The final publication is available at Springer via http://dx.doi.org/10.1007/s12671-017-0698-x

Sliwinski, J., Katsikitis, M., & Jones, C. M. (2017). A review of interactive technologies as support tools for the cultivation of mindfulness. *Mindfulness*, 1-10.

A review of interactive technologies as support tools for the cultivation of mindfulness

Abstract

This paper reviews interactive technological approaches to improve mindfulness, and fills a gap in the literature by using technology to target aspects of mindfulness that are missing in scientific research. Interactive approaches to train mindfulness are presented and discussed in relation to Bergomi's conceptual mindfulness model and Vago and Silbersweig's neurobiological approach for cognitive, emotional and behavioral processes. Based on existing interactive technologies, key design guidelines are developed to investigate the delivery of mindfulness by interactive media, including the design recommendations of personalization, gamification, and social features for the S-ART component Intention and motivation; biofeedback training and narrative for Emotion regulation; moral dilemmas, perspective taking, and cooperative design for Prosociality; and explorative self-reflection, visualization and immersive feedback, and the integration of internal stimuli for Self-transcendence. The paper recommends to apply a more extensive definition of mindfulness, which includes ethical and spiritual development. As a design premise for mindfulness technology, it is advised to strive for embodied experiences that adapt to the user's internal state.

Introduction

Mindfulness has become a popular area of research, and interactive programs to cultivate mindfulness are emerging (Mani et al. 2015; Plaza et al. 2013). While scientific studies predominantly reduce mindfulness to cognitive and emotion-regulatory skills, in classical Buddhist literature it is described as a personal and cognitive transformation (Chiesa 2013). The modern secular understanding of mindfulness addresses only one aspect of the traditional meaning, namely *satī,* the present moment awareness, whereas its ethical and spiritual dimensions, *appamāda* and *sampajañña*, are ignored (Lomas 2016). Addressing these aspects of mindfulness and investigating how to improve them with digital technologies has relevance for the design and application of modern mindfulness interventions such as mobile and ubiquitous technologies, and contributes to the endeavor of making mindfulness more accessible.

Sliwinski, Katsikitis, and Jones (2015) used Bergomi et al.'s (2014) eight-factor model of mindfulness to assess the feasibility of interactive technologies, and digital games in particular, to improve mindfulness. For each mindfulness factor, interactive applications and digital games were presented and discussed along with research evidence in support of their efficacy (Sliwinski et al. 2015). This model, called CHIME, integrates validated questionnaires to provide a comprehensive conceptualization of mindfulness. The individual factors of mindfulness were identified as (1) Awareness towards inner experiences; (2) Awareness towards outer experiences; (3) Acting with awareness (being in the present moment); (4) Acceptance (accepting, non-judging and self-compassionate orientation); (5) Decentering (non-identification and non-reactivity); (6) Openness to experience (non-avoidance); (7) Relativity of thoughts and beliefs; and (8) Insightful understanding (Bergomi et al. 2014).

For example, an interactive breath counting program has been shown in previous work to be helpful in improving the factors of Awareness towards inner experiences and Act-

ing with Awareness, through its ongoing cognitive demand and focus on interoceptive attention (Levinson et al. 2014). Furthermore, effective games were disaggregated according to their mechanics, dynamics, and aesthetics to provide specific design recommendations, e.g. how to provide visual feedback to indicate inhaling/exhaling (Sliwinski et al. 2015). The study found that games can have parallel qualities to meditation such as absorption and effortlessness, as well as beneficial effects on attention and emotional regulation, while providing valuable conditions to improve accessibility, for example by giving clear instructions and multisensory feedback (Sliwinski et al. 2015).

This review compares two models of mindfulness for the purpose of classifying interactive technologies. The CHIME (Bergomi et al. 2014) eight-factor models contrasted against the S-ART framework (Vago & Silbersweig, 2012), a systems-based neurobiological model that is based on empirical literature about the neurocognitive mechanisms of meditation practice to cultivate mindfulness. S-ART includes the ethical development towards virtues of prosociality, as well as emotion regulation and self-transcendence. Areas that have remained largely unstudied by scientific research, especially in the context of mindfulness, are the subject of this review, as their understanding provides significant potential for improving existing and future mindfulness interventions. This paper presents relevant interactive approaches to improve qualities of mindfulness, and discusses their implications.

Method

A keyword search was conducted on popular websites, search engines, and app stores, using appropriate search terms. Selected examples of keywords included mindfulness, mindful, meditation, Buddhist, Buddhism, rumination, intention, motivation, emotion regulation,

acceptance, attention, awareness, focus, concentration, compassion, positive, prosocial, decentering, transcendence, Zen, and Vipassana. To identify relevant research studies Scopus, Web of Knowledge, and Google Scholar were searched. Additionally, the first 50 results pages of a Google search were used to identify any other relating studies and programs. Game databases http://store.steampowered.com including Greenlight, http://www.moddb.com, and http://www.gamesforchange.org were searched, as well as the popular app-stores Google Play and Apple App Store, both iPhone and iPad, though the search was limited to the first 100 hits, filtered by most relevant. Furthermore, the strategy was extended with an opportunistic search for other relevant papers, where references of selected papers were explored.

Non-interactive presentations of mindfulness training such as web pages with only text, audio and video instructions, and guided meditation mobile apps were deliberately excluded from this review. Although these kinds of applications can teach mindfulness techniques, they do not tap into the potential of building experiential knowledge through interactivity (Sliwinski et al. 2015). For programs to be considered in this review, the minimum level of interactivity was defined as reacting to the participant's internal (e.g. breathing) or external (e.g. key strokes) responses. Likewise, research studies and applications that clearly relate to at least one of the eight CHIME factors, and have been already reported in our prior review (Sliwinski et al. 2015), were excluded. The search was conducted by the first author, whereas all authors were involved in the selection process, which was based on the results' conceptual fit at face value towards the S-ART framework. In the following, the individual S-ART components are explained and their relation to their associated CHIME factors, as outlined in Table 1.

