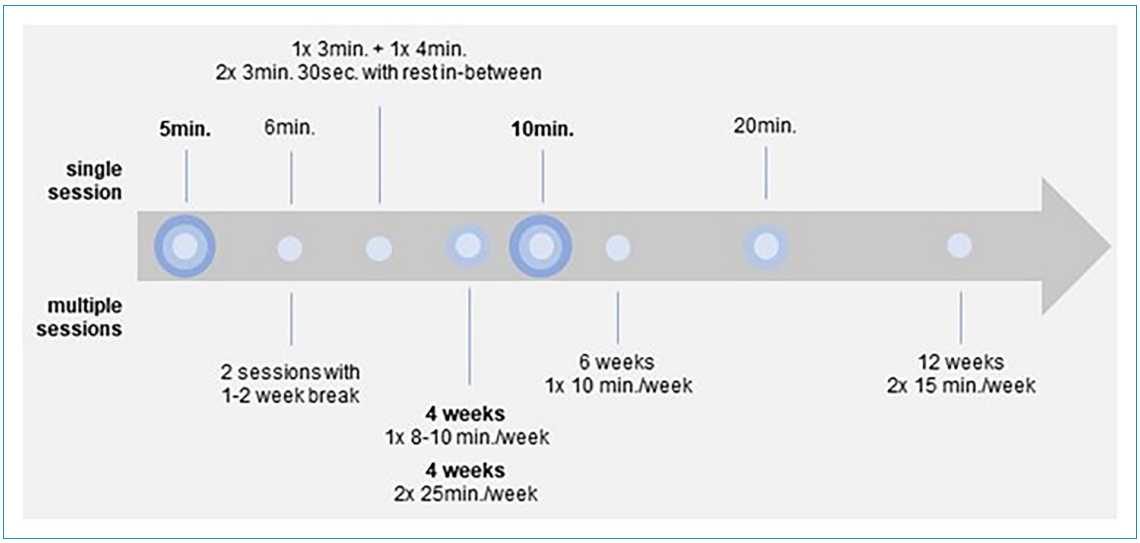


Figure 9. VR session designs.

target population and enable other researchers to understand the characteristics described that could impact on the study's objectives. Moreover, insufficiently articulated study descriptions might hinder the ability to faithfully replicate the research and subsequently, practitioners encounter heightened challenges when attempting to effectively implement these methodologies.[99]

Numerous studies in this analysis exhibit a pilot and feasibility nature. According to Hertzog[100] suggesting sample sizes of 20–25 participants for demonstrating intervention efficacy within a single group and 30–40 participants per group for between-group effect size estimation, such sizes are infrequently observed. Even with these recommended sizes, imprecision in estimates should be acknowledged. Julious[101] recommends a minimum of 12 participants per group for pilot studies in a parallel group trial. This design is scarcely observed in the selected studies, except for Tarrant et al.[76] and Mistry et al.[86] Among studies with single-group designs and pilot or feasibility attributes ($n = 9$; pre–post studies without control groups), only three meet Hertzog's[100] threshold.[69,72,80] However, the goal of feasibility and pilot studies is crucial in critically assessing sample size, as these studies focus on identifying implementation issues and assessing the feasibility of conducting a larger trial. Feasibility studies aim to assess whether an RCT of a particular intervention in a specific setting is viable. Pilot studies replicate the intended final design of the full RCT and serve as a rehearsal to ensure that key components, such as

eligibility assessment, randomization procedures and follow-up assessments, function effectively.[100,102] Even if some studies do not reach certain thresholds in terms of sample size, important findings have been gathered that now need to be deepened in larger trials.

In consideration of additional aspects of study design, the incorporation of a control group should be pursued more in future studies as only half of our studies ($n = 11$) implemented a control group. Using a control group has multiple benefits like enhancing internal and external validity, increasing statistical power and helping to make causal inferences. Moreover, a control group minimizes error variance, strengthens intervention effects and shows what might have happened without the intervention.[103] However, employing a control group comes with drawbacks that should be taken into account when planning a study. It can raise costs, introduce ethical and practical challenges, create biases, threaten study validity and limit the findings' applicability. Control groups can assume either an active or passive form. In the context of our research inquiry, which primarily centers on the investigation of VR-based mindfulness interventions, the inclusion of active control groups, sharing identical content with the experimental condition but omitting the VR component, offers valuable insights into the specific efficacy of this technological aspect. Furthermore, the introduction of an additional passive control group, if feasible, would facilitate a more comprehensive exploration of our research question. It is noteworthy that none of the studies under review incorporated this dual-control group approach, although 10 out of the 11 studies did employ active control groups. In three of these studies, the content of the intervention and control conditions remained the same, with the only difference in the type of presentation being that non-VR vs. VR only received an audio-based version.[83,86,87] This aspect should also be taken into account in the prospective planning of studies.

Randomization is crucial for creating comparable groups and eliminating biases in treatment assignments.[104] In our selected studies, five used a randomized assignment,[71,74,77,87,90] four used counterbalancing[73,81,86,88] and one study each used alternating[83] and nonrandomized assignment.[76] Those different randomization techniques all have their certain strengths and it is the researchers' task to find an appropriate technique for the particular study as was done in most of the included studies with control groups.[103]

Multiple measurement time points play an important role in experimental studies, because they allow researchers to track changes and developments over time. They can also help control confounding variables, identify trends and patterns in data, detect long-term and inter-individual effects and optimize experiments. In addition to the conventional pre–post survey design, a minority of the quasi- and true-experimental studies incorporate supplementary data collection time points, including baseline assessments,[76] measurements conducted during the intervention[73,90] and follow-up evaluations.[87] In forthcoming research, the integration of multiple measurement time points should be considered, particularly in studies characterized by the inclusion of multiple sessions within their design. This approach enhances the capacity to effectively evaluate temporal changes over the course of the study.

Subjective versus objective methods. The focus of the health outcomes examined in the included studies was clearly in the psychological area, consequently a substantial prevalence of subjective measurement instruments was observed in these studies. Given the inherent complexity of psychological constructs, they often elude direct observation, rendering their measurement a nontrivial task. Although subjective measurement methods have some limitations or perceived disadvantages like their limited interpretation due to their ordinal scale, they are nevertheless indispensable in many cases to capture personal experiences, attitudes and opinions.[105] The critical view of subjective measurements often refers to the need to carefully check their validity and reliability and possibly to complement them with objective measurements in order to obtain a more comprehensive picture.[106] In our case, the concurrent utilization of both subjective and objective methodologies for the assessment of psychological and physiological variables has the potential to enhance the comprehensive understanding of an individual's health status. Nevertheless, the validity of subjective measures can be independent of their relationship to objective measures. Consequently, subjective measures can serve the empirical purposes they were meant to serve.[105] Most of the subjective measures that were applied in the selected studies are evaluated and standardized tools like Mindfulness Awareness Attention Scale (MAAS),[107] Beck Anxiety Inventory (BAI)[108] or Generalizied Anxiety Disorder Scale-7 (GAD-7)[109] with good psychometric properties.

Furthermore, we would like to discuss the concepts of "subjective and objective measures" as researchers often use those terms to distinguish between procedures, that either rely on human judgment or record data with a diagnostic instrument. Since there is no clear consensus on what is an "objective" and what is a "subjective" result, there is rather a continuum between the two terms. It is clear from this that subjectivity and objectivity are not definitively delineated binary distinctions, which leads us to introduce the conceptual terms "captured by human" and "captured by device" for consideration.[110] In conclusion, we would like to state that we share the view, that the types of variables to be assessed in any given study should be determined on the basis of the hypotheses being tested, not on opinions about the value of different data collection strategies.[111]

Content mapping

Outcome variables. Anxiety seems to be the psychological health outcome with the highest empirical evidence[69–76] in our included studies, notwithstanding the need to acknowledge that, to some extent, distinct facets or dimensions of anxiety were assessed. This fact must also be taken into account for all other variables. Nevertheless, in 18% of our studies the reduction of anxiety through VR-based mindfulness interventions was demonstrated with large effect sizes ($d > |.96|/\eta_p^2 = .60$). With regard to the validity of these effects, one study used a true-experimental design (RCT)[74] and two a quasi-experimental design[73,76] and only one study[72] was carried out with a preexperimental design. A further four studies addressed anxiety in their study,[69–71,75] which would make a total of 36% of all studies that addressed anxiety as a health variable. The majority of these additional studies utilized preexperimental designs without control groups. Despite their ability to identify significant changes, they did not provide information on effect sizes. Thus, there is at least some robust evidence for the internal validity of the anxiety-reducing effect of VR-based mindfulness interventions that of course needs to be replicated in future methodologically rigorous studies.

Medium to large effects on mindfulness or related constructs ($d > .75$), such as interoceptive awareness, were found in 14% of the studies. This statement is based on two preexperimental studies[78,80] and one true-experimental study[74] (RCT). In two additional studies where mindfulness was considered a psychological health variable (constituting 23% of the total), no effect sizes were disclosed, despite the fact that these studies were either quasi-experimental[81] or true-experimental studies[77] and identified significant effects. At this stage, the evidence of the internal validity of a mindfulness-promoting effect of VR-based mindfulness interventions still needs to be expanded.

A similar picture of results can be seen for the variable various emotions/emotional state, as the positive effects of VR-based mindfulness interventions could be shown by 18% of our studies with medium to large effects ($d > .51$). Regarding validity of these effects, two studies used a true-experimental design[74,83] and two were carried out with preexperimental design.[80,82] Two further studies,[79,84] which would account for a total of 27% of all studies, dealt with emotions in their study, but only at a descriptive level. Consequently, there exists substantial evidence supporting the internal validity of the favorable impact of VR-based mindfulness interventions on emotions or emotional states. It is essential, however, that this evidence be substantiated through methodologically rigorous studies in the future.

For disease patterns, in particular depression, one true-experimental study[74] (RCT; 5%) reported a medium to large effect ($d = |.54|$). This suggests a promising internal validity of the results, but also needs to be strengthened by further methodologically rigorous studies and extended to other disease patterns. Depression was documented by three additional preexperimental studies[70,72,75] (constituting 18% of the total), but without any indication of effect sizes due to partial lack of inferential statistical evaluation. Besides depression, PTSD symptoms also fall into this category, but were reported in only one study on a descriptive level.[84]

In 9% of our studies the positive effect of VR-based mindfulness interventions on affect was demonstrated with large effect sizes ($d = .90|/\eta^2 > .338$). With regard to validity of these effects, one study used a quasi-experimental design[86] and one study used a preexperimental design.[82] Consequently, the evidence for the internal validity of this positive effect on affect needs more foundation. Nevertheless, affect was addressed in two further studies,[84,85] but only evaluated on a descriptive level.

In each case, 5% of the studies showed a positive effect on stress[78] respectively presleep arousal[82] with medium to large ($d = .55$) respectively small to medium ($d = .28/d = .35$) effects. Both were preexperimental studies, which does not directly support the internal validity of the effects and therefore more methodologically rigorous studies in the future are needed. Significant effects on distress could be found in another study,[87] but was not supported by effect sizes. The absence of effect sizes was similarly observed in another preexperimental study,[84] which exclusively provided descriptive values for stress variables. Regarding presleep arousal, another quasi-experimental[88] study that incorporated this variable into the study design failed to reveal any additional evidence, as no significant effects were observed.

In 9% of our studies VR-based mindfulness interventions support the ability to meditate respectively a positive meditation experience with large effect sizes ($d > 1.43/\eta^2 > .323$). Validity of these effects is based on one study carried out with a quasi-experimental[86] and one with a preexperimental[78] study design. In order to strengthen the internal validity of these effects, more methodologically rigorous studies should be pursued.

In our last category, other, no effect sizes are mentioned for variables such as quality of life or opioid craving. However, the latter is a very specific variable that only affects a certain target group and not as universally applicable as, for example, mindfulness or emotions.

As already mentioned in some instances statistically significant effects were discerned within the purview of the investigated psychological health outcomes, however no effect sizes could support them. Eleven studies alone did not provide any information on this, four of them exclusively reported their findings at a descriptive level, without engaging in statistical analysis.[75,79,84,85] This entails only limited inference, difficulties in replication and only limited possibilities for generalization. Statistical analyses are required to increase the significance and reliability of the results. They make it possible to test

hypotheses, identify patterns and distinguish statistically significant results from random fluctuations. While descriptive results can provide important initial information, they should be considered only as a first step in the analysis of research data. In addition, a complete reproduction of information in the statistical analysis is important for the classification of the results and should be aimed for in future studies.

Although the range of physiological variables is comparatively less diverse, they rarely denote a superordinate aspect of health or a superordinate construct. For this reason, the scope for interpretation of physiological health outcomes is diverse and is not further defined in many articles—in most cases they stand for themselves. For example, neurobiological markers can provide information about neurological health status, while HRV, salivary metrics, galvanic skin resistance, heart rate and blood pressure can serve as potential markers of (acute) stress and relaxation.[112] In addition, EEG spectra can also provide information about relaxation and stress.[113] For this reason, we recommend an even stronger theoretical embedding of the variables for future studies.

Nevertheless, in 9% of our studies the improvement of EEG-data based variables through VR-based mindfulness interventions was demonstrated with large effect sizes ($\eta_p^2 > .14$). With regard to the validity of these effects, those two studies were carried out with a quasi-experimental study design.[76,88] More large effects in the category of neurobiological markers could be detected in correlation-based relationships within pain neuromatrix activations ($r > .557$) based on a preexperimental study design.[70] Although partially significant results on cognitive bandwidth were found in a true-experimental study[71] (RCT), no information on effect sizes is available. In another preexperimental study,[82] EEG data were recorded but only documented at a descriptive level. Taking all these studies together, a total of 23% of all studies deal with neurobiological markers, but not all of them report or perform a complete inferential statistical analysis. Thus, there is only some slight evidence for the internal validity of the positive effect of VR-based mindfulness interventions on neurobiological markers that of course needs to be deepened in future methodologically rigorous studies.

In one quasi-experimental study[88] and therefore in 5% of our included studies, large effects in heart rate ($\eta_p^2 = .19$) and medium to large effects in HRV ($\eta_p^2 > .10$) were reported. Even if two further quasi-experimental studies[73,90] and one preexperimental study[72] show partially significant results in these two variables, these are accompanied by no further information on the effect size. Consequently, the internal validity of these effects has not yet been sufficiently confirmed and requires further methodologically rigorous studies.

Four studies, constituting 18% of all studies, included pain as a health variable in their design, including three preexperimental[69,70,91] and one true-experimental studies.[87] Nevertheless, only one preexperimental study[70] (5%) reported a large effect size ($\eta^2 = .265$), although significant effects were found across all four studies. This has not yet yielded strong evidence supporting the internal validity of the pain-reducing impact of VR-based mindfulness interventions, emphasizing the need for further research in the future.

Positive effects of VR-based mindfulness interventions on cortisol could be shown with large effects ($\eta^2 = .62/\eta_p^2 = .25$) by 9% of our studies. With regard to the validity of these effects, one study used a quasi-experimental design[88] and one study was only carried out with a preexperimental design.[70] Thus, there is only slight evidence for the internal validity of the cortisol-reducing effect of VR-based mindfulness interventions that of course needs to be replicated in future methodologically rigorous studies.

Although inferential statistical analyses were partially successful in identifying significant changes in physiological health variables such as blood pressure and galvanic skin resistance within three quasi-experimental studies,[73,88,90] they were not supported by effect sizes. To enhance the internal validity of the effects of VR-based mindfulness interventions on those variables, upcoming studies should furnish comprehensive statistical documentation.

VR scenarios: content and intensity. Even though attention regulation was present in half of all VR scenarios and is considered a basic mechanism for all other mechanisms, an appropriate VR scenario should always be tailored to the study objective.[46] Depending on the target group, e.g., beginners/advanced learners or healthy/prediseased people, VR contents can be less or more suitable. Equally important is the desired mechanism in order to be able to induce targeted effects and make them measurable.

