Mindful Moments: Exploring On-the-go Mindfulness Practice On Smart-glasses

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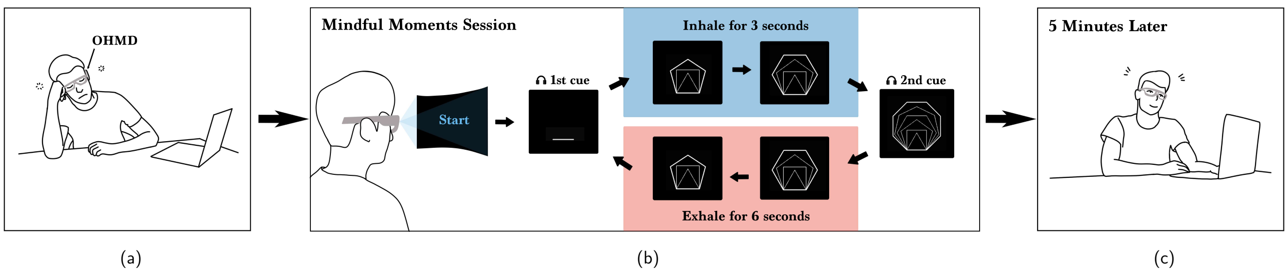

Figure 1: Mindful Moments provides breath-based guidance on the OHMD, facilitating short and easy mindfulness practice sessions for the everyday person during moments of the day. (a) An overworked individual is frustrated and losing focus at his desk. (b) He decides to take a 5-min walk with Mindful Moments playing on his OHMD. He lets the audio-visuals guide his breath; as the shape expands for 3s, he inhales, and as the shape contracts for 6s, he exhales slowly and mindfully. At the start of every inhale, a pleasant sound also cues him to breathe in, and at the beginning of every exhale, another gentle sound cues him to breathe out. A continuous smooth chord plays in the background throughout, immersing him in the flow of the activity. (c) He returns to his desk feeling relaxed and mentally rejuvenated, readier to undertake his tasks.

ABSTRACT

Mindfulness technologies have gained research interest in recent years. We explore the use of smart-glasses (Optical Head Mounted Displays or OHMDs) for breath-based mindfulness practice as a well-being technology for everyday users. Since OHMDs do not occlude the wearer's view, practitioners can access the digital environment while performing daily activities. Through our pilot series, we identified suitable visual and auditory attributes for OHMD mindfulness sessions in casual walking settings, and combined user-preferred features into our proposed Mindful Moments design. Results on physiological, sustained attention and self-reported mindfulness measures suggest that Mindful Moments facilitates higher state mindfulness than the Control. Its results proved comparable to the state-of-the-art Walking Meditation, while also being more accessible, convenient, and easy for novice practitioners to implement in everyday environments. We further evaluate Mindful Moments in a realistic setting, enhancing current understanding of mindfulness practice on OHMDs, thereby contributing a technique for improved health and well-being.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**.

KEYWORDS

Smart glasses, Mindfulness, OHMD, On-the-go, Breath-based guidance

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1 INTRODUCTION

Mindfulness is a multidimensional construct that has been conceptualized as "the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment" [47]. It can refer to a person's momentary state, or longer-term trait associated with mindful capacity and disposition [11]. The physiological, psychological and spiritual benefits of mindfulness practice are well-established [39, 44, 84], serving as an antidote to fast-paced living. It is no surprise that technologically-assisted mindfulness interventions have gained widespread research interest in recent years [92]; applications such as Calm [13], Headspace [42] and Smiling Mind [57] are popular amongst the mainstream, offering sound- and visuals-based guided meditations that can be ubiquitously accessed via mobile devices.

While an increasing affinity towards well-being technologies has encouraged many to attempt mindfulness practice, the perceived time-cost and space requirements has prevented the adoption of daily practice. Practitioners are often required to dedicate time away from their daily schedules, which they may be reluctant to carve out [5]. Similarly, meditation is also best practiced in a quiet conducive environment, and such a space may not always be readily accessible [80].

Our research explores the possibility of reducing barriers to mindfulness practice through the use of smart-glasses (Optical Head Mounted Displays, henceforth OHMDs). We leverage this emergent platform, as a means of more seamlessly fusing common daily tasks (we focus on the walking activity) with mindfulness practice, allowing users to easily practice mindfulness anywhere and anytime. The OHMD's heads-up display is unique in that its transparent screen presents visuals to the wearer while they remain in view of the external environment, i.e. a layer of digital information is superimposed upon the wearer's vision via the OHMD [96]. Recent research has also demonstrated the potential of OHMD technology for supporting on-the-go tasks without compromising our presence in the physical world [34, 74, 78]. We relate these threads of research to our mindfulness application, and believe that an OHMD-specific design may offer novel ways of supporting on-the-go mindfulness practice, in a manner that other display platforms (e.g. smartphone and smartwatch) cannot.