Intention and motivation are prerequisites for mindfulness meditation, as they are the driving force behind the practice and its desired outcomes (Vago and Silbersweig 2012).

However, these components are not mapped by the CHIME factors, which measure trait mindfulness and not the process of its cultivation. Attention regulation is the most studied facet of mindfulness and present in nearly all of the available mindfulness scales (Sauer et al. 2013). It relates to the CHIME factors of Awareness towards inner and outer experiences, and Acting with awareness, all which require attentional control.

Emotion regulation is defined as the ability to shift attentional focus to alter emotional activity, for example to stop negative self-talk and view stimuli more neutrally and with equanimity (Vago and Silbersweig 2012). The CHIME model does not measure emotion regulation directly, but describes it as a result of being mindful, i.e., being curious and non-avoidant towards experiences, being non-reactive and to not identify with experiences, and have a non-judging and accepting orientation towards the present moment experience. The S-ART model, being a process, places emotion regulation in a temporal sequence: upon becoming aware of a stimulus, emotion regulation is expressed by the act of mental noting and labelling of the experience, and the response of equanimity that supports the "extinction and reconsolidation of maladaptive procedural and declarative memories" (Vago and Silbersweig 2012; p.14), i.e. habitual patterns. Prosociality includes all forms of empathetic and prosocial behavior that benefit others, such as sympathy, empathy, and altruism (Vago and Silbersweig 2012). Prosociality and ethical development are emphasized as fundamental parts in all Buddhist traditions and acknowledged as essential for contemporary mindfulness training (Baer 2015).

Memory extinction and reconsolidation is the process of exposure to a memory and re-evaluation of its conditioned response, to alter maladaptive habitual behavior, decrease emotional reactivity and cultivate stillness of the mind (Vago and Silbersweig 2012). Through meditation, the mindful examination of memories that represent sensory-affective-

motor scripts and schemas causes their resolution, and increase in equanimity. In CHIME, this is achieved by various aspects. The first aspect is Relativity of thoughts and beliefs, which refers to the recognition that thoughts, beliefs, and memories do not possess universal truth, but are completely subjective and might not always correspond to reality. The second is Insightful understanding, which derives from the understanding that the quality of an experience is influenced by its subjective evaluation. Both support the relearning of habitual behavior by creating an orientation of the mind that enables change. With Openness to experience negative reactive patterns can be transformed into positive reactions or no reaction. A total extinction and reconsolidation would correspond to the elimination of all suffering, and transformation into Self-transcendence (Vago and Silbersweig 2012).

Non-attachment and decentering relate to Self-transcendence in S-ART through the realization of no-self as described in Buddhist literature and the release of mental fixations by acknowledging the nature of impermanence (Vago and Silbersweig 2012). Decentering, the ability to take a distanced perspective and not identify, is a key ability that is included in CHIME, however Self-transcendence is not.

For the purpose of classification for this review, the components Memory extinction and reconsolidation, and Non-attachment and decentering, were combined to form one all-inclusive component, namely Self-transcendence. It is acknowledged that all components to cultivate mindfulness are needed to achieve the state of Self-transcendence, and an interdependent and reductionist concept of Self-transcendence is not appropriate, however, these two components give too much room for interpretation to classify them more specifically. S-ART defines Self-transcendence as “the development of a positive relationship between self and other that transcends self-focused needs and increases prosocial characteristics” (Vago and Silbersweig 2012, p.2). In this sense, ethical conduct and Prosociality are also a quality

of Self-transcendence, and should therefore not be seen as an isolated construct (Vago and Silbersweig 2012).

For this review, the term Self-transcendence was applied more broadly to account for any methods that strive for enlightenment/awakening (Davis and Vago 2013) and spiritual growth in general. Both S-ART components integrate into Self-transcendence, for memory constitutes the foundation of the narrative self, which has to be overcome to achieve Self-transcendence, while Non-attachment and decentering characterize qualities of the mind that facilitate its cultivation. Existing measures that aim to capture associated states include self-report questionnaires, which are acknowledged to lack conceptual clarity (Chiesa 2013), and functional neuroimaging, which is still too limited in temporal resolution and data analysis (Davis and Vago 2013). Because Self-transcendence is very imprecise and impossible to measure adequately with current scientific methods (Davis and Vago 2013), it is used explor-atively for this review.

Results

Digital games, mobile application (apps), digital psychological interventions and ex-perimental installations such as unevaluated systems and hardware setups, including those built for a different purpose than mindfulness training, that relate to components of S-ART are presented and discussed in this section. Key design guidelines are deduced and presented as an effective way to deliver mindfulness and its associated components. A summary of all results is presented in Table 2 in the summary section.

Intention and motivation

Intention and motivation are described as the “fundamental building blocks” (Vago and Silbersweig 2012, p.15) behind the neurocognitive mechanisms of mindfulness. Both are necessary to start and strengthen the mindfulness practice, as well as to attain its continuity.

To help with mindfulness practice and to motivate regular practise, the mobile app Insight Timer (Insight Network 2017) provides tips, frequently asked questions, as well as access to forums and discussion groups that connect with other people struggling with motivation. Furthermore, statistics are tracked and milestones set. At the end of each meditation session, a journal entry can be written to assist contextual reflection. Additionally, a list of other users who meditate at the same time is presented, which might strengthen feelings of connectedness and commitment. Insight Timer is freely available for mobile devices, yet there is no research available to report its impact.

The Virtual Coach is a web-based app designed to provide support for beginners to mindfulness meditation Hudlicka (2011). It is an embodied conversational agent with whom the user can interact using text, and is intended as a substitute for a human mindfulness teacher. The coach reacts to user input and its avatar adapts its facial expression to the content. The effectiveness of this program was evaluated by comparing 16 Virtual Coach users to a control group of 16 participants that used pre-prepared written and audio material only.