Conspicuous across most VR scenarios is the nature aspect that significantly defines the virtual environment. Nature can be characterized as "areas containing elements of living systems that include plants and nonhuman animals across a range of scales and degrees of human management, from a small urban park through to relatively 'pristine wilderness.'"[114] The possible interaction between mindfulness and exposure to nature might be explained by the psychological mechanism "attention" which is suggested to underlie positive effects of both mindfulness training as component of trait mindfulness and exposure to nature as part of attention restoration.[115–117] These findings currently exist superficially with tangible real nature, but they manifest the potential for a meaningful transfer to VR as evidenced by van Rompay et al.[118] Building on the attention restoration theory[119] and stress recovery theory,[120] both central to people–environment research, these approaches highlight the importance of vastness and spaciousness for the beneficial effects of nature interaction on mental health and well-being. van Rompay et al.[118]

demonstrated that VR simulations of spacious landscapes can enhance selflessness and related measures such as connectedness and positive affect. This mediation effect of spaciousness on selflessness and positive affect is explained by an embodied process in wherein body boundaries loosen up.[121] This process is associated with awe, a "nonbasic emotion"[122] respectively a sense of being in the presence of something greater than oneself and integrating elements of self-transcendence.[123] Considering this in the context of mindfulness mechanisms, particularly the change in perspective on the self, which was difficult to identify directly in our VR scenarios, some parallels can be drawn. Spacious VR-based nature scenarios may help address the static sense of self by promoting reduced self-centeredness and a heightened sense of connectedness with the broader world.[124,125] Experiencing nature-based awe and achieving a state of self-transcendence may lead individuals to adopt a more dynamic sense of self. This shift, initiated by spacious nature-based VR scenarios, may not only enhance mindfulness but also offer various other mental health benefits. This approach is supported by Chirico and Gaggioli's[126] assumption that VR can facilitate so-called transformative experiences (TEs). These are defined as brief, extraordinary and unique events that lead to durable and/or irreversible outcomes, contributing to changes in an individual's self-conception, worldviews and perspectives on others as well as their personality and identity. TEs involve an expansion of knowledge about oneself, others and the world (epistemic expansion) and are characterized by heightened emotional complexity, which includes emotional variability, high intensity and mixed emotions as their core phenomenological features.[127] These experiences emerge through the combination and manipulation of specific emotional and epistemic affordances. Notably, emotional affordances that elicit complex emotions such as awe are more readily implemented in VR settings than in real-world environments. This perspective is embedded in Gaggioli et al.'s transformative experience design[128] model, from which it can be deduced, as outlined above, that the mechanism of mindfulness, the change of perspective on the self, can be addressed through a VR-based awe experience. In addition to changes in perspective on the self, another mechanism that can benefit from these experiences is reappraisal, which was also challenging to identify directly in our studies. This mechanism involves adopting an accepting and nonjudgmental approach to ongoing emotions. The spectrum of transformative effects is comprehensive, manifesting on both emotional and behavioral levels. This can positively influence an accepting and nonjudgmental approach to emotions, while also highlighting the complexity involved in designing and structuring virtual realities.[126] The challenge in identifying these two mindfulness mechanisms may stem from our focus on predominantly recognizable and identifiable mechanisms, potentially leading to the prioritization of more accessible and fundamental mechanisms such as attention regulation or body awareness. Moreover, obtaining clear identification information, that could be relevant for change of perspective on the self and reappraisal is difficult without personal insight into the scenarios or detailed descriptions of the virtual environment and content. However, this should be considered by future developers of VR-based mindfulness scenarios who aim to incorporate these specific mechanisms. Consequently, critical questioning, including the integration of desired emotional and epistemic affordances or nature-based awe, should be incorporated into the development process. For instance, to evoke a sense of awe, the virtual environment should be designed to convey a sense of vastness and promote cognitive accommodation, thereby helping users transcend familiar schemas of the world, themselves and others.[126] Additionally, emotional VR scenarios viewed from a first-person perspective (experiencer) rather than a third-person perspective (observer) have the potential to enhance mental involvement and influence behavioral intentions.[129] Although explicit information on the user's perspective was not given in our included studies, it can be assumed that in most cases it is a first-person perspective. To sum it up, current studies seem to apply VR-based mindfulness scenarios with focus on especially three out of six possible mindfulness mechanisms, namely attention regulation (50%), body awareness (29%) and emotion regulation (18%). However, as attention regulation is seen as a building block for practitioners to benefit from the other mechanisms of mindfulness practice,[95] it is only natural and important to integrate this mechanism into the VR scenarios in order to appeal to a wide range of users.

In addition to natural scenarios, specific environments could also find their way into VR in the future and make the content even more target group-specific addressing the aspect of personalized interventions.[130]

Many of our conducted studies have primarily employed single-session methodologies, demonstrating the immediate beneficial effects of brief VR-based mindfulness interventions. For future research, a focused exploration on short-term mindfulness interventions is recommended, incorporating for example a self-regulated training protocol enabling participants to engage in repeated and consistent VR-based mindfulness practices over an extended duration rather than a singular session. Adopting such an approach would facilitate the examination of the effects of VR-based mindfulness interventions on psychological well-being and especially the immediate (state) and enduring (trait) mindfulness. The work of Cahn and Polich,[131] for example, supports the idea that sustained and comprehensive meditation training contributes to a lasting improvement in cognitive abilities and general well-being. In addition to further investigation of possible short-term effects on health outcomes, various long-term multi-session protocols should also be conducted, as the empirical

basis in this area requires more evidence. The overall goal of future studies is to identify an appropriate dose–response relation for different target groups.

Study limitations

As with any review, this study entails several considerations that could potentially constrain the robustness of the conclusions drawn. In addition, this review is meant not as a complete description of the research in the field but to stimulate scientific debate, especially on a methodological level.

With regard to our primary aim of providing a comprehensive insight into this specific area of research, the main bias affecting the study's conclusions arises from the incompleteness of the search process and the selection of studies. Despite conducting the trial search across major digital libraries pertinent to health psychology and human–computer interaction themes, a possibility of overlooking relevant studies remains. Furthermore, achieving complete exhaustiveness in the search was unattainable, even though the PICO criteria were employed to formulate a comprehensive search string aimed at gathering a diverse array of relevant elements.

Moreover, potential bias during the data extraction phase might have influenced the accuracy of the extracted data. To mitigate this concern, two authors (AW and FS) engaged in discussions to establish consensus on the data items for extraction in this study. However, as the data extraction was conducted by a single reviewer, a risk of errors that could introduce considerable inconsistencies in the outcomes exists. Single data extraction processes can potentially lead to extraction errors, such as inadequacies, incomplete data and omissions. While it's common for systematic reviews to employ duplicate data extraction by at least two reviewers independently, following PRISMA guidelines, it's noteworthy that some reviews in other areas have utilized single data extraction with subsequent double checking, yielding significant results.[132,133] The use of single data extraction presents a practical approach to complete reviews within constraints of time and cost when implementing a double-extraction process may not be feasible. Possible bias can also be noticed in conclusions regarding the presence or absence of relationships. To address this concern, the study has carefully managed any phase where there could be disagreement between the authors, ensuring discussions until a consensus was reached. Additionally, apart from textual descriptions, the use of various charts to represent results aimed to strengthen the connection between extracted data and the study's conclusions, enhancing traceability.

From a content point of view, the possible side effects of VR should also be briefly discussed at this point. In addition to the numerous positive effects described, VR also always harbors risks or adverse effects, which must be taken into account in terms of effectiveness and safety. As summarized by Simón-Vicente et al.[134] in their review article, VR side effects are more likely to be observed with HMDs than with desktop systems. For this reason, we screened all articles for possible adverse effects, looking in particular for symptoms from the Simulator Sickness Questionnaire[135] such as discomfort, fatigue, headache, eyestrain, dizziness or nausea.

In eight of our 21 included studies adverse effects were reported. They reach from discomfort of the headset,[77] hypervigilance, mildly elevated feelings of embarrassment and self-consciousness in the presence of the assessor while wearing the HMD to sadness, anger, irritation, guilt and nervousness in PTSD patients.[84] In Hawes and Arya's[71] study, eight out of 56 participants felt some level of discomfort and one participant experienced some cyber nausea and had to stop the experiment. Moreover, symptoms like motion sickness and headache were also present, but only to a small extent. Within the study of Kim et al.,[85] where a VR mindfulness game with mysterious stones was used, some participants reported distracting elements such as visuals. Adverse side effects, such as distraction, were documented in the study by Mistry et al.,[86] affecting only 22.9% of participants. Similar findings were reported by Semertzidis et al.,[82] where distracting bodily sensations were associated with the inter dream system. In this system, participants interact with graphic images projected in space and VR through EEG manipulation while resting in an interactive bed. Other side effects were documented by Wren et al.,[69] with a single participant reporting symptoms such as dizziness and increased anxiety following the VR sessions. Three studies[87,90,91] incorporated potential adverse effects within their exclusion criteria. Consequently, individuals predisposed to such side effects or those with prior negative experiences with VR were systematically excluded from participation. One study explicitly mentioned that there were no adverse effects from the use of VR.[75]

On a positive note, even when side effects did occur, they were usually very mild and did not prevent the participants from completing the experiment, with the exception of one person. Nevertheless, it is important to take precautions to ensure the safe and enjoyable use of VR and to reduce the likelihood of undesirable effects. The specific target population plays a decisive role in this context, just as it does in the selection of a suitable VR content.

Besides those adverse effects, the VR scenarios within our included studies all have inherent mindfulness aspects as shown by our content analysis. From a technological perspective, an important question is how these VR scenarios can support the cultivation of mindfulness practice. While mindfulness is superficially characterized by internal aspects such as interoceptive perception and decentering, it also includes external components like focused attention. Conversely, VR and its environment are primarily

associated with external aspects. Those challenges and opportunities have been reviewed by Döllinger et al.[136] showing that VR provides promising characteristics that can support mindfulness and related health outcomes. Particularly, HMDs offer advantages in shielding external extractors.[137] For example, visual cues can make it possible to subtly direct the user's focus, which is more effective than audio-only meditation instructions or visual guidance on screen. In addition, bodily and mental states can be promoted by adding neuro-/biofeedback. However, embodying a virtual avatar or lacking any visual body reference might distract the user from their physical body and self-awareness/focus.[138] So, the created VR/AR/MR experience should be carefully designed to maintain focus and avoid creating new distractions with overly complex elements. In their systematic review, Döllinger et al.[136] explain a comprehensive range of influencing factors in the development of such scenarios, which leads to a kind of design guideline. These factors include types of virtual environments, objects, self-representation and the presence of other people as well as guidance, feedback and interactivity. In addition, they highlight other important influences, such as individual user characteristics, including previous meditation experiences and the synthesis of effects. Given the abundance of these factors, this is not part of this systematic review, but it should be considered, especially for future developments of VR-based mindfulness interventions.

Implications of the results

The results of this systematic literature review, which includes a comprehensive mapping and classification analysis, are relevant for researchers and practitioners in the field of VR-based mindfulness interventions to enhance psychological and physiological well-being.

As the temporal and geographic mapping has shown, this field of research is still in its infancy, which is why the initial but important findings of our studies should be deepened and expanded. From a methodological perspective, researchers need to pay considerable attention on their experimental design strategy including aspects such as sample size, sampling, a transparent reporting of inclusion and exclusion criteria, the incorporation of active and passive control groups and the implementation of multiple measurements and follow-up assessments. The selection of appropriate measurement tools also constitutes a critical methodological consideration. It is essential to acknowledge that simultaneous employment of both subjective and objective methods for evaluating psychological and physiological variables holds promise for enriching the comprehensive understanding of an individual's health status. Furthermore, from a content perspective, future research should focus on additional studies involving short- and long-term intervention protocols to provide more precise dosage recommendations.

For a brief theoretical classification of VR-based mindfulness interventions in the health context, we would like to refer again to Antonovsky's salutogenesis model[28] mentioned at the beginning, as a corresponding model under the aspect of digitalization, in particular with the inclusion of immersive VR, is currently still pending. Our research underscores the potential for VR-based mindfulness interventions to function as GRRs, supporting movement toward the health ease pole of the so-called health ease/dis-ease (HEDE) continuum by strengthening the SOC, despite SOC not being directly measured in our included studies. Mindfulness induced through VR scenarios assumes a mediating role by enhancing the regulation of psychological health outcomes such as emotions, fears, affect and stress. This improved regulation and adaptive response fosters more effective coping mechanisms, thereby contributing viewing life as more manageable. By cultivating present-moment attention and awareness, mindfulness can help individuals to better comprehend and respond to challenging experiences like illness or pain. Moreover, these beneficial effects extend beyond pain management to include physiological parameters like HRV and blood pressure, improving overall health improvements across the continuum. The mediating influence of mindfulness, observed in traditional settings, is similarly evident in the digital respectively virtual world, whereby the psychological effects may be more accessible or better observable for humans as for example a reduced blood pressure or increased HRV might not so easily perceived by everyone. An example highlighting mindfulness's capacity to foster psychological adaptations and enhance coherence can be found in the study by Weissbecker et al.,[139] which examined its effects among women with fibromyalgia.

Regardless of practitioners' specific interest in particular variables, target groups or VR content, this systematic review provides a good opportunity to create relevant filters and filter out studies that meet their specific needs. It enables practitioners to identify and select studies that are most suitable for their intended applications and objectives. In addition, they have the task to create and validate diverse virtual environments, each tailored to accommodate target-specific elements or incorporating biofeedback mechanisms within the scenario. This integration enables guided practices to dynamically respond to users' physiological states, such as adjusting to the user's breathing patterns, thereby enhancing the immersion experienced by the user within the virtual environment.[140] Furthermore, these findings should be passed on and translated into other settings.

Compared to both existing reviews, that are quite close to our research question, there is an overlap of nine papers with Arpaia et al.[45] (53 in total) and six papers with Zhang et al.[44] (nine in total). A total of 13 out of 22 of our studies cannot be found in either of them. This deviation is partly due to the temporal dimension of the

publication date of these studies, which goes beyond the time frame of the two aforementioned reviews. Nine studies from 2021 and 2022[69–71,78,83,85,87,88,91] alone cannot be included in the two reviews. This confirms the assertion made at the beginning that this field of research is developing dynamically and rapidly. In terms of content, Zhang et al.'s[44] review primarily identified psychological health effects on depression, stress, emotions or anxiety. Physiological health effects, on the other hand, were limited to EEG data ($n = 1$), respiratory rate ($n = 1$) and pain levels ($n = 1$). Especially new findings on physiological variables such as galvanic skin response, salivary cortisol, blood pressure or heart rate and HRV could be identified in the data we included. Findings from the narrative review by Arpaia and colleagues focus on the research question of how VR technology can improve mindfulness practice respectively therapeutic effects of mindfulness, particularly those of interoceptive awareness and decentering. Furthermore, technological design solutions in VR-based mindfulness training will be discussed. With regard to these research questions, physiological and psychological health outcomes are mentioned, but the focus lies on the therapeutic effect/clinical target group and the technological implementation, from which further design proposals are then derived. Clinical use cases include chronic/acute pain, anxiety, stress, depression, borderline and addiction. Even if Arpaia et al.'s[45] work has a different focus, the group of authors also comes to the conclusion that this field of research has the need for more rigorous, randomized controlled studies in the future.

Conclusion

This paper reports on a systematic literature review that summarizes the existing research regarding VR-based mindfulness interventions and their effects on psychological and physiological health outcomes. From an initial set of 949 papers retrieved from six databases, 22 studies were selected. These papers were investigated using a hermeneutic approach for conducting literature reviews including evidence mapping with distributional, methodological and content analyses.

Regarding our studies, it has been observed that since 2016, researchers, particularly in the North American and South Korean regions, have shown increasing interest in VR-based mindfulness interventions and their impact on psychological and physiological health outcomes. The majority of related publications have been published through journals, with around half of them adopting a pre-experimental research design. There is an obvious need for further empirical evidence to support and extend the existing findings. Future studies should take into account important methodological parameters such as sample size, sampling, inclusion and exclusion criteria, control groups, randomization or multiple measurement times. This aspect also includes the selection of appropriate measurement instruments, which in our studies were mostly of a subjective nature. Simultaneous use of subjective (human-captured) and objective (device-captured) methods can help to obtain a holistic picture of the state of health and should be taken into account in future studies.