During a 4-week training period, one lesson per week was administered, which was followed by a 3-week coaching period, during which Virtual Coach users were free to interact with the coach, while the control group read a manual. In both groups participants were asked to meditate five times a week for 20 minutes. Using self-report measures, results indicate that the virtual coach group practiced more frequently, for longer time and the experience was found to be significantly more enjoyable and engaging (Hudlicka 2011). The authors suggest that the added value of customized feedback and support provided by the app

might be the key factor for its superiority to traditional training. Furthermore, the Virtual Coach group was found to have fewer dropouts. However, users reported the non-verbal expressions to be inadequate in support of the context (Hudlicka 2011) and the feeling of personal connection was perceived to be missing.

The Virtual Meditation Coach is another example of a conversational agent and was developed by Shamekhi and Bickmore (2015). Unlike Virtual Coach, the Virtual Meditation Coach does not engage in a dialogue with the participant, but rather provides guided meditation instructions with synthetic speech enriched by animated face and body expressions. Interactivity is achieved by a breathing sensor, which is used to control the participant's progress.

In a pilot study, nine participants used the Virtual Meditation Coach and were compared to a control group that watched video instructions. No significant differences were found between the experimental and control groups on measures of self-reported mindfulness, positive affect, anxiety, flow, and physiological arousal (Shamekhi and Bickmore 2015). Participants reported to be no more satisfied with the virtual agent than with the human in the video, but the agent was reported to be more aware of their breathing (Shamekhi and Bickmore 2015). Motivation was not specifically addressed, however, the use of biofeedback may increase the practitioner's motivation by adapting the training to the meditator's progress and personal needs.

Based on the discussed interactive experiences, it is our conclusion that effective techniques to increase the practitioner's 'Intention and motivation' include the personalization of the experience through emotional design and customized feedback. Available mobile apps can be useful by providing goal tracking and reminder notifications, rewarding and engaging game design elements, as well as harnessing the social power of online communities.

Emotion regulation

Improving Emotion regulation or self-regulatory skills is the main reason why people become interested and start practising mindfulness (Pepping et al. 2016). Research shows that technology, especially digital games, is able to trigger positive behavior change and improve Emotional regulation (Jones et al. 2014). We therefore advocate for the exploration of digital technologies for mindfulness.

The game Zoo U (3C Institute 2015) focuses on six core social skills, namely impulse control, empathy, initiation, communication, cooperation, and Emotion regulation. In this point-and-click problem solving game, children play as a zookeeper in training, in a school-like setting. The main game mechanic in Zoo U is confronting children with social situations, letting them choose what to say, and reflect upon their feelings. In an evaluation of Zoo U, 187 US students from 14 third- and fourth-grade classrooms played the game and teachers assessed their social skills (DeRosier et al. 2012). Results revealed significant correlations between in-game social skills assessments and teacher obtained psychological assessments (DeRosier et al. 2012). Establishing Zoo U as a valid measure for social skills, it can be used as a safe training ground for the development of Emotion regulation skills, as demonstrated by a later report with 47 children (Personalized Learning Games 2015).

Crystals of Kaydor (Games Learning Society 2014) was developed as a mobile game for training Emotion regulation and Prosociality. The user plays as a robot, exploring an alien planet and attempting to recruit inhabitants to assist in finding parts for the robot's stranded and broken spaceship. In order to achieve this, the player has to successfully interpret body language and non-verbal cues. Being aware of one's own mental state, but also of the emotions of others, and to react appropriately upon them, is aimed to increase Emotion regulation

and prosocial behavior. Development and evaluation of this game is currently ongoing with middle school-aged children (Games Learning Society 2017).

The Spire (2017) is a wireless activity tracker for breath. Based on the breathing pattern, it recognizes the mental state of its wearer, sends an alarm if it registers a state of high tension, and gives instructions to practise deep breathing to calm down. Moreover, Spire rewards its user for periods of being calm or focused by visualizing breath metrics over time and tying them to individual goals like being calm for 50% of the day.

The practice of observing the breath is also an integral part of teachings in traditional Buddhist meditation known as ānāpānasati, with the goal to sharpen the mind before confronting one's own sensations deliberately (Gilpin 2008). Increasing the awareness of the breath, and with it insight about one's own internal state, is a way to improve Emotion regulation. Results from studies investigating mindful breathing show significant associations with more meta-awareness, less mind-wandering, better mood, and greater non-attachment (Levinson et al. 2014). The added value of the Spire breath-tracker lies in providing better feedback mechanisms for conscious breathing and tracking the user's progress.

Relaxation

Many interactive technologies and games developed for the purpose of cultivating mindfulness try to achieve this goal by inducing relaxation, often by consciously manipulating the breath. This is contrary to mindfulness meditation, where the breath is to be observed naturally, without the intention to change it, and relaxation is only a by-product. However, innovative approaches for improving mindfulness that make use of relaxation can contain valuable elements for mindfulness practitioners and are therefore explored here.

The serious game PlayMancer was developed by Fernandez-Aranda et al. (2012) to train Emotion regulation and self-control in impulse related mental disorders. To identify the emotional state of the player the game makes use of a variety of bio-sensors, including Galvanic Skin Response (GSR), oxygen saturation, heart rate (HR), heart rate variability (HRV), skin temperature, and breathing frequency, as well as facial recognition and speech analysis. PlayMancer is a 3D adventure game in which the player is stranded on an island and has to complete various mini games. Game elements in the virtual world are controlled with the player's physiology, predominantly by requiring the player to relax to achieve desired outcomes in the game world.