Studies show a higher level of evidence in the area of psychological health outcomes, particularly for anxiety, mindfulness and various emotions. These findings are mainly supported by methodologically more rigorous studies that fully document the results of their statistical analyses, including the reporting of effect sizes (see paper numbers 15, 19 and 20). However, even in true-experimental studies (RCTs like paper numbers 1, 5 and 7), this full range of information is not always available and makes it challenging to classify the results. The majority of the positive effects in terms of physiological health variables can be seen in neurobiological markers and heart rate or HRV. Two papers (numbers 2 and 22) in particular make an important contribution to this by fully reflecting health effects at a statistical level, although these are not true-experimental study designs.

In the VR scenarios, the mindfulness mechanism of attention regulation was superficially represented, while the environment was strongly characterized by natural elements. VR protocols with single sessions and durations of 5 and 10 minutes were the most common, but both short- and long-term programs should be further investigated in future studies in order to make more specific dose–response statements.

In summary, the included studies have provided important initial findings and show that this young field of research requires further studies to secure and expand the evidence base.

Contributorship: All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Declaration of conflicting interests: The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding: The authors received no financial support for the research, authorship and/or publication of this article.

Guarantor: AW.

Registration and protocol: This study was not preregistered and no formal protocol was established at the start of this systematic review. Given the anticipated complexity and diversity of the studies included, as evidenced by many variables and potential outcomes, preregistration of all aspects of the research was considered a potential limitation of the exploratory nature of this systematic review.

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Supplemental material: Supplemental material for this article is available online.

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Virtual Reality (2025) 29:152
https://doi.org/10.1007/s10055-025-01235-9

ORIGINAL ARTICLE

Physiological and psychological health effects of a mobile VR-based mindfulness breathing meditation with integrated biofeedback: a replication study

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Received: 13 February 2025 / Accepted: 3 September 2025 / Published online: 15 September 2025
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Abstract
Mindfulness, characterized by a non-judgmental present-moment awareness, has been empirically associated with numerous psychological and physiological health benefits. Advances in technology, particularly immersive virtual reality (VR) using head-mounted displays, provide interactive and engaging environments that enhance mindfulness practices. This study builds on a primary investigation to explore the integration of a mobile VR-based mindfulness breathing meditation with biofeedback and its effects on physiological and psychological health. This replication study used a within-subject design, with 45 participants (M_{age} = 22.9 years; 30 men, 15 women) completing six consecutive days of supervised self-guided VR-based training ($M_{session}$ = 8 min 52 s). Physiological measures such as breathing parameters, heart and respiratory rates and heart rate variability were combined with psychological measures including momentary relaxation, burnout symptoms and relaxation-related self-efficacy. Additional health parameters, objective instruments and measurement points were incorporated into the study design to offer a more comprehensive view of participants' health status as well as capturing both short-term and medium-term effects. Our study showed positive effects on health concerning diaphragmatic breathing, breathing awareness, heart and respiratory rates, momentary relaxation, burnout symptoms and relaxation-related self-efficacy, with several benefits persisting not only short- but also medium-term (1-week/1-month post-intervention). Moreover, the feasibility of the VR intervention was confirmed through high user satisfaction. This study was able to demonstrate positive health effects of VR-based mindfulness breathing meditation with integrated biofeedback, which emphasizes the importance of replication studies. Future research should focus on different target groups in terms of external validity and use different VR protocols to more accurately define the dose-response relationship.

Keywords Virtual reality · Respiratory biofeedback · Diaphragmatic breathing · Health · Mindfulness

1 Introduction

The following section provides an overview of the core components central to this study[1]. Mindfulness is first introduced as the central construct within the context of health and well-being. Following this, virtual reality (VR) is presented as an innovative delivery medium, highlighting its connection to mindfulness and health interventions. Finally, biofeedback is discussed as an additional relevant modality. Throughout the section, the theoretical background and current empirical findings are briefly reviewed, primarily referencing the comprehensive systematic review by Wieczorek et al. (2024), which also provides a more detailed overview of these entities and their interrelations.

1.1 Mindfulness and health

Mindfulness is a multifaceted construct that has garnered growing attention in both scientific research and public discourse. Its applications have expanded significantly beyond

[1] The theoretical derivation and categorization of the constructs presented in Sect. 1.1 and 1.2 are primarily based on, re-used and adapted from the systematic review by Wieczorek et al. (2024)

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its traditional origins in Buddhist meditation and mental practices (Kabat-Zinn 2003; Thera 1962). Commonly, mindfulness is characterized "(…) as a kind of non-elaborative, non-judgmental, present-centered awareness in which each thought, feeling, or sensation that arises in the attentional field is acknowledged and accepted as it is." (Bishop 2002, p. 232).

Mindfulness has been widely incorporated into the field of psychology, especially within clinical or therapeutic contexts, through well-established approaches such as the mindfulness-based stress reduction (MBSR; Kabat-Zinn 1990), the mindfulness-based cognitive therapy (MBCT; Segal et al. 2002; Teasdale et al. 1995) or the acceptance and commitment therapy (ACT; Hayes 2004).Those mindfulness-based interventions (MBIs) are supported by extensive evidence demonstrating their health-promoting effects. Psychologically, MBIs have been shown to enhance well-being, behavioral regulation (Keng et al. 2011) and positive affect (Erisman and Roemer 2010; Jha et al. 2010), while reducing anxiety and depressive symptoms (Elices et al. 2017; Evans et al. 2008; Goldin and Gross 2010), stress (Grossman et al. 2004) and burnout (Montero-Marin et al. 2015). Physiologically, MBIs are linked to beneficial changes including decreased heart and respiratory rates, reduced hypertension symptoms (Ditto et al. 2006; Zeidan et al. 2010), lowered skin conductance (Jevning et al. 1992; Scavone et al. 2020), diminished pain (Reiner et al. 2013) and increased heart rate variability (Christodoulou et al. 2020; Krygier et al. 2013).

To place those empirical findings within a theoretical framework, we refer to Antonovsky's Salutogenesis Model of Health (1979), which conceptualizes health as continuum ranging from ease to dis-ease thus demonstrating a transfer of focus from pathogenesis to salutogenesis (Vinje et al. 2022). This journey is framed by two fundamental key concepts of the Salutogenesis Model, namely generalized resistance resources (GRRs) and the sense of coherence (SOC). Integrating mindfulness into the Salutogenesis Model of Health (Antonovsky 1979), which can be characterized as a "way of being" that fosters an open and engaged living, enables individuals to actively respond to life's challenges rather than simply react (Kabat-Zinn 1990). By promoting this ability to react in a targeted and adaptable manner, mindfulness can also serve as a generalized resistance resource, functioning as a coping strategy that enhances the sense of coherence. Mindfulness can improve manageability by encouraging flexible reactions to difficulties and boosting awareness of the present moment, which promotes a greater sense of openness and insight into one's experiences. Additionally, mindfulness can enhance the perception of life's meaning by allowing individuals the space to explore and reflect on their purpose. These elements align with the core components of SOC, which include perceiving life as comprehensible, manageable and meaningful. Within this framework, mindfulness can support individuals in progressing along the health-ease and dis-ease (HEDE) continuum, moving in the direction of the ease-pole (Wieczorek et al. 2024).

1.2 Mindfulness, health and virtual reality

As the potential for utilizing various technologies continues to expand, VR is transforming the way we interact with digital environments, offering new opportunities across fields such as healthcare, education and entertainment by blending digital and real-world experiences. It includes essential elements that make the experience highly engaging, often referred to as the "three I's" of VR, namely immersion, imagination and interaction (Burdea and Coiffet 2003), which are also described in greater detail by Wieczorek et al. (2024).

Among different VR technologies, head-mounted displays (HMDs) offer fully immersive VR experiences with six degrees of freedom, enabling natural movement and interaction. Compared to stationary systems, they are more portable, personalized, cost-effective and benefit from advances in display and tracking technology (Zhang et al. 2023). Immersive VR has become increasingly integrated into healthcare, proving effective in treating conditions such as chronic pain, anxiety, psychosis, eating disorders, post-stroke balance and depression (Hill et al. 2017; Li et al. 2011; Valmaggia et al. 2016; Pot-Kolder et al. 2018; Clus et al. 2018; Rooij et al. 2016a, b; Falconer et al. 2016). Applications also include exposure therapy, mental wellness and mindfulness training (Carl et al. 2019; Roche et al. 2019; Chandrasiri et al. 2020; Navarro-Haro et al. 2017). Notably, mindfulness serves both as an outcome and a core component of many immersive VR interventions aimed at enhancing psychological and physiological health (Rockstroh et al. 2021; Wieczorek et al. 2024).

Taking a closer look at mindfulness in the context of VR, it is important to note that it is is typically cultivated through formal meditation practices such as sitting, walking, loving-kindness or mindful movement (Kabat-Zinn 1990). Hölzel et al. (2011) identified key mechanisms underlying mindfulness benefits, including attention regulation, body awareness, emotion regulation and changes in self-perspective. Among these, attention regulation and body awareness have been identified as predominant mechanisms in VR-based mindfulness interventions that aim to improve psychological and physiological health (Wieczorek et al. 2024). Consequently, attention regulation serves as basis for benefiting from the other mechanisms of mindfulness practice. It involves sustaining focus on a selected object and refocusing after distraction, while body awareness pertains to

monitoring internal sensory experiences such as breathing emotions or other bodily sensations (Hölzel et al. 2011).

1.3 Mindfulness, health, virtual reality and biofeedback

Building on the findings, the integration of biofeedback into VR scenarios opens new possibilities for enhancing health outcomes. Biofeedback itself is the real-time detection of biological signals (e.g., heart rate, heart rate variability, respiration, electrodermal activity, muscle activity or brain activity) through sensors, which provide users with information about otherwise hardly observable bodily functions, ultimately aimed at improving their conscious control (Giggins et al. 2013; Rockstroh et al. 2021; Yu et al. 2018). Therefore, biofeedback offers the possibility of making the state, but also the change and changeability of biological processes "visible". With practice, individuals can learn to regulate feedback processes more effectively even without devices, leading to enhanced self-regulation of both physical and psychological processes (Haus et al. 2020).

The integration of biological signals as biofeedback within virtual reality has been successfully demonstrated across multiple studies, utilizing measures such as electroencephalographic oscillations, electrodermal activity, heart rate and heart rate variability (Rockstroh et al. 2019, 2020, 2021; Berger and Davelaar 2018; Kosunen et al. 2016; Gromala et al. 2015; Gradl et al. 2018; Houzangbe et al. 2019; Blum et al. 2019).

The combination of biofeedback and VR creates a powerful synergy, where immersive environments can dynamically respond to physiological signals, offering real-time, personalized feedback that enhances both the effectiveness and engagement of the training experience (Rockstroh et al. 2021). This synergy is further strengthened by VR's ability to amplify the visual appeal and prominence of feedback stimuli, which in turn can increase motivation and engagement (Rockstroh et al. 2019, 2021; Soyka et al. 2016; van Rooij et al. 2016a, b). Additionally, the fully adjustable and customizable features of virtual environments enable the development of a safe and supportive training environment (Blum et al. 2019; Gromala et al. 2015; van Rooij et al. 2016a, b), where unwanted external audiovisual stimuli can be blocked and replaced with task-relevant cues (Rockstroh et al. 2021). This reduces distractions and helps maintain a continuous focus on the biofeedback task (Blum et al. 2019; Rockstroh et al. 2021). Last but not least, biofeedback can help learners believe in their ability to relax their body and mind (i.e., relaxation-related self-efficacy) by providing real-time feedback on successful target behaviors or skills, thus making progress immediately apparent (Giardino et al. 2004; Paul and Garg 2012; Rockstroh et al. 2021; Teufel et al. 2013). When paired with immersive VR, these feedback stimuli aiming to increase self-efficacy become more prominent, which can increase once again the impact of biofeedback training on relaxation-related self-efficacy (Blum et al. 2019; Rockstroh et al. 2021; Weerdmeester et al. 2017).

Having outlined the benefits of integrating VR and biofeedback along with brief insights into its successful implementation, we want to focus on the potential of diaphragmatic breathing (DB) as a biofeedback mechanism in light of the growing evidence supporting its positive effects on human health (Hamasaki 2020). In general, DB is a breathing technique that involves activating the diaphragm to take a deep breath, causing the lungs to expand beyond the abdominal or intercostal muscles (Janet and Mangala Gowri 2017; Sundram et al. 2014). This method emphasizes mindful breathing, aiming to slow the respiratory rate by employing practices such as breath counting. During diaphragmatic breathing, one inhales deeply through the nose while expanding the abdomen, pauses briefly and then contracts the abdomen to exhale slowly and fully through the mouth (Goleman and Gurin 1993; Janet and Mangala Gowri 2017; Sundram et al. 2014).This regulated breathing pattern is designed to reduce respiratory rate (Busch et al. 2012; Christakis et al. 2012; Goleman and Gurin 1993; Ma et al. 2017; Sundram et al. 2014), enhances circulation, lowers heart rate and blood pressure by stimulating vagal tone and mitigating sympathetic nervous system activity (Janet and Mangala Gowri 2017). The modulation of the vagal tone of the parasympathetic nervous system can be explained by the maximization of the respiratory arrhythmia (Rockstroh et al. 2021; Vaschillo et al. 2006; Yasuma and Hayano 2004). Therefore, slow diaphragmatic breathing can activate an autonomic relaxation response (Subbalakshmi et al. 2014), assisting in re-establishing equilibrium within the autonomic nervous system (Rockstroh et al. 2021). In addition to these positive physiological effects, there are also numerous psychological effects (Rockstroh et al. 2021), such as the reduction of anxiety and negative affect (Chen et al. 2017; Ma et al. 2017), as well as an increase in mood and relaxation (Hopper et al. 2019; Perciavalle et al. 2017). Diaphragmatic breathing can be self-initiated when an individual for example recognizes a stress trigger, providing an easily accessible technique for stress management. However, it takes practice to regulate physical and psychological processes yourself in order to regulate these feedback processes without electronic devices (Haus et al. 2020).

VR-based breathing biofeedback can be considered a form of mindfulness practice because it shares key characteristics such as attention regulation and body awareness, both essential components of mindfulness practice as already mentioned (Hölzel et al. 2011; Wieczorek et al. 2024). In mindfulness, attention regulation often involves directing

attention to the breath, thoughts or bodily sensations, fostering a heightened awareness of the present moment (Hölzel et al. 2011). Similarly, VR-based breathing biofeedback can encourage users to concentrate on their breathing patterns and physiological responses, facilitating an understanding of how these elements affect their overall state of being. Moreover, mindfulness promotes body awareness and encourages individuals to focus on their physical sensations, emotions and thoughts (Hölzel et al. 2011). VR-based breathing biofeedback can also emphasize body awareness by providing real-time feedback on physiological changes related to breathing, which helps users to develop a deeper understanding of their bodily responses, enabling them to make conscious adjustments to their breathing patterns by getting a deeper connection between mind and body.

1.4 Primary research: replication and hypotheses

Rockstroh et al. (2021) explored the interplay among the introduced key elements "health, mindfulness, virtual reality and biofeedback" with a particular focus on diaphragmatic breathing. In continuation of their research, we aim to replicate their original study, which evaluated the effectiveness of a VR-based respiratory biofeedback game designed to foster diaphragmatic breathing. Replication studies are essential for testing the robustness and generalizability of findings, particularly with novel approaches like VR-based biofeedback games (Makel et al. 2012). Beyond exact duplication, they also allow for further exploration and help identify limitations in existing research (Roediger 2012).

The original study by Rockstroh et al. (2021) explored both the feasibility and potential health benefits of the VR game called *Flowborne*, a gamified breathing exercise within an immersive, restorative virtual environment using controller-based breathing biofeedback. This approach utilizes the motion-tracking capabilities of standard VR hand controllers, by placing the controller on the abdomen, where its relative positional changes over time approximate respiration-induced abdominal movements. An algorithm processes this data in real time to monitor and provide feedback on diaphragmatic breathing without the need for additional devices or systems (Blum et al. 2019). Inhalation and exhalation are reflected through visual changes in the environment, such as color shifts and particle effects, enhancing the immersive experience. Additionally, the game incorporates a breath-controlled locomotion system, where users progress along a predefined path by synchronizing their breathing, thereby reinforcing proper diaphragmatic techniques (Rockstroh et al. 2021).

The study was conducted using a within-subjects longitudinal design with 45 healthy undergraduate participants (M_{age} = 22.9 years, SD_{age} = 5.4 years) who underwent two baseline assessments (t_0 and t_1), followed by six VR training sessions over one week and a direct post-training assessment (t_2). Participants received initial assistance with the VR setup and controller placement, while all subsequent sessions were completed as a self-guided intervention without further support.

Rockstroh et al. (2021) were able to show promising findings on the feasibility of the game (dropout rates, user satisfaction, ease-of-use, perceived usefulness and symptoms of simulator sickness), alongside its impact on breathing patterns through metrics such as diaphragmatic breathing, perceived ease of performing diaphragmatic breathing and breath awareness. Further positive health effects were also found in the area of mental health and well-being parameters including relaxation, perceived stress, burnout symptoms and relaxation-related self-efficacy (Rockstroh et al. 2021).

The original study chose not to include a control group, a decision that raised certain methodological challenges. However, this approach is understandable given the specific context of the intervention. The complex and interrelated nature of its components including VR, restorative environments, breathing exercises and biofeedback, makes it difficult to isolate their effects in a traditional control group design (Rockstroh et al. 2021). Being aware of these limitations, we also decided against the inclusion of a control group in our study. Instead, we focused on refining our methodology by addressing the need for detailed specifications at the measurement level like additional physiological outcomes (respiratory rate, heart rate and heart rate variability), objective measurement tools and assessment measurement time points, to address limitations and enhance the scope of the research. This approach highlights the dual purpose of replication: verifying prior findings while refining and advancing scientific understanding. In doing so, our study expands upon the original study and offers new insights while preserving the essential framework established by Rockstroh et al. (2021). Based on a critically rationalist view of the necessity of replication, we aim to examine the following hypotheses concerning breathing (related) parameters, that cover aspects of physiological health:

H_{1a} *The VR-based mindfulness breathing meditation with integrated biofeedback improves the* ***diaphragmatic breathing*** *over the course of the six sessions.*

H_{1b} *The VR-based mindfulness breathing meditation with integrated biofeedback improves the* ***respiratory rate*** *over the course of the six sessions.*

H_{1c} *The VR-based mindfulness breathing meditation with integrated biofeedback reduces participants* ***heart rate****.*

H_{1d} *The VR-based mindfulness breathing meditation with integrated biofeedback improves the* ***ease of performing diaphragmatic breathing*** *over the course of the six sessions.*

H_{1e} *The VR-based mindfulness breathing meditation with integrated biofeedback improves the* ***perceived breath awareness****.*

In alignment to the original study (Rockstroh et al. 2021) we also investigated the impact of the game on the participants' mental health and well-being, addressing psychological aspects of health, for which we have formulated the following hypotheses:

H_{2a} *The VR-based mindfulness breathing meditation with integrated biofeedback improves participants* ***momentary relaxation*** *(HRV).*

H_{2b} *The VR-based mindfulness breathing meditation with integrated biofeedback reduces the* ***perceived stress****.*

H_{2c} *The VR-based mindfulness breathing meditation with integrated biofeedback reduces* ***symptoms of burnout****.*

H_{2d} *The VR-based mindfulness breathing meditation with integrated biofeedback increases the* ***relaxation-related self-efficacy****.*

2 Methods

2.1 Study design and procedure

The study was conducted in the department's laboratory using an adapted longitudinal within-subjects design (see Fig. 1) with a total length of six weeks. All participants underwent two assessments before training (t_0 and t_1) with one week in-between to determine untreated baseline values. This was followed by a training phase, which consisted of six supervised self-guided VR sessions on consecutive days and ended with a post-assessment (t_2). In line with the original study, different starting points were defined over a two-month period to control for external and seasonal influences. Participants completed their six sessions at the same time slot on each of the six consecutive days (weekends excluded), with time slots scheduled between morning and afternoon hours.

In order to answer the discussed limitations by Rockstroh et al. (2021) into account, two follow-up phases (t_3 and t_4) were included in the study design to determine possible medium-term effects. In addition to revising the study's design, modifications were made to the measurement methodology in order to supplement the inherently subjective measurements with objective measurement tools like the Firstbeat Bodyguard 2 (Parak and Korhonen 2015) to additionally measure respiratory rate, heart rate and heart rate variability. This step was undertaken to enhance the comprehensive assessment of the effects observed and the participants' health status, thereby aiming for a more holistic picture. Selected variables were examined in order to test both the user experience and the formulated hypotheses relating to diaphragmatic (related) breathing as well as mental health and well-being parameters. The parameters recorded and the corresponding measurement instruments are described in detail below.

Throughout each assessment, participants completed the perceived breath awareness scale (Rockstroh et al. 2021), the PSS-10 (Schneider et al. 2020), the CBI (Kristensen et al. 2005) and the relaxation-related self-efficacy scale (Blum et al. 2019) via Social Science Survey, an online survey tool (Leiner 2024). At measurement time point t_0, t_3 and t_4, the survey took place remotely and the participants were sent a link to complete the survey by email. At measurement time point t_1 and t_2 the survey took place in the lab at the authors institution before and after the VR sessions respectively. At t_0 additional demographic data like gender, age, student status and previous experience with virtual reality were assessed and participants received further information with a practical explanation of the diaphragmatic breathing technique. At measurement time point t_2, the perceived usefulness of training and the perceived ease of use were also measured once after the training phase.

Pre- and post-measurements of the VR session, performed while participants were in a sitting position include HRV parameters to record the momentary relaxation, respiratory rate and heart rate. For this purpose, the Firstbeat Bodyguard 2 sensors were attached and activated for a period of 5 min before the VR session and the same was done immediately after the VR session.

During the VR sessions, only HMD-based breathing parameters were recorded.

After each VR session, participants filled out questionnaires regarding user experience like liking and simulator sickness as well as questions on the perceived ease of performing diaphragmatic breathing (Rockstroh et al. 2021).

At the first VR training session setting options of the HMD were explained and the interpupillary distance for each subject was noted for future sessions. The participants received a short tutorial which was integrated in the applied VR scenario *Flowborne* explaining the breathing technique and the locomotion mechanics behind the scenario. In the next step, participants were instructed to select only those scenarios labeled as 'long' to ensure a maximum possible intervention duration per session. However, the actual

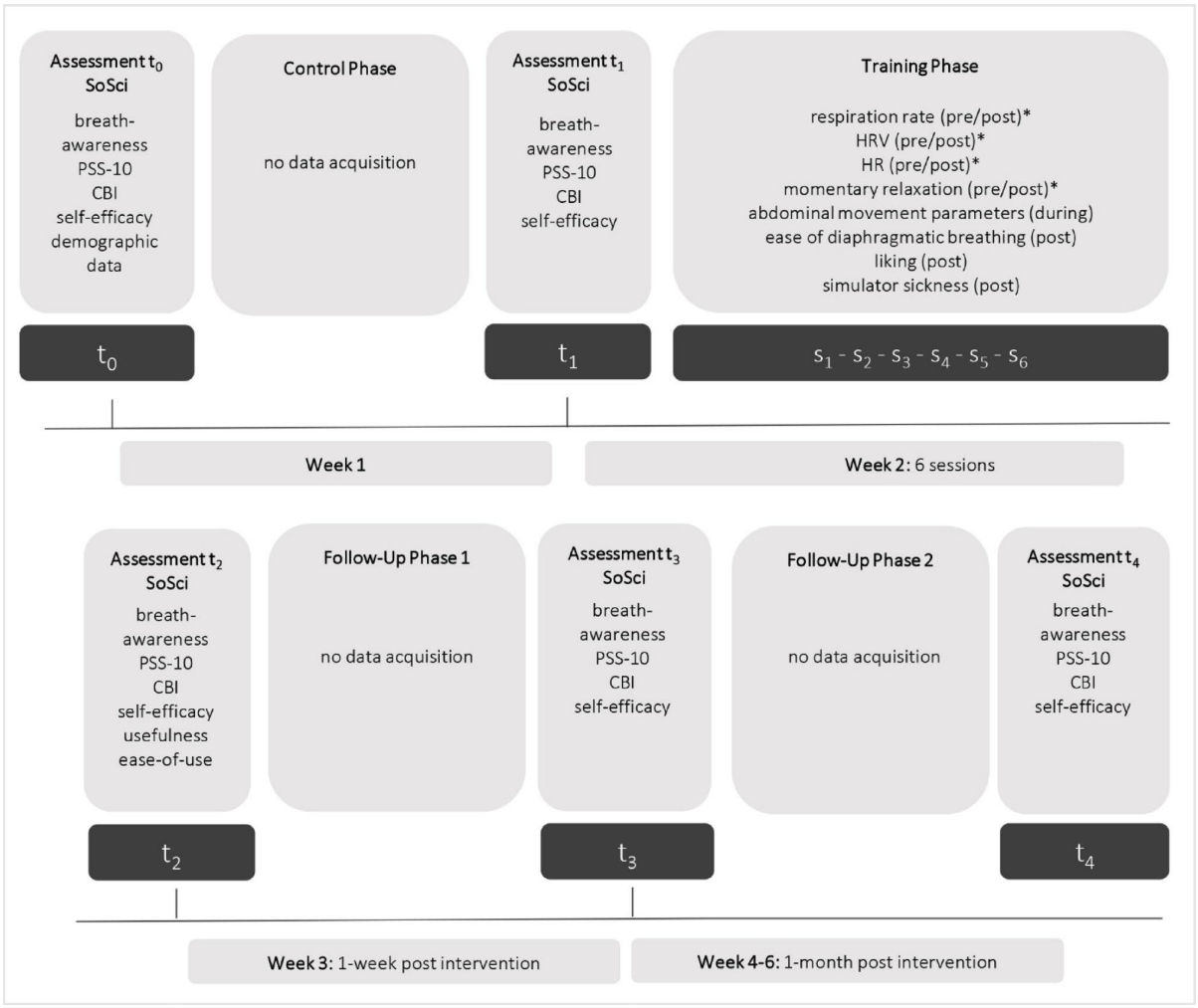


Fig. 1 Timeline of the study. t=measurement time point, s=training session. * = adapted/extended measurements, PSS-10=Perceived Stress Scale, CBI=Copenhagen Burnout Inventory

duration remained individual, as it depended on how effectively participants performed deep diaphragmatic breathing to progress through and ultimately complete the scenario. The duration of the Flowborne scenarios is determined by a fixed virtual trajectory. The technical development and configuration of *Flowborne* is described in more detail in the original study (Rockstroh et al. 2021), but will be shortly explained later on. The following VR sessions were carried out relatively independently by the participants and were only interrupted by the study personnel for measurements of the respiratory rate, heart rate and HRV parameters.

2.2 Participants

A total of 45 participants (15 women) took part in the study, including both undergraduate and postgraduate individuals. The age of participants ranged from 20 to 32 years, with a mean age of 22.9 years (*SD*=2.3). Five participants stated that they had previous experience with virtual reality, which were limited to isolated encounters in other research projects and without a biofeedback component, so they are still considered VR-naïve. Recruitment of participants was conducted through internal communication channels and students were either compensated with requisite laboratory hours or offered optional course credits. No monetary incentives were provided. Prior to their involvement, all participants provided written informed consent in accordance with ethical guidelines of the author's institutional board. Our participants represent a demographically comparable cohort to the original study by Rockstroh et al. (2021), which was our primary aim in this replication, as no further inclusion or exclusion criteria were set. In addition to demographic

similarities, none of the participants had prior experience with VR-based biofeedback, which aligns with the characteristics of the original sample. However, an a priori sample size calculation using G*Power Version 3.1.9.7 (Faul et al. 2007), indicated, that 32 participants would have been sufficient in terms of an optimal sample size.

2.3 Instruments

2.3.1 User experience

To assess the user experience, the same subjective methods were used as those implemented by Rockstroh et al. (2021) with the aim of confirming the (technical) feasibility of the VR-based mindfulness-based breathing meditation.

After each VR session (s_1–s_6) liking and simulator sickness were assessed using one item, respectively "How would you rate today's session?" (from *1 = very bad* to *5 = very good*) and "Did you experience any sickness or nausea during the session?" (from *1 = did not experience any sickness or nausea* to *5 = experienced sickness or nausea very often*).

The perceived usefulness of training as well as the perceived ease of use were both assessed at the measurement time point t_2 right after the training phase. The perceived usefulness of training consists of one item assessing the diaphragmatic breathing perspective ("The game helped me learn diaphragmatic breathing.") and one item regarding the benefit for relaxation ("The game helped me relax."). A visual analogue scale (VAS) ranging from *0 = not at all* to *1 = very much* was used for this purpose. To assess the perceived ease of use, the user friendliness subscale of the Technology Usage Inventory (TUI-BEN; Kothgassner et al. 2012) was applied (Cronbach's $\alpha = 0.90$; Rockstroh et al. 2021). This subscale consists of three items assessing the level of ease associated with utilizing a specific technology employing Likert scales ranging from *1 = not applicable at all* to *7 = completely applicable*, with higher scores indicating a higher degree of ease of use.

2.3.2 Breathing (related) parameters

Diaphragmatic breathing

On an objective level, the used head-mounted display (HMD), a Meta Quest 2 for Business, recorded any change in the current respiratory status namely inhalation movement, exhalation movement, movement artifacts or no movement. These states were calculated during each VR session (s_1–s_6) using a specialized breathing tracking algorithm based on positional changes of the VR controller during training. For further analysis, the relative share (percentage of the total training session duration; in %) of inhalation movements, exhalation movements and movement artifacts, which denote non-respiratory-related movements, was determined. Additionally, the individual mean durations of individual inhalation and exhalation movements (in sec) were computed.

Respiratory rate.

In light of the constraints highlighted by Rockstroh et al. (2021), supplementary pre-post assessments of breathing parameters were incorporated into the study framework. Our objective, from a methodological standpoint, was to integrate more objective instrumentation in this replications study, especially breath-based or -related parameters. Therefore, Firstbeat Bodyguards 2 (Parak and Korhonen 2015), beat-to-beat heart rate monitoring devices with a mean absolute error (MAE) of 0,54% in R-to-R interval measurements compared to a standard ECG (Parak and Korhonen 2015), were used to record the mean respiratory rate (times/minute) before and after each VR session (s_1–s_6) for a duration of five minutes.

Heart rate

In accordance with this line of reasoning, the study protocol incorporated not only objectively measured breathing-based parameters but also heart rate data collected before and after the VR sessions (s_1–s_6). Heart rate (beats per minute; bpm) was also recorded using the Firstbeat Bodyguard 2 system (Parak and Korhonen 2015) for a duration of five minutes, concurrently with the respiratory rate measurements.

Perceived ease of performing diaphragmatic breathing

On a subjective level, the perceived ease of performing diaphragmatic breathing was assessed via a single item ("How easy was it to perform diaphragmatic breathing?") after each VR session (s_1–s_6), as done in the original study by Rockstroh et al. (2021), using a Likert scale ranging from *1 = very difficult* to *5 = very easy*.

Perceived breath awareness

Perceived breath awareness was assessed at each assessment point (t_0–t_4) via a self-constructed 8-item scale by Rockstroh et al. (2021) with Cronbach's alpha ranging from $\alpha = 0.77$ to $\alpha = 0.87$ where participants were asked to rate their current breath awareness on a 7-point Likert scale (from *1 = not at all* to *7 = completely*). Examples of statements to be evaluated here include "I mainly breathe through my belly." or "When I take a calm breath, I feel relaxed.". For the entire scale, see Appendix.

2.3.3 Mental health and well-being parameters

Momentary relaxation

In contrast to the original paper, the subjective assessment of momentary relaxation was replaced by an objective measurement approach in the present study, utilizing again Firstbeat Bodyguard 2 devices (MAE = 0.54%; Parak and

Korhonen 2015). Heart rate variability (HRV) parameters, including SDNN (standard deviation of NN intervals) and RMSSD (root mean square of successive RR interval differences), were captured for a duration of 5 min before and after each VR session (s_1–s_6).