On a sample of nine female bulimia nervosa patients, PlayMancer was tested as an additional tool to Cognitive Behavioural Therapy. Biofeedback data associated with 'Emotion regulation' improved during the gameplay sessions, suggesting a benefit of this game-based approach. Additionally, anxiety as a correlated factor for emotional and impulse control was found to decrease between pre and post-test, supporting its feasibility for clinical contexts. The main limitation of PlayMancer, however, is its sophisticated and lengthy setup for the biofeedback hardware. Instead, modern smartphones and low-cost sensors now allow the easy collection of some of the required biofeedback data, though it remains unclear how many individual bio-sensors are needed and how accurate they must be to reliably compute a player's emotional states.

There are a number of consumer EEGs with associated mindfulness programs on the market, which claim to measure meditative states, though applications generally do not extend beyond simple scenarios for focus or relaxation. Whilst there are a growing number of cheap to build and easy to use biofeedback technologies, there has been no research to evaluate their effectiveness to train emotion regulatory skills. However, these new biofeedback

devices, often embedded in smartphones or wearables, represent a step towards making sophisticated trainings such as the PlayMancer game more accessible.

In the art installation Sonic Cradle (Vidyarthi et al. 2012), participants lay down on a hammock in a dark room. Through respiratory biofeedback sensors, sound is controlled to create an interactive experience. The way participants breathe generates and manipulates different soundscapes and encourages users to explore and play with the breath. Sonic Cradle was developed as an educative and demystifying tool for mindfulness meditation, yet the authors admit that the relationship between individual elements of the installation and mindfulness remains unclear (Vidyarthi et al. 2012). While one subsequent study found the installation to be feasible for relaxation (Vidyarthi and Riecke 2013), a later study revealed no significant benefit compared to just lying in the hammock (Kitson et al. 2014). Comments from participants emphasized the engaging nature of the installation, which is often one key advantage of technologies over traditional approaches. However, the lying position in a hammock may induce sleep during meditation, which is why most traditional meditation techniques instruct the practitioner to be in a sitting position.

The Meditation Chamber (Shaw et al. 2007) designed for mindfulness and relaxation training combines virtual reality and biofeedback technologies to reduce stress. In this installation participants sit on a chair and wear a head-mounted display and headphones, while being connected to biometric sensors measuring arousal, respiration, and heart rate. The program is divided into three modules. The first module is a relaxation activity, and the second module is a progressive muscle relaxation exercise. The third module provides practice for mindfulness meditation by asking participants to focus on their breath by attending to the sensations around the nostrils while breathing. Participants hear calmly moving water and see abstract swimming jellyfish on their displays, which pulse synchronous to the own respira-

tion. The jellyfish fade and disintegrate with increased relaxation of the participant, measured with the biometrics. The Meditation Chamber was tested on 411 attendees during an exhibition and results suggest that it promoted relaxation. GSR values generally decreased throughout the mindfulness module and breathing became deeper. Additionally, self-reported relaxation was significantly higher after the session than before.

In summary, many different approaches were identified that aim to improve Emotion regulation skills relevant for cultivating mindfulness. One promising approach is the development of awareness about one's own internal state by using biometric sensors such as the Spire. Additionally in games, narrative can be a powerful element to engage players in the readjustment of their moral compass and teach self-control and appropriate emotional responses (3C Institute 2015). Choices provided to the player should be context-dependent and nuanced with the game providing appropriate responses and material for discussion. Game mechanics can be used to learn core skills about the correct interpretation of interpersonal situations and emotional cues (Games Learning Society 2014), while the narrative and its emergent choices work as a procedural guidance and trigger for self-reflection. However much more research is needed to clarify the exact requirements under which those game elements are effective.

Interactive technologies can use biofeedback to recognize emotional states and train the practitioner's emotional muscle (Fernandez-Aranda et al. 2012). Predominantly these applications use breath manipulation to induce a state of relaxation with the aim to teach emotional responses that are characterized by calmness and equanimity. The efficacy for improving mindfulness in this way has not be confirmed to date and more research is needed. Furthermore, there are conceptual differences between relaxation and mindfulness meditation,

which can lead the practitioner on the wrong track or wrong mindfulness, which was criticized as “McMindfulness” (Purser and Loy 2013).

Prosociality

Most mindfulness conceptualizations and interventions do not include Prosociality or ethical development of any kind. However a growing number of scholars promote the re-contextualization of mindfulness to integrate ethical virtues of Prosociality (Chiesa 2013; Lomas 2016). Playing digital games, especially those that have been traditionally labelled as violent and anti-social games, can increase the moral sensitivity of players (Grizzard et al. 2014). In the study by Grizzard et al. (2014) gamers playing the role of terrorists have been compared to players playing as UN-peacekeepers. Those players playing as terrorists showed significant correlations with measures of guilt that lead to increases in moral foundations (Grizzard et al. 2014). The authors argue that contrary to widely-held beliefs that playing violent video games makes players more antisocial through the activation of aggressive cognitions, playing these types of games can lead to prosocial behavior through increased moral sensitivity.

In the game Papers, Please (3909 2013), the player engages in ethical decision making by working as an immigration officer at the border of a politically unstable country and must decide who to let in and who not. Situations in the game provide numerous moral dilemmas, like for example whether to take a bribe to feed the family in times when the regular salary is not enough or whether to let in a spouse, whose papers are incomplete and run the risk of accepting a potential terrorist. Another issue is the time pressure to process as many people as possible since the salary is paid per processed individual, however accepting or denying immigrants too quickly might cause mistakes. Personal interests have to be balanced against

national risks and those of financial penalties, while at the same time challenging the player's own values and compassion.

This game shows how decisions are often more complex than simply choosing right or wrong and may increase the player's moral sensitivity. Papers, Please forces the player to think about and dispute the concepts of fairness, righteousness, corruption, human rights, personal freedom and liberty. Furthermore, unlike many other games there is no hidden morality system that would reward certain decisions. Instead, players have to justify their decisions to themselves, to be in alignment with their own conscience.

A study by Ahn et al. (2013) investigated the influence of embodied experiences on perspective taking, empathy, attitude, and helping behavior. In this experiment, one group of participants was asked to engage in traditional perspective taking, through imagination, towards people with disabilities, whereas another group experienced a disability, in this case red-green color-blindness, through the use of a head-mounted display. Participants who experienced the disability though the immersive technology showed, compared to the other group, more concern towards disabled people, greater self-other merging, i.e. greater feelings of oneness, and spent twice as much time and effort to help people with color-blindness in the real world (Ahn et al. 2013).

The games discussed for Prosociality provide practical implications for personal development that is aligned with classical teachings of mindfulness, and cultivating ethical virtues such as compassion, loving kindness and courage (Gilpin 2008). Games that enable this transformation put a strong emphasis on the content and context of narrative and use player choices to engage the player in the process of self-reflection through which experiential knowledge for personal positive transformation is imparted. These games can provide aware-

ness about the correct interpretation of emotions and behaviors along with appropriate responses.

Studies show that digital games have the potential to increase empathy (Greitemeyer 2013; Greitemeyer et al. 2010) and decrease pleasure in the misfortune of others (Greitemeyer et al. 2010). The games used in these studies were Lemmings (DMA Design 1991), where creatures have to be saved by leading them to a safe exit, and The Settlers (Blue Byte Software 1994), a strategy game about city building and resource management. In addition, perspective taking was shown as an effective method of games to develop compassion towards other human beings, with efficacy that extends beyond the virtual world (Ahn et al. 2013).

Self-transcendence

While in its original definition Self-transcendence includes prosocial qualities (Vago and Silbersweig 2012), we applied a more distinct definition that addresses interactive experiences that aim for transcendental states to achieve the dissolution of the narrative self , i.e. ego. It would be naïve to claim that technology in its current state has the ability to achieve the goal of permanent Self-transcendence, but there are digital experiences which can temporarily mimic a state of similar quality. Understanding these experiences enables designers to better develop interactive approaches to cultivate this aspect of mindfulness.

In an artistic installation called Mind Pool (Long and Vines 2013), developed to cultivate self-reflection, participants sit in front of a bowl with magnetic fluid that reacts to the participant's brainwaves that are captured by an EEG. The feedback is deliberately ambiguous to motivate participants to interact with the system and to stimulate them to draw their own interpretations about their mental states and the behavior of the liquid. Although no for-

mal evaluation has been conducted to date, Mind Pool can provide an opportunity to see oneself in the liquid, which with practice might lead to disembodiment and a state of Self-transcendence. The use of visualization is also part of Vajrayana meditations, where practitioners focus their attention on a self-generated deity or one "visualizes the dissolution of the Deity and its entourage into emptiness, and aspires to achieve awareness devoid of conceptualization" (Amihai and Kozhevnikov 2014, p.3).

SOLAR (Prpa et al. 2016) is a visual virtual environment for mindfulness meditation, which is controlled by the participant's breath and brain activity. On a screen, the meditator sees a silhouette of themselves along with a circle that increases and decreases in size corresponding to the breath. When breathing in, the soundscape becomes more complex. A circular background animation changes in color according to the meditators depth of meditation, which is computed from data of the EEG sensors. The interesting element of this feedback system is that the silhouette of the meditator becomes more and more transparent the deeper they meditate. The metaphorical dissolution of the body and mind is aligned with the concept of Self-transcendence. The expressive visualization of transcending may help mediation however to date SOLAR not formally evaluated. It may also be that intentional goal setting is an obstacle to mediation as it stands in contradiction to mindfulness meditation, which is instead an effortless effort and the art of not trying.

Combining neurofeedback with virtual reality, RelaWorld (Kosunen et al. 2016) is a meditation system that uses different scenarios to engage its players in meditation. Here, the player wears a head-mounted display, through which one of two possible game scenarios are presented. In the first a body scan practice is visualized by a silhouette and highlighting different body parts. The second is a focused attention practice where the player has to focus on one out of five balls. Both scenarios are encompassed by a calm seaside setting, accompanied

by subtle animations and sound. Based on the player's EEG signals, their level of concentration is mapped to the degree of levitation, which is realized by a vertical movement in the virtual world. An energy bubble that surrounds the scene becomes more visible the more the participant relaxes.

RelaWorld was evaluated with 43 participants who were placed into one of three conditions, corresponding to using RelaWorld on a computer screen or with a head-mounted display with or without neurofeedback (Kosunen et al. 2016). The virtual reality neurofeedback condition was found to elicit the highest level of presence and to provide the highest levels for all aspects of the meditation experience, as measured by the Meditation Depth Questionnaire (MEDEQ; Piron 2001). The MEDEQ includes the factors Transpersonal Qualities and Transpersonal Self, which correspond to the concept of Self-transcendence, as they measure aspects such as transcendence of time, feeling at one with everything, becoming formless, and expanding consciousness into infinity (Piron 2001). Results did not differ between the two scenarios (Kosunen et al. 2016), suggesting that the effective mechanisms at play emanate from the immersive qualities of the virtual environment.

This result supports other research that has demonstrated how immersive virtual reality technology can cause significant changes in consciousness. A study by Lenggenhager et al. (2009) used head-mounted displays to present incongruent cues about the bodily self-location to induce an out-of-body-like experience, causing shifts in self-awareness, accompanied by sensations of floating. RelaWorld also induces the sensation of floating by creating the illusion of levitation, which is a common phenomenon of both studies and might play a role in altering states of consciousness. Future studies, ideally including physiological measurements such as brain activity, are needed to confirm RelaWorld's effect on Self-transcendence and clarify the exact mechanisms responsible.