Perceived stress

The Perceived Stress Scale (PSS-10) as one of the most widely and well-established self-reported scale measuring perceived stress (Schneider et al. 2020) and being considered broadly applicable for any population subgroup was used at each assessment point (t_0–t_4) reaching Cronbach's alpha ranging from $\alpha = 0.82$ to $\alpha = 0.93$ in the original study (Rockstroh et al. 2021). In our adapted version, it assesses the degree to which life has been experienced as unpredictable, uncontrollable and overloaded over the last week, deviating from the original scale's focus on the last month (Cohen et al. 1983; Schneider et al. 2020). On a Likert scale raining from *0 = never* to *4 = very often*, participants indicate in 10 items how they perceive situations in their lives as stressful, for example "In the last week, how often have you felt that things were going in your way?".

Burnout symptoms

In line with the original paper by Rockstroh et al. (2021), work-related (7 items; Cronbach's α between 0.77 and 0.85) and personal burnout (6 items; Cronbach's α between 0.78 and 0.84) symptoms were assessed through subscales of the Copenhagen Burnout Inventory (CBI) by Kristensen et al. (2005) at every assessment point (t_0–t_4). Personal burnout captures the degree of physical and psychological fatigue and exhaustion experienced by individuals, independent of any specific context, while work-related burnout focuses on exhaustion directly attributed to one's job and professional responsibilities. Different fatigue and exhaustion components as the core of burnout are assessed as follows, depending on the item for example "How often do you feel worn out?" or "Do your work frustrate you?": *0 or 1 = (almost) never/to a very low degree*, *25 or 2 = seldom/to a low degree*, *50 or 3 = sometimes/somewhat*, *75 or 4 = often/to a high degree*, *100 or 5 = always/to a very high degree*. This outcome was integrated in the analysis as an indicator of a potential halo effect of the training impacting self-reported measures that are not directly related to the training objective as intended by the original paper.

Relaxation-related self-efficacy

In terms of the ability cope with various stressors, the relaxation-related self-efficacy was measured at every assessment point (t_0–t_4) via a 10-item scale used by Blum et al. (2019) with Cronbach's alpha ranging from $\alpha = 0.91$ to $\alpha = 0.95$ (Rockstroh et al. 2021). This kind of self-efficacy refers to an individual's belief in their ability to effectively engage in relaxation techniques (Blum et al. 2019). For each item, participants are asked to specify their level of confidence of executing the described action like "How confident are you right now that you can relax even when under time pressure?" on a visual analog scale (VAS) ranging from *0* (*not confident at all*) to *1* (*completely confident*).

2.4 Experimental treatment

We used an Oculus Quest 2 (now Meta Quest 2) head-mounted display (HMD) to provide the *Flowborne* VR training. This is a mobile VR scenario that offers an immersive virtual reality experience via a standalone, portable headset. In this context, the term 'mobile' is used to denote the untethered, self-contained nature of the VR system, which operates independently of external hardware such as a computer or tracking infrastructure. This allows users to interact freely with virtual environments without being connected to a computer or external tracking systems. In the case of *Flowborne* scenario, it represents an immersive VR-based mindfulness abdominal breathing exercise with integrated biofeedback in a seated position and was designed for all-in-one VR headsets (Rockstroh et al. 2021). For the seated position, participants were provided with an eGaming chair that allowed effortless rotation and visual exploration in the virtual world and had a slight pre-set back tilt to make the breathing exercise comfortable. An associated controller identifies relative position changes of breath-induced abdominal movements: forward movements are registered as an expansion of the abdomen (inhalation) and backward movements as a contraction of the abdomen (exhalation) which are integrated into the VR scenario as biofeedback in real time. The controller, visually represented as a semi-circle and positioned with its flat side resting approximately at navel height, provides real-time biofeedback that is seamlessly integrated into the VR scenario. Participants receive instructions on proper placement and use of the controller during the initial tutorial. The user's diaphragmatic breathing is visually represented within the virtual environment by temporary changes in the virtual environment, like color shifts and particles from blossoms or growing grass (Rockstroh et al. 2021). This feedback is integrated into the scenery, enabling users to observe the restorative setting while receiving real-time breathing feedback. Moreover, *Flowborne* employs diaphragmatic breathing as a locomotion mechanic. Meaning that users progress along a fixed path controlled by their breath, which conserves attentional resources and shifts focus towards breathing rather than decision-making. This breath-based locomotion implies a constant gentle movement preventing complete stops as well as reducing demotivation and simulator sickness. While inhaling, a counter variable is increased (up to a maximum of 4 s), which is visually indicated by enhanced path visibility. While exhaling, an additional forward force is applied,

with its strength determined by the previously mentioned counter variable (Rockstroh et al. 2021). There is no upper limit for exhalation duration, but optimal movement occurs with slow inhales (≥4 s) followed by slow exhales (~6 s), ensuring smooth and consistent travel leading to an exhale-inhale ratio of 1.5 (Rockstroh et al. 2021). This approach requires conscious diaphragmatic breathing for successful navigation through the game, improper breathing prevents forward movement (Rockstroh et al. 2021).

With this artificial virtual environment (see Fig. 2), *Flowborne* is pursuing a learning environment that is not influenced by potential negative experiences from the real world. This design uses the innate curiosity of users to create an intuitive and rewarding experience.

2.5 Data analyses

The Oculus data, extracted from the head-mounted displays and the subjective data collected via the Social Science Survey tool were both processed using Microsoft Excel (Microsoft Corporation 2021). Meanwhile, the Firstbeat data were analyzed with Kubios Scientific Software ("Kubios HRV Scientific Lite," 2023). All datasets were then integrated for further statistical analysis. Missing data were rare, as the subjects participated almost completely in the study. Isolated technical missing values occurred occasionally for values measured by the Firstbeat system and/or the Oculus VR headset. However, in the few cases where data was missing, a case-wise exclusion was performed, whereby only the specific observations with missing values were removed, while the integrity of the entire participant dataset was maintained. Furthermore, an outlier analysis was performed through visual inspection of boxplots for all relevant outcome variables. A small number of mild outliers were identified, defined as values located between 1.5 and approximately 3–4 interquartile ranges from the quartiles (Tukey 1997). These outliers appeared randomly distributed across measurement points and did not suggest any systematic pattern, thereby reducing the likelihood of underlying conspicuous technical issues or assessment-specific anomalies between VR sessions (Tabachnick and Fidell 2013). Furthermore, repeated measures ANOVA, as selected statistical method in this replication study, has been shown to be robust to violations of normality as long as the assumption of sphericity is met (Blanca et al. 2023). Therefore, no data transformation or exclusion of mild outliers was deemed necessary. To evaluate the hypotheses, the whole data set was subjected to a series of repeated-measures ANOVAs (two-tailed). The Mauchly test of sphericity was conducted to assess whether the sphericity assumption was violated, which ensures the equality of variances between all pairs of within-subject conditions. When sphericity was violated, Greenhouse-Geisser or Huynh-Feldt corrections were applied to adjust the degrees of freedom and obtain accurate p-values, ensuring reliable ANOVA results (Sawyer 2009). In some cases, difference contrast analyses were conducted after a significant ANOVA to assess continuous changes over time or distinct differences at specific time points. This approach identified patterns such as linear or other non-linear trends, beyond just general mean differences. Therefore, a Bonferroni-Holm correction was applied to sequentially adjust p-values for multiple comparisons (Aickin and Gensler 1996). The significance level for all statistical tests was predefined at $\alpha = 0.05$. Data analysis was performed using IBM SPSS Statistics, Version 29 (IBM Corp., Released 2023).

3 Results

3.1 User experience

Satisfactory average values are shown across all four user experience parameters including liking (s_1–s_6), simulator sickness (s_1–s_6), perceived usefulness of training (t_2) and perceived ease of use (t_2). No standard values are available for the items and scales used, nevertheless the fact that all



Fig. 2 Screenshots from the original study of the VR environment in *Flowborne*. Note that screenshots appear darker in than the in-game view with the VR headset

Table 1 Liking and simulator sickness across six training sessions

Session	Liking, M (SD)	Simulator sickness, M (SD)
1	4.42 (0.66)	1.33 (0.67)
2	4.36 (0.74)	1.29 (0.63)
3	4.41 (0.76)	1.32 (0.83)
4	4.39 (0.90)	1.11 (0.49)
5	4.51 (0.76)	1.22 (0.74)
6	4.51 (0.63)	1.11 (0.39)

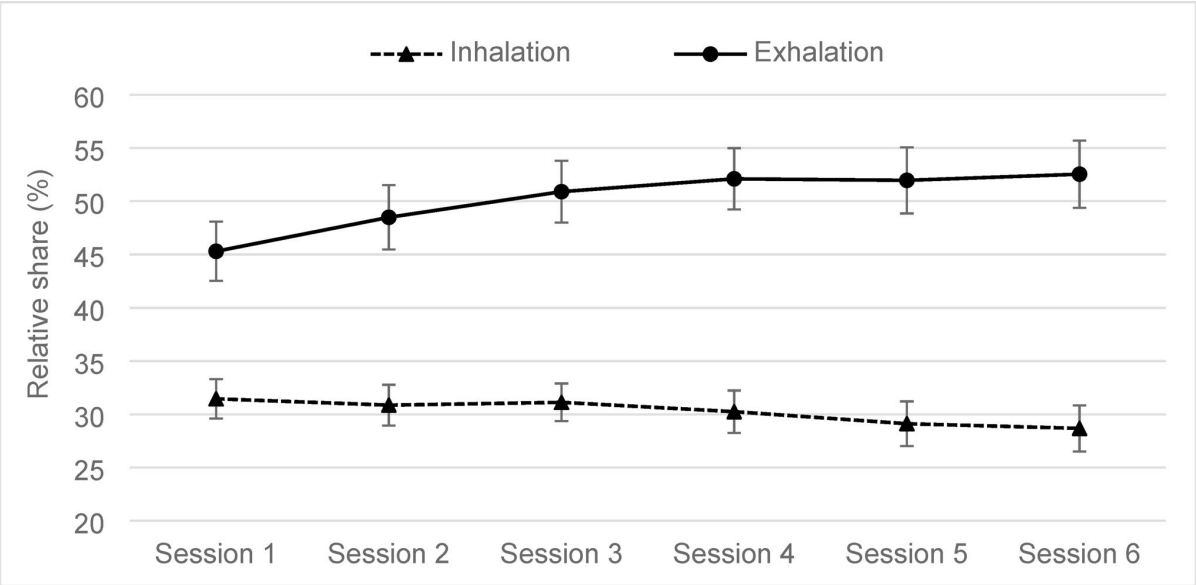


Fig. 3 Relative share (in %) of inhalation and exhalation movements by training session. Error bars represent 95% CI

means exceed the midpoint of their respective scales suggests a favorable user experience. Additionally, the absence of any participants withdrawing from the training further underscores the positive user experience.

Participants evaluated all training sessions positively with high liking scores (M=4.43, SD=0.74, scale from 1 to 5) and indicated rarely any occurrences of simulator sickness (M=1.23, SD=0.64, scale from 1 to 5). This is demonstrated across successive training sessions, as depicted in Table 1. Moreover, no differences in liking, F(4.523, 189.953)=0.482, p=0.772, η_p^2 = 0.011, and simulator sickness, F(3, 138)=1.212, p=0.309, η_p^2 = 0.028, could be found between the sessions.

In addition, participants stated that the training helped them to learn diaphragmatic breathing (M=0.60, SD=0.33, VAS from 0 to 1) and relax (M=0.79, SD=0.20, VAS from 0 to 1) according to their perceived usefulness of training. From a more technological perspective, use was rated as predominantly easy to understand (Item 1), generally simple (Item 2) and not very complicated (Item 3, overall: M=19.51, SD=1.89, maximum scale value: 21) through the TUI-BEN subscales.

3.2 Breathing (related) parameters

3.2.1 Diaphragmatic breathing

To analyze the HMD-based breathing parameters, artifacts (M=20.12%, SD=2.09%) were identified by the Meta Quest 2 and excluded for any further computation.

In order to evaluate the impact of the training on respiration-induced abdominal movements as an indicator of diaphragmatic breathing (H_{1a}), we examined two aspects: (1) the relative amount of involving diaphragm during each session and (2) the mean duration of diaphragm expansion (inhalation) or contraction (exhalation) for individual breaths.

First, we performed two separate repeated-measures ANOVAs to analyze the relative share (in %) of both inhalation and exhalation movements over six individual sessions (H_{1a}) as within-subjects measurement points (see Fig. 3). In the case of significant effects, further difference contrast analyses were carried out by analyzing one session with the respective previous sessions. The ANOVA on the relative share of inhalation movements revealed no significant effect of the training over time (F(2.899, 121.768)=2.221,

$p=0.091$, $\eta_p^2 = 0.05$), in contrast to the relative share of exhalation movements increasing over the course of the training ($F(3.481, 146.214)=11.600$, $p<0.001$, $\eta_p^2=0.216$). In line with that, further difference contrast analyses showed that the relative share of exhalation for each session was significantly higher compared to the average of all previous sessions (all $p<0.037$, all $\eta_p^2>0.100$) confirming the trend.

Next, we carried out two separate repeated-measures ANOVA of the mean duration of diaphragm expansion (inhalation) or contraction (exhalation) during individual breaths (H_{1a}; see Fig. 4). The ANOVA on the mean duration of inhalation movements revealed no significant effect ($F(4.375, 183.761)=2.073$, $p=0.08$, $\eta_p^2=0.047$), in contrast to the mean duration of exhalation movements increasing over the course of the training ($F(3.707, 155.675)=5.269$, $p<0.001$, $\eta_p^2 = 0.108$). However, difference contrast analyses revealed only significantly higher exhalation movements in the third VR-session compared to the two previous ones ($p=0.041$, $\eta_p^2 = 0.155$). All other p-values exceeded values of $p=0.1096$ and the corresponding effect size (ηp^2) remained smaller than 0.111 in the other contrast analyses.

3.2.2 Respiratory rate

A repeated measures analysis of variance (ANOVA) was performed to determine the specific effects of the training sessions on breathing patterns, particularly the mean respiratory rate (H_{1b}). This analysis included the factors "training session" (with six different sessions as measurement time points within the subject) and "time" (with two levels within the subject: pre-session and post-session).

The ANOVA on the average respiratory rate (see Fig. 5) revealed a significant effect of "training session" ($F(1, 39)=33.918$, $p<0.001$, $\eta_p^2 = 0.465$), indicating that, on average, the mean respiratory rate differs throughout the training phase. Moreover, a significant effect of "time" ($F(5, 195)=9.832$, $p<0.001$, $\eta_p^2 = 0.201$) with lower respiratory rates post-session ($M=14$ times/minute, $SD=0.45$ times/minute) than pre-session ($M=15$ times/minute, $SD=0.79$ times/minute) but no significant interaction effect between "training session" and "time" ($F(5, 195)=1.488$, $p=0.195$, $\eta_p^2 = 0.037$) was found.

3.2.3 Heart rate

A repeated measures analysis of variance (ANOVA) was conducted to assess the specific effects of the training sessions on the heart rate (H_{1c}). This analysis incorporated two within-subject factors: "training session," consisting of six distinct sessions as measurement time points and "time," consisting of two levels, pre-session and post-session. On the one hand, the ANOVA (see Fig. 6) revealed no significant effect of "training session" ($F(5, 200)=0.375$, $p=0.866$, $\eta_p^2 = 0.009$) on the heart rate. But on the other hand, there is a significant effect of "time" ($F(1, 40)=24.525$, $p<0.001$, $\eta_p^2 = 0.380$), with lower heart rates post-session ($M=75$ bpm, $SD=10.03$ bpm) than pre-session ($M=77$ bpm, $SD=11.59$ bpm). Further, there is no significant interaction effect between "training session" and "time" ($F(4.465, 178.601)=0.213$, $p=0.945$, $\eta_p^2 = 0.005$).