Digital games may be valuable for facilitating Self-transcendence as they can provide a high level of engagement and immersion, absorbing the player completely, thus giving no cognitive room for worry and thinking, hence no room for self-identity. For example Tetris (Pajitnov 1984), a puzzle game where falling bricks of different shapes have to be arranged to fill empty spaces, was found to have such a quality. A study by Holmes et al. (2009) using Tetris for trauma shows that mentally rotating shapes interferes with the development of post-traumatic memories and their identification, and significantly reduces flashbacks (Holmes et al. 2009).

The central quality of fast-paced meditative games is their high level of immersion. Immersion, also referred to as presence, is an experiential state of being completely absorbed in the game that is closely linked to the concept of Flow (Csikszentmihalyi 1992). Qualities that are associated with the state of immersion are a focused attention, altering the sense of time and losing a sense of self (Brown and Cairns 2004). The qualities fit with the experience of deep meditation. Based on a study investigating dream and waking consciousness of gamers and meditators, Gackenbach and Swanston (2015) argue that games and meditation share a similar role on consciousness, as the absorbing qualities of both were found to impact dream control.

However, games and meditation have a significant distinction, which is their intention. While meditation cultivates the intentional achievement of Self-transcendence by training present-moment awareness, fast-paced games can absorb the player in a flow state that blocks all meta-awareness. For a mindfulness game that is aimed to facilitate Self-transcendence it is desirable to target the player's internal stimuli (instead of distracting them with external stimulation), while exploiting its immersive potential to deepen the practice. An example is the game SoundSelf (Arnott 2017) which uses the player's voice and breath as a

playful input. The player controls the game exclusively with sound, which is being manipulated and replayed as a feedback mechanism. At the same time, it creates psychedelic visuals to induce a trance-like state and to facilitate absorption.

The interactive technologies discussed aim to develop Self-transcendence by applying an alternative mode of meditation that makes use of sensory stimuli. Participant controls, often biofeedback, is used to emerge auditive or visual experiences to facilitate self-reflection through the exploration of ambiguous stimuli (Long and Vines 2013). Visualizing meditation progress with metaphors of transcendence in immersive virtual reality technologies can alter the sense of self (Kosunen et al. 2016; Prpa et al. 2016) and provides opportunities for future mindfulness research. Another approach is to evoke trance-like states to loose oneself in the experience and induce a "no-self"-like state (Vago and Silbersweig 2012). These experiences, created mostly by digital games, can therefore be classified as non-dual-oriented practices, as they are designed to elicited an experiential shift into a mode of experiencing in which the cognitive structure of self is no longer dominant (Dahl et al. 2015).

This is supported by behavioral studies showing that some gamers identify more with their virtual representation than their real self (Bessière et al. 2007), which was further confirmed with neuroimaging data (Ganesh et al. 2012). The quality of digital games to shift a player's consciousness might be a powerful tool for inducing transcendental states and is probably closely linked with the level of immersion, as this phenomenon is more likely for long-term players (Ganesh et al. 2012). To achieve high immersion, it is recommended to develop mindfulness technologies with ease of use in mind and to put an emphasis on utilizing all senses extensively (Brown and Cairns 2004).

The identified design recommendations to develop interactive digital experiences for mindfulness include the use of personalization, gamification, and social features for Intention and motivation; biofeedback training and narrative for Emotion regulation; moral dilemmas, perspective taking, and cooperative design for Prosociality; and explorative self-reflection, visualization and immersive feedback, and the integration of internal stimuli for Self-transcendence.

Discussion

The increased attention in the field of contemplative science sheds positive light on the convergence of technology and mindfulness. This review discussed interactive technologies that have or are likely to have an influence on mindfulness or associated qualities, and which have not previously been explored. The CHIME mindfulness model (Bergomi et al. 2014) and S-ART neurobiological framework (Vago and Silbersweig 2012) were used to identify the research gap, outlining components of mindfulness that have not been studied in this context. These were Intention and motivation, Emotion regulation, Prosociality, and Self-transcendence.

For all components, digital games or game-like interactions were found to be promising. Games have a naturally motivating appeal with great technical and creative possibilities, and are therefore concluded to be a valuable medium for mindfulness training. Integrating the player's internal state and adapting the virtual world to create a tailored and personalized mindfulness experience should be a design premise, which has been to date largely neglected in game design. Furthermore, interactive mindfulness games are to date limited to single user experiences only. Social interactions with other users by implementing cooperative scenarios,

can facilitate feelings of oneness and community, *saṅgha*. Guiding or enriching an experience with a meaningful narrative that includes moral dilemmas and encourages perspective taking might, moreover, benefit the development of empathy and other prosocial qualities of mindfulness.

Self-transcendence in the broader context of this review needs more scientific exploration, with current interactive approaches being highly experimental and still in their infancy. Modern virtual reality technology can play a key role in this perspective, as it offers a high sense of presence and immersion compared to other media, while providing a controlled and safe setting (Riva et al. 2015). The opportunities of visualizing feedback, together with the integration of user sensing by affordable biofeedback, create new opportunities for exploring the inner self and cultivating self-reflection and mindful awareness. For technology to be a valuable aid to Self-transcendence, interactive digital approaches have to rise from being mere support tools and become embodied experiences.

This paper contributes insights and practical pointers for the design of interactive experiences to facilitate the cultivation of mindfulness. It complements the structured analysis by Sliwinski et al. (2015), which, for each CHIME factor, assessed the feasibility of interactive technologies, and digital games in particular, to improve mindfulness through the development of experiential knowledge in an engaging way. Future research would profit from a more theoretical consensus about the conceptualization of mindfulness and its effective delivery by digital technology. We encourage the application of a more extensive definition of mindfulness, beyond relaxation and attention training. The study of available commercial media and technologies poses a largely untapped potential in this regard. Finally, as mindfulness is a way of personal transformation, more longitudinal studies and in-depth analysis is needed to examine the impact of technology on mindfulness and the self.