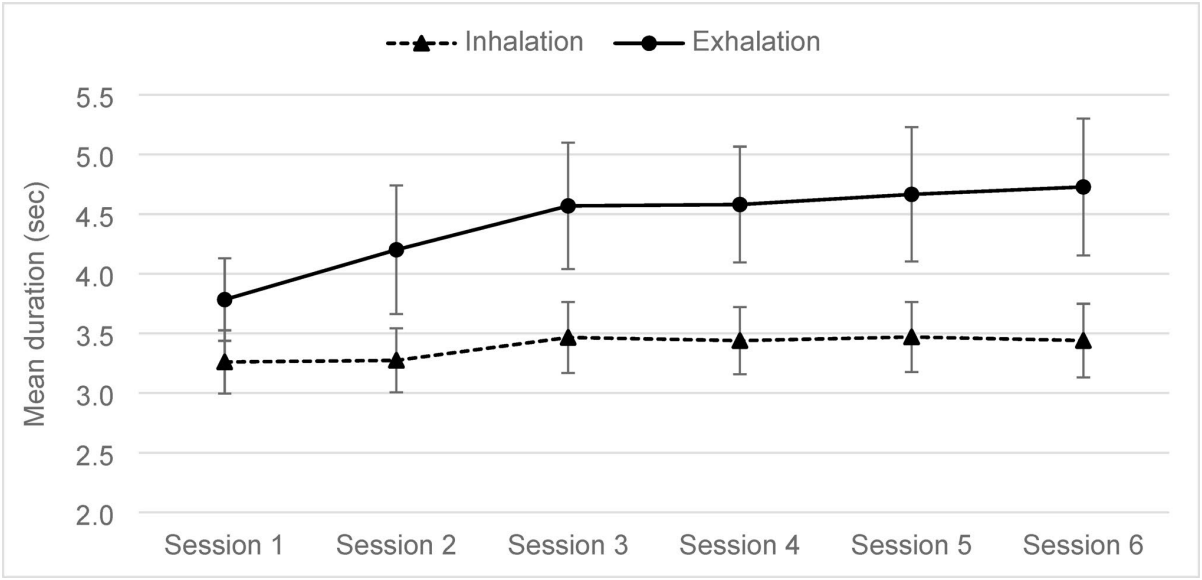


Fig. 4 Mean duration (in sec) of inhalation and exhalation movements by training session. Error bars represent 95% CI

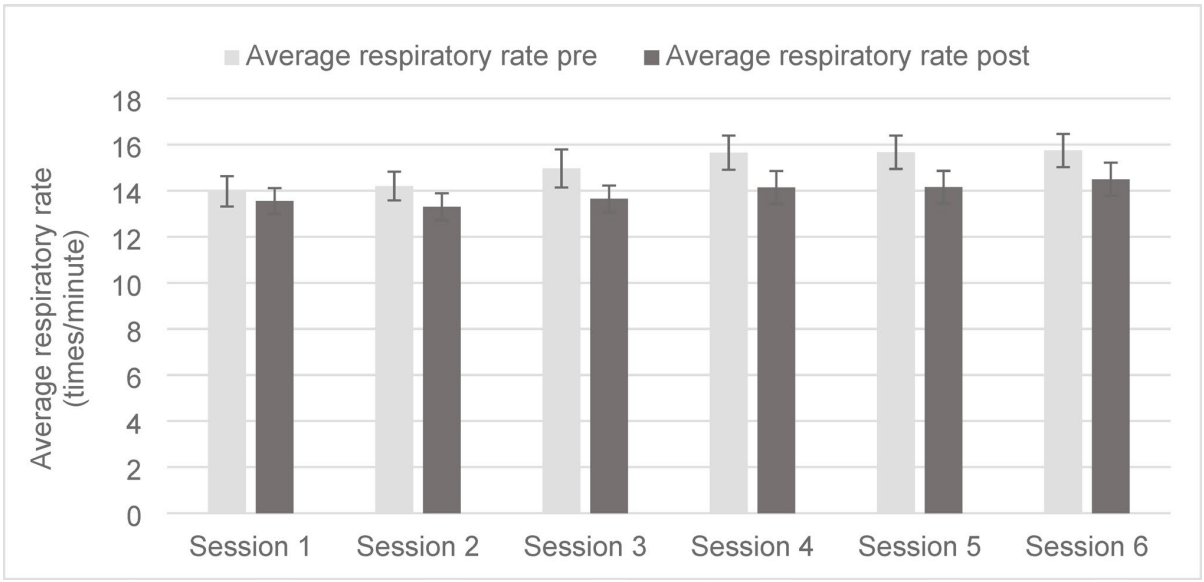


Fig. 5 Average respiratory rate (pre/post) by training session. Error bars represent 95% CI

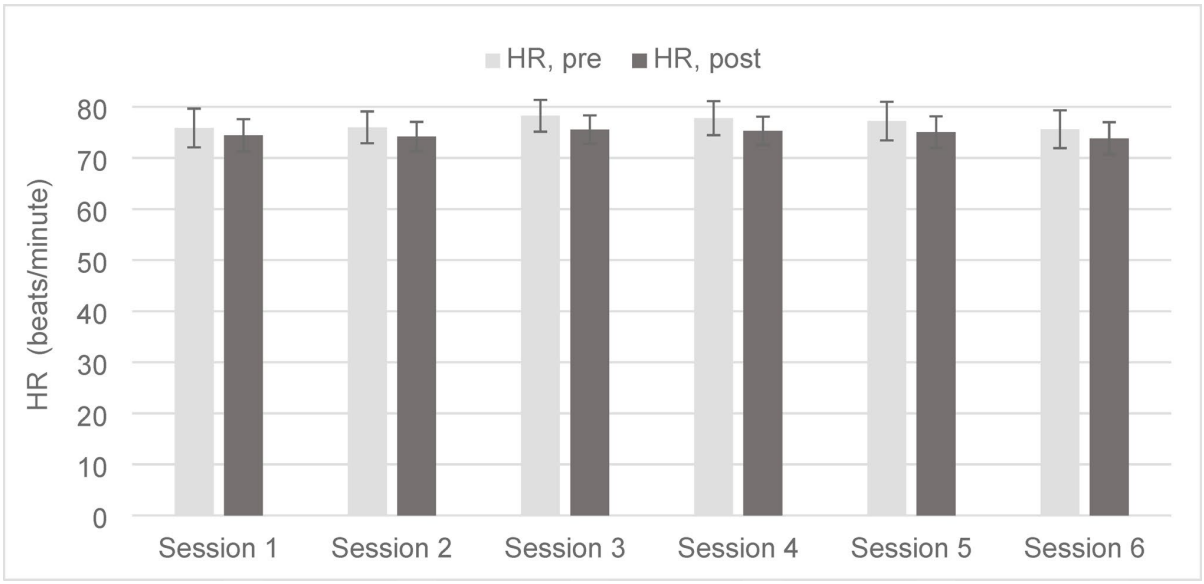


Fig. 6 Heart rate (in bpm) by training session. Error bars represent 95% CI

3.2.4 Perceived ease of performing diaphragmatic breathing

To assess the impact of training on participants' perceived ease of performing diaphragmatic breathing (H_{1d}), we executed a repeated-measures ANOVA, employing six individual VR-training sessions as within-subject measurement time points (see Fig. 7). The analysis unveiled a significant temporal effect of training ($F(3.525, 148.068) = 5.309$, $p < 0.001$, $\eta_p^2 = 0.112$). Further difference contrast analysis showed that only session 4 was significantly higher than the average of all previous sessions ($p = 0.011$, $\eta_p^2 = 0.204$), while there were no further significant differences between any other VR-session and their previous ones (all $p > 0.060$, all $\eta_p^2 < 0.133$).

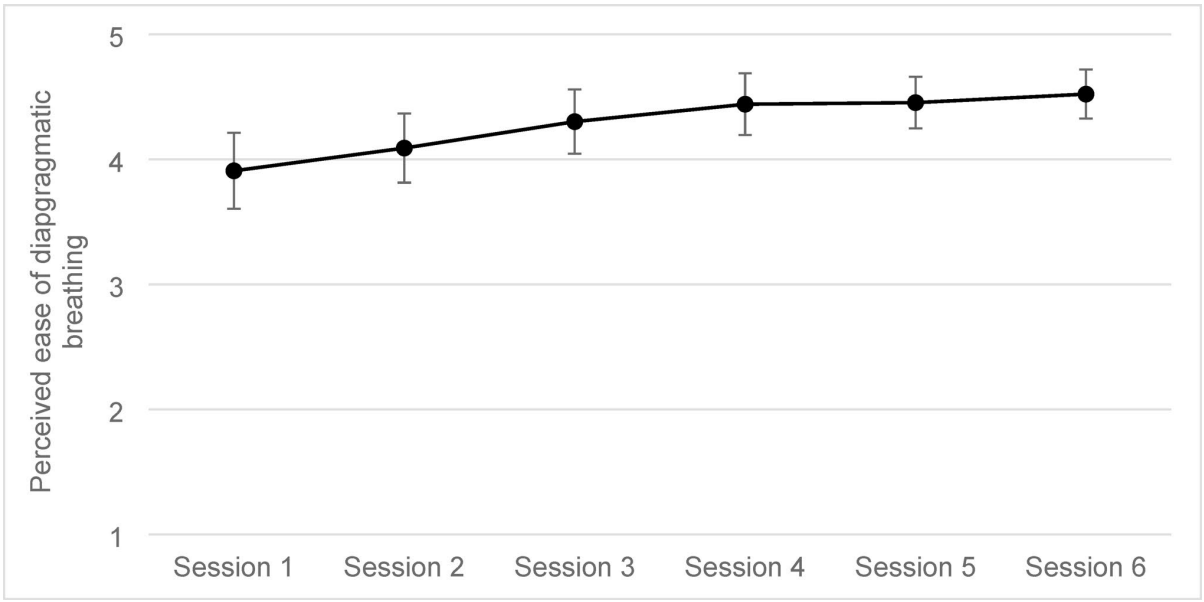


Fig. 7 Perceived ease of performing diaphragmatic breathing by training session. Error bars represent 95% CI

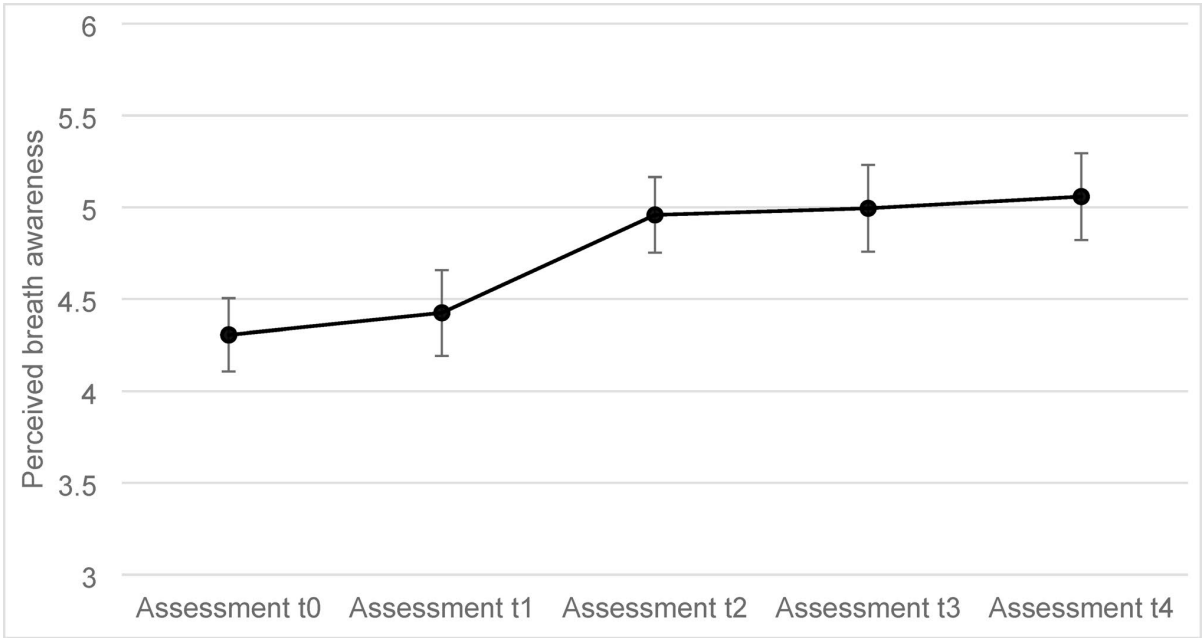


Fig. 8 Perceived breath awareness by measurement time point. Error bars represent 95% CI

3.2.5 Perceived breath awareness

To evaluate the perceived breath awareness throughout all assessments (H_{1e}) a self-constructed scale developed by Rockstroh et al. (2021) was employed. A repeated-measures ANOVA was conducted in order to examine the effect of the training on the perceived breath awareness (t_0–t_4 as within-subjects measurement time points, see Fig. 8). An effect of training across all assessment points was observed with $F(2.368, 78.140) = 22.472$, $p < 0.001$, $\eta_p^2 = 0.413$. Further difference contrast analyses revealed that the perceived breath awareness was significantly higher compared to the average of all previous sessions (all $p < 0.023$, all $\eta_p^2 > 0.153$) confirming the trend with an exception between t_0 and t_1.

3.3 Mental health and well-being parameters

3.3.1 Momentary relaxation

In contrast to the methodology of the original study, an objective rather than a subjective measurement instrument (1-channel ECG) was used to assess the immediate effect of the VR training sessions on participants' relaxation (H_{2a}). Therefore, we executed two repeated-measures ANOVAs including the factors "training session" (with six different sessions as measurement time points within the subject) and "time" (with two levels within the subject: pre-session and post-session).

The analysis conducted on SDNN, a time-based HRV parameter serving as primary source of parasympathetically mediated respiratory arrhythmia, as illustrated in Fig. 9, revealed a significant effect to the "training session" factor ($F(5, 205)=4.303$, $p<0.001$, $\eta_p^2 = 0.961$). This results indicates, that, on average, there is a significant change in the parasympathetic innervation of the heart mediated by the vagus nerve (Fisher et al. 2022). Moreover, there is also a significant effect of the factor „time" ($F(1, 41)=30.794$, $p<0.001$, $\eta_p^2 = 1.000$) with higher SDNN values post-session ($M=59.15$ ms, $SD=19.47$ ms) compared to pre-session ($M=50.63$ ms, $SD=20.19$ ms). In addition, a significant interaction effect was observed between both factors ($F(4.426, 181.484)=2.676$, $p=0.029$, $\eta_p^2 = 0.768$) indicating that the variation in SDNN differs across training sessions relative to the time point (pre-session vs. post-session).

The analysis conducted on RMSSD, a time-based HRV parameter serving as primary source of parasympathetically activity, as illustrated in Fig. 10, revealed neither a significant effect to the "training session" factor ($F(5, 205)=1.051$, $p=0.389$, $\eta p^2 = 0.025$) nor to the factor „time"($F(1, 41)=2.836$, $p=0.100$, $\eta p^2 = 0.065$). In contrast, a significant interaction effect was observed between both factors ($F(4.362, 178.835)=2.426$, $p=0.045$, $\eta p^2 = 0.056$) indicating that the variation in RMSSD differs across training sessions relative to the time point (pre-session vs. post-session).

3.3.2 Perceived stress

To evaluate an effect and its sustainability of training on perceived stress (H_{2b}), we conducted a repeated-measure ANOVA on the PSS-10 scores (t_0 to t_4 as within-subjects measurement time points, see Fig. 11). The training had no significant impact on stress indicated by PSS-10 scores ($F(2.913, 119.427)=1.772$, $p=0.158$, $\eta_p^2 = 0.041$).

3.3.3 Burnout symptoms

To evaluate the impact of training on burnout symptoms (H_{2c}), we conducted two separated-measures ANOVA on the personal and work-related CBI scores (t_0–t_4 as within-subjects measurement time points, see Fig. 12).