References

Ahn, S. J., Le, A. M. T., & Bailenson, J. (2013). The effect of embodied experiences on self-other merging, attitude, and helping behavior. *Media Psychology, 16*(1), 7-38.

Amihai, I., & Kozhevnikov, M. (2014). Arousal vs. relaxation: a comparison of the neurophysiological and cognitive correlates of vajrayana and theravada meditative practices. *PloS one, 9*(7), e102990.

Baer, R. (2015). Ethics, Values, Virtues, and Character Strengths in Mindfulness-Based Interventions: a Psychological Science Perspective. *Mindfulness, 6*(4), 956–969.

Bergomi, C., Tschacher, W., & Kupper, Z. (2014). Construction and first validation of the Comprehensive Inventory of Mindfulness Experiences. *Diagnostica, 60*(3), 111-125.

Bessière, K., Seay, A. F., & Kiesler, S. (2007). The ideal elf: Identity exploration in World of Warcraft. *CyberPsychology & Behavior, 10*(4), 530-535.

Brown, E., & Cairns, P. (2004). A grounded investigation of game immersion. In *Extended Abstracts of the 2004 Conference on Human Factors in Computing Systems,* pp. 1297-1300: ACM.

Chiesa, A. (2013). The Difficulty of Defining Mindfulness: Current Thought and Critical Issues. *Mindfulness, 4*(3), 255-268.

Csikszentmihalyi, I. S. (1992). *Optimal experience: Psychological studies of flow in consciousness*: Cambridge: Cambridge University Press.

Dahl, C. J., Lutz, A., & Davidson, R. J. (2015). Reconstructing and deconstructing the self: cognitive mechanisms in meditation practice. *Trends in cognitive sciences, 19*(9), 515-523.

Davis, J. H., & Vago, D. R. (2013). Can enlightenment be traced to specific neural correlates, cognition, or behavior? No, and (a qualified) Yes. *Frontiers in psychology, 4*, 870.

DeRosier, M. E., Craig, A. B., & Sanchez, R. P. (2012). Zoo U: a stealth approach to social skills assessment in schools. *Advances in Human-Computer Interaction, 2012*, 7.

Fernández-Aranda, F., Jiménez-Murcia, S., Santamaría, J. J., Gunnard, K., Soto, A., Kalapanidas, E., … Penelo, E. (2012). Video games as a complementary therapy tool in mental disorders: PlayMancer, a European multicentre study. *Journal of Mental Health, 21*(4), 364-374.

Gackenbach, J., & Swanston, D. (2015). Effects of video game play versus meditation/prayer in waking and dreaming experiences. *Association for Transpersonal Psychology, 47*(2), 188-218.

Games Learning Society (2017). Games+Learning+Society Center. Retrieved January 25, 2017, from http://www.gameslearningsociety.org/kaydor_microsite/.

Ganesh, S., van Schie, H. T., de Lange, F. P., Thompson, E., & Wigboldus, D. H. (2012). How the human brain goes virtual: distinct cortical regions of the person-processing network are involved in self-identification with virtual agents. *Cerebral Cortex, 22*(7), 1577-1585.

Gilpin, R. (2008). The use of Theravāda Buddhist practices and perspectives in mindfulness-based cognitive therapy. *Contemporary Buddhism, 9*(2), 227-251.

Greitemeyer, T. (2013). Playing Video Games Cooperatively Increases Empathic Concern. *Social Psychology, 44*(6), 408-413.

Greitemeyer, T., Osswald, S., & Brauer, M. (2010). Playing Prosocial Video Games Increases Empathy and Decreases Schadenfreude. *Emotion, 10*(6), 796-802.

Grizzard, M., Tamborini, R., Lewis, R. J., Wang, L., & Prabhu, S. (2014). Being Bad in a Video Game Can Make Us More Morally Sensitive. *Cyberpsychology, Behavior, and Social Networking, 17*(8), 499-504.

Holmes, E. A., James, E. L., Coode-Bate, T., & Deeprose, C. (2009). Can playing the computer game "Tetris" reduce the build-up of flashbacks for trauma? A proposal from cognitive science. *PloS one, 4*(1), e4153.

Hudlicka, E. (2011). Virtual coach for mindfulness meditation training. In *Proceedings of AI and Health Communication (AAAI 2011 Spring Symposium)*, p. 17-24: AAAI.

Jones, C. M., Scholes, L., Johnson, D., Katsikitis, M., & Carras, M. C. (2014). Gaming well: links between videogames and flourishing mental health. *Frontiers in psychology, 5*(260).

Kitson, A., Riecke, B. E., & Vidyarthi, J. (2014). Sonic Cradle: Investigating Meditative Aspects of an Interactive Technology. In *GRAND NCE 2014*, pp. 1-4: GRAND.

Kosunen, I., Salminen, M., Järvelä, S., Ruonala, A., Ravaja, N., & Jacucci, G. (2016). RelaWorld: Neuroadaptive and Immersive Virtual Reality Meditation System. In *Proceedings of the 21st International Conference on Intelligent User Interfaces*, pp. 208-217: ACM.

Lenggenhager, B., Mouthon, M., & Blanke, O. (2009). Spatial aspects of bodily self-consciousness. *Consciousness and Cognition, 18*(1), 110-117.

Levinson, D. B., Stoll, E. L., Kindy, S. D., Merry, H. L., & Davidson, R. J. (2014). A mind you can count on: validating breath counting as a behavioral measure of mindfulness. *Frontiers in psychology, 5*(1202).

Lomas, T. (2016). Recontextualizing Mindfulness: Theravada Buddhist Perspectives on the Ethical and Spiritual Dimensions of Awareness. *Psychology of Religion and Spirituality. Advance online publication.*

Long, K., & Vines, J. (2013). Mind pool: encouraging self-reflection through ambiguous bio-feedback. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, pp. 2975-2978: ACM.

Mani, M., Kavanagh, D. J., Hides, L., & Stoyanov, S. R. (2015). Review and Evaluation of Mindfulness-Based iPhone Apps. *JMIR mhealth and uhealth, 3*(3), e82.

Pepping, C. A., Walters, B., Davis, P. J., & O'Donovan, A. (2016). Why Do People Practice Mindfulness? An Investigation into Reasons for Practicing Mindfulness Meditation. *Mindfulness*, 1-6.

Personalized Learning Games (2015). Zoo U Research Whitepaper [White paper]. Retrieved January 25, 2017, from http://www.centervention.com/wp-content/uploads/2016/10/ZooU_Whitepaper_16.pdf.

Piron, H. (2001). The meditation depth index (MEDI) and the meditation depth questionnaire (MEDEQ). *Journal for Meditation and Meditation Research, 1*(1), 69-92.

Plaza, I., Demarzo, M. M. P., Herrera-Mercadal, P., & García-Campayo, J. (2013). Mindfulness-Based Mobile Applications: Literature Review and Analysis of Current Features. *JMIR mhealth and uhealth, 1*(2), e24.

Prpa, M., Cochrane, K., & Riecke, B. E. (2016). Hacking Alternatives in 21st Century: Designing a Bio-Responsive Virtual Environment for Stress Reduction. In *Pervasive Computing Paradigms for Mental Health*, pp. 34-39: Springer.

Purser, R. E., & Loy, D. (2013). Beyond McMindfulness. *The Huffington Post.* Retrieved January 25, 2027, from http://www.huffington-post.com/ron-purser/beyond-mcmindfulness_b_3519289.html.

Riva, G., Botella, C., Baños, R., Mantovani, F., García-Palacios, A., Quero, S., et al. (2015). Presence-Inducing Media for Mental Health Applications. In *Immersed in Media*, pp. 283-332: Springer.

Sauer, S., Walach, H., Schmidt, S., Hinterberger, T., Lynch, S., Büssing, A., et al. (2013). Assessment of mindfulness: Review on state of the art. *Mindfulness, 4*(1), 3-17.

Shamekhi, A., & Bickmore, T. (2015). Breathe with Me: A Virtual Meditation Coach. In *Intelligent Virtual Agents 2015*, pp. 279-282: Springer.

Shaw, C. D., Gromala, D., & Seay, A. F. (2007). The meditation chamber: Enacting autonomic senses. *Proceedings of ENACTIVE/07*, pp. 405–408: ACROE.

Sliwinski, J., Katsikitis, M., & Jones, C. M. (2015). Mindful Gaming: How Digital Games Can Improve Mindfulness. In *Human-Computer Interaction–INTERACT 2015*, pp. 167-184: Springer.

Vago, D. R., & Silbersweig, D. A. (2012). Self-awareness, self-regulation, and self-transcendence (S-ART): a framework for understanding the neurobiological mechanisms of mindfulness. *Frontiers in Human Neuroscience, 6*(296), 1-30.

Vidyarthi, J., & Riecke, B. E. (2013). Mediated meditation: cultivating mindfulness with Sonic Cradle. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, pp. 2305-2314: ACM.

Vidyarthi, J., Riecke, B. E., & Gromala, D. (2012). Sonic Cradle: Designing for an immersive experience of meditation by connecting respiration to music. In *Proceedings of the Designing Interactive Systems Conference DIS '12*, pp. 408-417: ACM.

Computer programs

Crystals of Kaydor [Computer software]. (2014). Madison: Games Learning Society.

Insight Timer [Computer software]. (2017). San Francisco: Insight Network.

Lemmings [Computer software]. (1991). Edinburgh: DMA Design.

Papers, Please [Computer software]. (2013). Mount Pleasant: 3909.

SoundSelf [Computer software]. (2017). Austin: Robin Arnott.

Spire [Computer software]. (2017). San Francisco: Spire.

Tetris [Computer software]. (1984). Moscow: Alexey Pajitnov.

The Settlers [Computer software]. (1994). Düsseldorf: Blue Byte Software.

Zoo U [Computer software]. (2015). Durham: 3C Institute.

Table 1.

Comparison between S-ART and CHIME.

S-ART	**CHIME**
Intention and motivation	
Attention regulation*	Awareness towards inner experiences
	Awareness towards outer experiences
	Acting with awareness
Emotion regulation	Openness to experience
	Decentering
	Acceptance
Prosociality	

Self-transcendence	
Memory extinction and reconsolidation	Relativity of thoughts and beliefs
	Insightful understanding
	Openness to experience
Non-attachment and decentering	Decentering

Note. * Component not explored in this review, as it is already covered by a previous investigation using CHIME (Sliwinski et al. 2015). Memory extinction and reconsolidation and Non-attachment and decentering were aggregated into Self-transcendence.

Table 2.

Summary of interactive approaches to mindfulness using S-ART components.

S-ART component	**Interactive experience**	**Type**
Intention and motivation	Insight Timer*[F]	Mobile app
	Virtual Coach [F]	Mobile app
	Virtual Meditation Coach [N]	Web app
Emotion regulation	Crystals of Kaydor*[N]	Mobile game
	PlayMancer [N]	PC game (biofeedback)
Relaxation	Spire*[$]	Biofeedback sensor, mobile app
	Sonic Cradle [N]	Art installation (biofeedback)
	The Meditation Chamber [N]	Art installation (biofeedback)
Prosociality	Papers, Please*[$]	PC/mobile game

	Lemmings[$]	PC game
	The Settlers[$]	PC game
Self-transcendence	Mind Pool*[N]	Art installation (biofeedback)
	Solar*[N]	Art installation (biofeedback)
	RelaWorld[N]	PC game (Virtual reality)
	SoundSelf*[$]	PC game (Virtual reality)

Note. * Potentially effective but untested; [F] Available for free; [$] Available at charge; [N] Not available.