The analysis of personal burnout scores revealed a significant effect of training ($F(4, 164)=6.972$, $p<0.001$, $\eta_p^2 = 0.145$). Further post-hoc contrast analyses revealed a statistically significant decrease in scores between the baseline

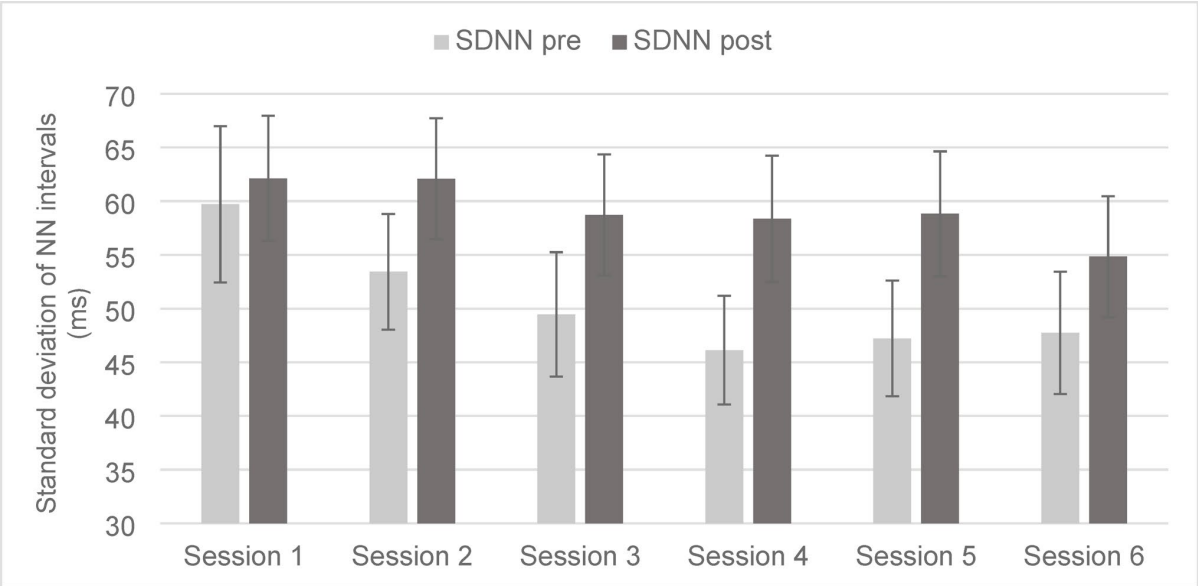


Fig. 9 SDNN (in ms) by training session. Error bars represent 95% CI

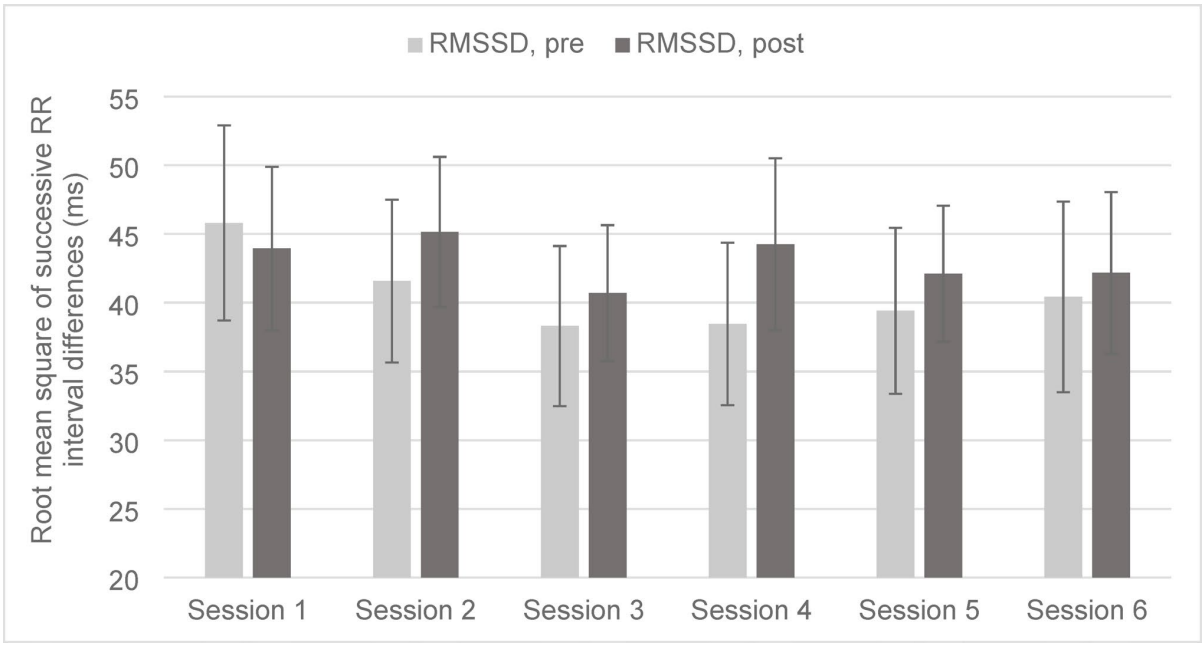


Fig. 10 RMSSD (in ms) by training session. Error bars represent 95% CI

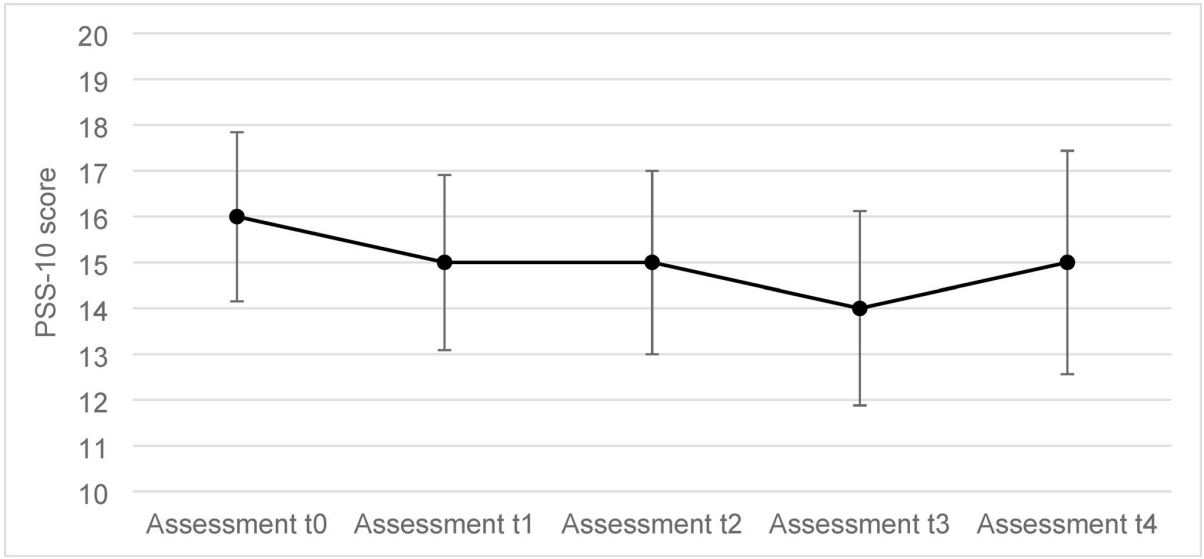


Fig. 11 Perceived stress (PSS-10) by measurement time point. Error bars represent 95% CI

assessment (t_0) and the subsequent assessment (t_1) with $p<0.001$ and $\eta p^2 = 0.341$. A similar pattern was observed when comparing scores at assessment t_2 with those from both prior assessments (t_0+t_1; $p=0.026$, $\eta p^2 = 0.156$). No significant differences were identified in the comparisons of scores at assessments t_3 and t_4 with earlier time points (all $p>0.999$, all $\eta p^2 < 0.010$). Furthermore, there was no significant effect on the work-related burnout scores ($F(3.569, 146.335)=0.237$, $p=0.900$, $\eta_p^2 = 0.006$).

3.3.4 Relaxation-related self-efficacy

To assess an effect of training on relaxation-related self-efficacy (H_{2d}), we conducted a repeated-measures ANOVA (t_0–t_4 as within-subjects measurement time points, see Fig. 13).

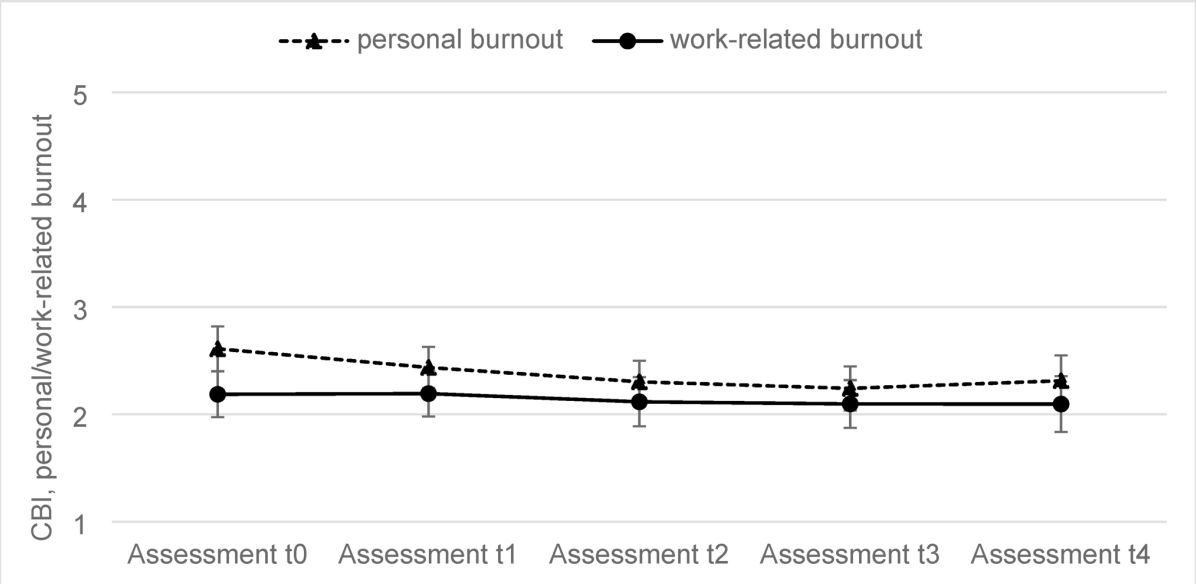


Fig. 12 Work-related and personal burnout (CBI) by measurement time point. Error bars represent 95% CI

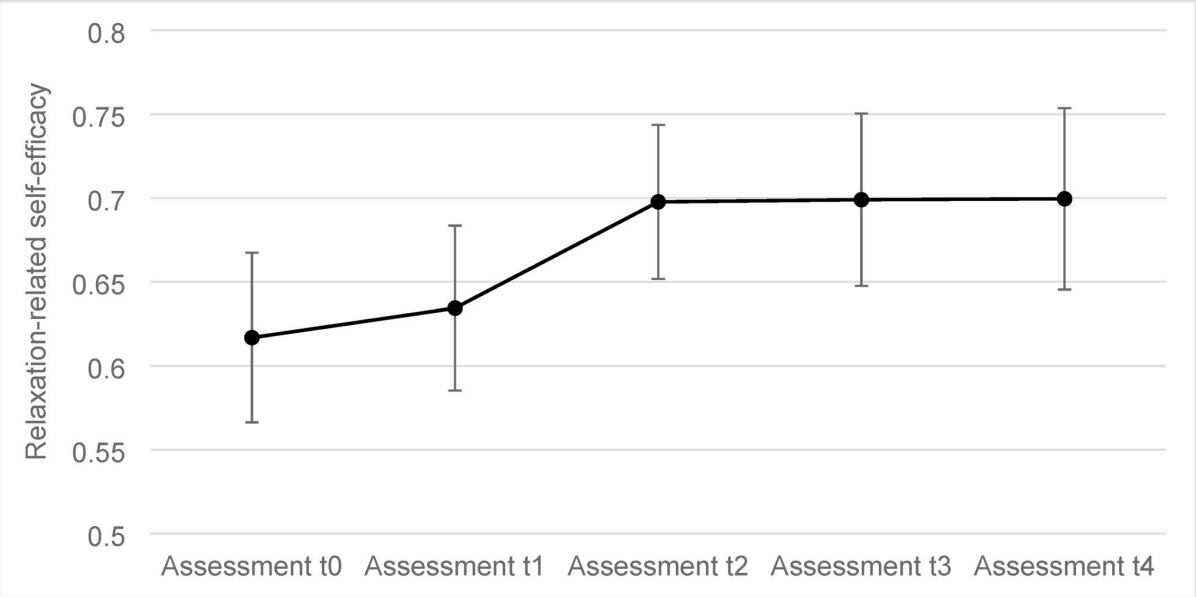


Fig. 13 Relaxation-related self-efficacy by measurement time point. Error bars represent 95% CI

The analysis revealed a significant effect of training on relaxation-related self-efficacy ($F(2.215, 90.812) = 11.129$, $p = 0.001$, $\eta_p^2 = 0.213$). Further difference contrast analyses showed that relaxation-related self-efficacy did not differ significantly between t_0 and t_1 ($p = 0.194$), but after the training phase (t_2) compared to the average of all previous assessments (all $p < 0.040$, all $\eta_p^2 > 0.125$).

4 Discussion

This replication is based on the study by Rockstroh et al. (2021), which examined the effects of *Flowborne*, a mobile VR-based mindfulness breathing meditation with integrated biofeedback, on different health outcomes. Health was assessed from both a physiological perspective, focusing on breathing (related) parameters (H_{1a}–H_{1e}) and a

psychological perspective, evaluating mental health and well-being (H_{2a}–H_{2d}) of participants. In addition to these primary health-related aspects, we have also included the feasibility of the VR scenario in our investigations, as done in the original study. The study protocol, including the measurement time points and methods, was closely to the original study. Conceptual adjustments were mainly made by introducing additional objective measurement methods and physiological parameters. Further adjustments concerning an extended longitudinal design up to six weeks provided valuable insights into the sustainability of the effects regarding not only short-term but also initial medium-term insights on the participants health status after the intervention.

4.1 User experience

In examining the feasibility of the VR scenario, we briefly wanted do address the participants' potential preferences for color schemes within *Flowborne*. The original study accounted for that by incorporating two landscapes, each with a distinct color scheme, into the test protocol. Building on this approach, we maximized participant autonomy by allowing them to select their preferred color scheme for each session. This self-selected based approach was found important for mood benefits when using VR, in this case a sports-based VR task, which we have translated into our context (Legrand et al. 2011; Neumann et al. 2018).

Despite a slightly longer total duration of approximately 53 min (vs. 46 min) across the six VR training sessions ($M_{session}$ = 8 min 52 s; $SD_{session}$ = 39 s), findings from our feasibility analysis reaffirm the robustness of this VR game as a tool for mindful breathing training. Liking ratings remained consistently high throughout the training period, with no irregularities observed. Additionally, simulator sickness levels were comparably low to those reported in the original study, supporting the assumption by Rockstroh et al. (2021) that the simultaneous occurrence of artificial movement within the game and conscious exhalation reduces the likelihood of simulator sickness.

From a more technologically-driven perspective, results of the perceived ease of use (TUI-BEN) indicated that participants rate the game as user-friendly and easy to use. So, this VR experience seems to be designed easily accessible and intuitive, making.

it approachable for a wide audience, which ultimately leads to a greater engagement and satisfaction (Bruno and Muzzupappa 2010).

This level of user-friendliness is also important for the effective implementation of the content and intention of the VR game, whether the aim is to help users relax or to learn diaphragmatic breathing. Aligning with findings from the original study, participants report a strong perceived usefulness of the training.

To sum it up, from a user experience perspective, *Flowborne* appears to be a suitable option for VR-based mindfulness breathing training.

4.2 Breathing(-related) parameters

The main objective of *Flowborne* is to develop a deep diaphragmatic breathing technique, a goal that has been successfully met as demonstrated by the HMD-based breathing parameters (H_{1a}), in line with the findings from the original study.

The relative amount of diaphragmatic breathing (inhalation + exhalation) reached a level of 81.2% at the last VR session, which even exceeds the relative amount of 80.6% reported in the original study. Between the first and last session the relative amount differs by 4.5%, which equals a 5.5% increase. This increase is initially significantly lower than in the original study, which was 22%. However, it is important to highlight those participants in this replication study began their intervention phase from a notably higher baseline level, especially regarding relative exhalation (~36% vs. 45%). The development of deep diaphragmatic breathing in our intervention is particularly due to a gradually increase in the relative amount of exhalation (45.3–52.5%). The percentage of inhalation remains at a level of about 30% over the whole training course, which is similar to the values reached in the original study.

This pattern can be transferred to the mean duration of inhalation and exhalation with an overall mean duration (inhalation + exhalation) of 7.0 s at the first VR session and 8.2 s at the last VR session. Most of the development can again be attributed to the increase in the mean duration of exhalation. As outlined initially, an exhale-to-inhale ratio of 1.5 was desired, closely approximated here with a mean ratio of 1.39 (SD = 0.40) in the last VR session, which was suggested by the locomotion-based feedback implementation. Regarding diaphragmatic breathing cycles, different approaches are discussed in literature suggesting brief pauses of 1–2 s between inhalation (4 s) and exhalation phases (6 s) or a more general one suggesting six seconds for both inhalation and exhalation (Hamasaki 2020; Mirgain et al. 2016; Rockstroh et al. 2021). By adopting the first approach and adding a 1–2 s pause into the 8.2 s duration of the last VR session, the resulting breathing cycle is about 6 breaths per minute. This respiratory rate is associated with greater psychological and physiological well-being, like higher subjective relaxation and reduction in blood pressure (Kral et al. 2023).

These positive findings in the estimated respiratory rate during the intervention can also be seen in the pre-post

measurements of the respiratory rate (H_{1b}), but at a different respectively higher level. The important message that can be derived from these results is that participants from each session come out of it with a lower respiratory rate than they went in, regardless of their personal state on that particular day. Thus, these breathing effects during the intervention as just described can also have a brief lasting effect beyond the end of the VR game. But it also shows the tendency for physiologically-based breathing effects to occur particularly in the active execution of a diaphragmatic breathing. So, with estimated respiratory rates of 7–9 breaths per minutes during intervention, pre an post values are obviously higher. A similar pattern is present in the pre-post measurements of the heart rate (H_{1c}) with lower rates after the VR session than before. Lying in the nature of this parameters, no trend over time (s_1-s_6) could be identified in respiratory rate and heart rate. Nevertheless, these findings support the substantial and immediate effect diaphragmatic breathing can have on various physiological parameters. While the original study did not offer these immediate pre- and post-session insights, our study has incorporated them, addressing limitations of the original research. It underlines how valuable this breathing technique can be in a stressful situation counteracting the body's physiological response by for example slowing heart rate and respiratory rate.

In addition to these objectively measured parameters, the inclusion of a subjective perception of breathing-related aspects enables a comprehensive understanding of the participants development throughout this intervention.

So, the perceived ease of performing diaphragmatic breathing (H_{1d}) shows a continuously increase over time with already high ratings at the beginning and then seems to stabilize at a value of 4.5—on Likert scale ranging from 1 to 5—after the fourth session. Therefore, the effectiveness of the training is not only present in the abdominal movement data, especially with regards to the exhalation, but also in the participant's impression to perform a proper diaphragmatic breathing. Furthermore, this subjective assessment indicates that the feedback implementation effectively informs participants about their breathing style and that participants are aware of their improvement. This could already be shown in the original study by Rockstroh et al. (2021).

This awareness can be confirmed by the measurement of increased perceived breath awareness (H_{1e}) after the training phase and even beyond that. Participants reported that they maintained and even increased their awareness of their breathing for up to one (t_3) respectively four weeks (t_4) after training. Once this awareness is established, it appears to remain stable, suggesting effective maintenance and supporting the effectiveness of biofeedback training in promoting mid-term physiological self-regulation. However, participants already showed significant increased breathing awareness between the baseline measurement time point (t_0) and the start of the intervention (t_1), which might be explained due to an increased attention of their breathing, caused by the awareness of being part of a study or the anticipation of the upcoming intervention also known as the Hawthorne effect (Becker-Carus et al. 2017).

Similar to the original study, the subjects appear to have developed the best possible breathing style by the end of the training phase. This can even be seen in the flattening development of the exhalation from the third session onwards, which is accompanied by a settling ease of performing diaphragmatic breathing from the fourth session onwards. As already suggested by Rockstroh et al. (2021), future training protocols should consider repeated and spaced sessions with for example 10–12 sessions with increasing intervals in-between. Since this replication study aimed to retain the original structure of the training sessions, we did not make any fundamental changes. This recommendation is therefore directed toward future research efforts and aligns with the need for more precise dose-response assessments (Wieczorek et al. 2024).

4.3 Mental health and well-being

In addition to the findings obtained from subjective and objective (breathing) related parameters, the focus now shifts to metrics within the domain of mental health and well-being, reflecting the objectively measured findings of the momentary relaxation (H_{2a}) in contrast to the subjective-based approach used in the original study (Rockstroh et al. 2021; Terathongkum and Pickler 2004). Therefore, the positive effects observed in the time-domain HRV parameter SDNN are primarily driven by parasympathetically mediated respiratory sinus arrhythmia (RSA), especially in resting-state recordings with slow, paced breathing protocols (Shaffer et al. 2014). Therefore, the post-session increase in parasympathetic activity can be explained through HR variations related to the respiratory cycle. During inhalation, the cardiovascular center reduces vagal outflow, leading to an increase in heart rate. In contrast, during exhalation, vagal outflow is restored, slowing the heart rate through the release of acetylcholine, which is the primary neurotransmitter for parasympathetic nervous system (Eckberg and Eckberg 1982). The magnitude of oscillation is variable, but can usually be exaggerated by slow, deep breathing as just shown in our analysis. The observation that SDNN values increase immediately after each VR session but decrease over time suggests a complex physiological response. The pre-post increase in SDNN reflects acute parasympathetic activation as just described. However, the overall decrease in SDNN over time may indicate adaptation to the meditation, where the body becomes less responsive to the relaxation effects.

Additionally, external factors (Sammito and Böckelmann 2016) like cumulative stress, fatigue or daily events could contribute to a shift toward lower parasympathetic activity or increased sympathetic tone. It is also possible that a baseline shift or longer-term adaptation of the autonomic nervous system has not yet become apparent, as six sessions might be too few to capture these effects. Moreover, the chosen measurement time points may not fully reflect the general state of the ANS. Including additional assessments beyond pre- and post-session measures—such as during the meditation itself (Lumma et al. 2015) or after getting up in the morning (Laborde et al. 2017)—could have provided a more comprehensive picture of both the long-term effects and the underlying physiological processes during the intervention.

In line with the physiological processes in SDNN, RMSSD captures beat-to-beat variations in heart rate and thus effectively reflects vagal changes in HRV (Shaffer and Ginsberg 2017), as evidenced by significant interaction effects in our intervention. These results confirm the subjectively observed effects reported in the original study.

The brief effect of *Flowborne* as seen in the momentary relaxation session by session could not be made visible statistically in the subjectively recorded stress parameter (H_{2b}) at the assessment points (PPS-10; t_0-t_4), even if a slight downward trend can be seen descriptively. The lack of development in this parameter can be probably explained by the fact that participants started the training phase with a relatively low baseline stress level (value: 16; maximum value: 50). By contrast, the participants in the original study started with a score of just over 25 (t_0/t_1) and ended with a score of just under 20 (t_2), which left more room for potential changes and thus led more easily to significant effects. Future studies should examine the effects on a new cohort that is more vulnerable and sensitive to stress in order to expand empirical findings. Even though the students in this study were already in the preparation phase for upcoming exams, depending on when they started the intervention, they did not yet appear to be easily affected by stress at that time.

Furthermore, positive effects were observed on personal burnout symptoms (H_{2c}), with a decreasing trend up until one-week post-intervention (t_3), followed by a slight increase by the final assessment (t_4). That trend indicates that while the VR intervention initially alleviates personal burnout symptoms, covering aspects like physical and emotional exhaustion or health vulnerability, its effects may diminish over time. Therefore, to sustain the benefits, ongoing or follow-up sessions might be necessary. The significant decrease between assessment t_0 and t_1 appears to be a consistent pattern across some different parameters likely reflecting the Hawthorne effect (Becker-Carus et al. 2017). Moreover, the lack of an effect on work-related burnout symptoms (H_{2c}) is nonetheless positive, since the VR game did not address these aspects. Furthermore, the results suggest that there is no halo effect, meaning the participants' ratings were not biased by unrelated positive perceptions (Dennis 2007). This allows for a more accurate and objective assessment of the specific effects of VR-based mindfulness breathing meditation. Both findings regarding burnout symptoms are consistent with those of the original study by Rockstroh et al. (2021).

As mentioned at the beginning, previous research suggests that combining immersive VR with self-efficacy-enhancing biofeedback can strengthen the effect of biofeedback training on relaxation-related self-efficacy (Rockstroh et al. 2019, 2021; Weerdmeester et al. 2017). The results of both the original study and this replication study confirm these findings. After the training phase, the participants seemed to have more confidence in their relaxation abilities, which can be attributed to the effects of diaphragmatic breathing in particularly with regards to the perceived ease of performing diaphragmatic breathing. The increased relaxation-related self-efficacy (H_{2d}) seems to have been maintained in the subjects even beyond the training period, once again emphasizing the short- and medium-term effects of this VR-based mindfulness breathing meditation. Consequently, participants have greater belief and confidence in their ability to effectively use relaxation techniques, specifically performing deep diaphragmatic breathing in order to calm and relax body and mind respectively to reduce stress (Bandura 1977).

4.4 Limitations and future research

The findings of this replication study are largely consistent with the positive outcomes reported in the original study by Rockstroh et al. (2021). However, the absence of a control group represents a limitation, which was already addressed at the beginning. The decision to not include a control group in this replication study is based on the fact that this study design consists of several potentially effective components like VR, restorative environments, breathing exercises and biofeedback. It would be extremely difficult to isolate the effects of each element as already outlined by Rockstroh et al. (2021). Furthermore, we considered the potential risk of making incomparable comparisons, as done by Rockstroh et al. (2021), to be too high to justify the allocation of resources for an active control condition. In line with the underlying argument of Rockstroh et al. (2021), the study partially compensated for the lack of an active control group by conducting a double pre-measurement to minimize possible test effects. In addition, efforts were made to take seasonal and external influences into account by starting the

intervention over a period of two months. Therefore, the replication study focused on confirming the overall effectiveness of the intervention, while largely maintaining the approach of the original study and preserving methodological consistency.

Nevertheless, we were able to address some limitations by including additional assessment measurement time points in the study protocol, enabling us to examine mid-term effects alongside short-term effects. We also enhanced the measurement methodology by incorporating additional objective pre-post data collection instruments to more comprehensively capture breathing-related parameters. In order to remain as consistent as possible with the original study, we chose not to follow the recommendation to test a more heterogeneous study population. This decision was made to ensure comparability of results across studies and to maintain the validity of the replication process. By focusing on a similar sample, we aimed to reduce confounding variables that could hide the observed effects.

A limitation of the present study concerns the unequal gender distribution in the sample, which included 30 male and 15 female participants (2:1 male-to-female ratio). While this imbalance may raise concerns about the generalizability of the findings, it is noteworthy that the original study by Rockstroh et al. (2021), which served as the basis for our replication, also exhibited a substantial gender asymmetry, albeit in the opposite direction, with 16 male and 29 female participants (approximately a 1:2 male-to-female ratio). Thus, neither study employed a gender-balanced sample and both are subject to similar limitations regarding potential gender-related biases. Despite this asymmetry, the impact on the interpretation of the results is considered to be limited. Although gender differences in VR experiences have been reported in some studies, recent systematic reviews (Grassini and Laumann 2020) indicate that such effects, particularly in relation to simulator sickness, sense of presence and performance, are typically small, inconsistent or context-specific. Additionally, research by Stanney et al. (2020) suggests that symptoms such as cybersickness are more strongly influenced by technical variables, such as the proper adjustment of the headset's interpupillary distance (IPD) to individual users. In the present study, IPD was measured and individually adjusted for each participant, which likely reduced the influence of gender-related physiological differences. Furthermore, overall user experience ratings were good, suggesting that participants, regardless of gender, engaged positively with the VR intervention and reported a satisfactory experience. In addition, several empirical studies (Navarro-Haro et al. 2017; Lindner et al. 2019; Zhang et al. 2021) support the assumption that immersive VR interventions elicit comparable psychological and physiological responses across genders. These findings suggest that VR may serve as a relatively gender-neutral medium for delivering mindfulness-based interventions, thereby mitigating some of the concerns related to gender imbalance in the sample. While the gender imbalance in the sample is acknowledged as a possible limitation, it also presents an opportunity to assess the effectiveness of the intervention among male participants, who were relatively underrepresented in the original study. Future research should continue to investigate gender as a potential moderating factor in VR-based interventions. However, based on current empirical evidence and methodological safeguards implemented in the study design, the gender composition of the sample does not appear to significantly limit the generalizability or validity of the findings.

Moreover, we support the recommendation that future studies should expand their scope by including additional target groups. As already mentioned earlier, this could include vulnerable population groups with for example higher stress levels or as suggested in the original study, people from different age groups, with different levels of knowledge about breathing techniques or with different levels of technical affinity as well as participants with different clinical conditions (Rockstroh et al. 2021). In addition, adjustments to session numbers as well as durations in future research can contribute to a more precise dose-response relation in this still very young field of research (Wieczorek et al. 2024).

To enable effective replication, we followed some best practices to maximize rigor and reliability. These included conducting a performance analysis to determine an appropriate sample size and applying robust statistical methods for accurate data interpretation and to minimize the likelihood of Type I or Type II errors (Abreu 2023; Mackey 2012). Furthermore, the collaboration and communication with the original authors enabled a constructive dialogue that allowed clarifications, discussions and the exchange of valuable feedback during the replication process.

5 Conclusion

The aim of this study was to investigate the effects of a VR-based mindfulness breathing meditation with integrated biofeedback on physiological and psychological health parameters. Recognizing the crucial role of replication studies in improving the reliability and robustness of scientific findings by confirming or refining previous results, we focused on the replication of a promising prior study within the field of mindfulness, VR, health and biofeedback. In doing so, methodological adjustments were made to address certain limitations of the original study, including additional assessment time points and expanding objective

measurements. However, as in the original study, a control group was deliberately omitted—a decision that can be criticized, but was justified given the complexity of the study's individual components.

In summary, positive effects on diaphragmatic breathing, breathing awareness, respiratory and heart rates, momentary relaxation, burnout symptoms and relaxation-related self-efficacy were successfully replicated, with several benefits persisting medium-term. However, stress reduction measured by PSS-10 was not replicable, likely due to low baseline stress levels. The feasibility of the VR intervention was confirmed through high user satisfaction. This cost-effective and efficient approach highlights the potential of integrating mindfulness, VR and biofeedback to promote health. Future research should focus on expanding the target group and using different VR protocols to characterize the dose-response-relationship more precisely.

Appendix

Breath awareness scale by Rockstroh et al. (2021)
Please indicate to what extent the following statements apply.
(7-point Likert rating scale; 1 = not at all, 7 = completely).

1. I pay attention to my breath in everyday life.
2. I mainly breathe through my belly.
3. I consciously notice most of my breaths.
4. I am good at controlling my breathing.
5. I consciously take the time to take a deep breath.
6. When I take a calm breath, I feel relaxed.
7. I immediately take notice when my breath is quick or restless.
8. I feel the difference between abdominal breathing and chest breathing.

Author contributions All authors listed have made a substantial, direct and intellectual contribution to the work and approved it for publication. A.W. wrote the main manuscript text and prepared figures and tables. All authors reviewed the manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL. Open access funding was provided by the University of the Bundeswehr Munich. No further funds, grants or other support was received. Consent to participate: The study involving human participants was reviewed and approved by the Ethics Committee of the University of the Bundeswehr Munich (Institutional Review Board of the UniBw). The participants provided their written informed consent to participate in this study.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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