We focus on offering an OHMD breath-guidance design for the casual walking context, exemplifying how breath-based mindfulness practice can be integrated into a common daily task. The integration of mindfulness practice while walking is however, not novel, and has traditionally been practiced as Walking Meditation, that instructs practitioners to notice their bodily sensations and breath as they walk. Walking Meditation has been found to confer a range of health benefits [30, 70, 93], though it often requires dedicated time and space, guidance from a trained teacher and is harder to implement for novice practitioners who may not have built a foundation in mindfulness practice [25]. Technologically-assisted sessions on OHMDs can potentially address these pain points by offering in-the-moment breath guidance through an audio-visual experience, helping users practice mindful breathing while walking.

We design a mindfulness technique on OHMD with an iterative approach, by first narrowing down on a design for effective breath-guidance when a user is casually walking. Over four pilot studies, we investigated various visual and auditory designs that influence the effectiveness of a one-time session in terms of mindfulness effects and user preference. Each pilot provided more insight into the attributes that should be tested next. These design factors included the abstract or realistic representation of visuals, visual dimensionality and complexity, as well as the rhythmic function and naturalness of sound. Subsequently, we combined the best features into a formative design called *Mindful Moments*, which is targeted for casual walking situations on OHMDs.

Mindful Moments was evaluated against two comparison groups:

(1) A control walking condition, i.e., walking without any mindfulness-based guidance which we use as the absolute baseline.
(2) Another walking mindfulness intervention, the Walking Meditation devised by Kabat-Zinn [48] which we consider state-of-the-art (refer to Study 1 for more information).

As opposed Walking Meditation which is usually practiced as a dedicated activity (where practitioners carve out quiet time and deliberate space for this), Mindful Moments was designed for the OHMD, to be used "casually" in everyday walking scenarios, while users also carry out other daily activities. From this perspective, Mindful Moments aims to integrate the meditative experience more seamlessly into daily activities. We believe that this facilitation not only removes barriers to consistent mindfulness practice for the novice practitioner, but also emphasizes the importance of building mindful capacity in daily life contexts, rather than only in controlled meditation spaces.

Given its "casual" use case, we do not expect that Mindful Moments will outperform "dedicated" meditation interventions such as the Walking Meditation. It can largely be considered a success if it approaches the effectiveness of Walking Meditation, as it provides the additional advantage of a lowered barrier of entry for beginners to enjoy the benefit of mindfulness practice. In reality, our results on multiple dimensions (relating to mindfulness state such as sustained attention performance, mindfulness state scores and physiological measures) exceeded our expectations, and showed that Mindful Moments achieves comparable effects to Walking Meditation. Furthermore, Mindful Moments led to better results on certain measures, such as the 10.7% lower response time variability on SART compared to Walking Meditation, indicating improved mindfulness and less mind-wandering.

We also assessed whether Mindful Moments supports mindfulness states practically by evaluating its use in a realistic field setting. We focused on typical days at the office and work-from-home settings given that these places are where individuals spend a substantial amount of their daily time undertaking a range of activities [62]. Over a few typical days, participants experienced at least three Mindful Moments sessions throughout the day at self-initiated times. They found that Mindful Moments improved their energy, relaxation, mood and focus levels in realistic settings, and was most beneficial in two situations: after mentally draining tasks, and after long periods in sedentary positions. In addition, the visuals and audio worked complementarily to provide a better experience without impeding path navigation when walking. With the increasing adoption of daily OHMD use [35], Mindful Moments offers the novice user an opportunity to integrate breath-based mindfulness practice into their lives, freeing them of space and time restrictions. Our study has found that Mindful Moments is easier for beginners to implement when compared to the traditional Walking Meditation, with comparable mindfulness benefits.

This paper has three main contributions: Firstly, we tease out audio-visual design factors that influence breath-awareness mindfulness practice on OHMD, offering suggestions for future designs on this emergent platform. Secondly, we empirically demonstrate possibilities of 'casual' mindfulness practice with comparable benefits to conventional meditation interventions. Thirdly, we show that Mindful Moments can facilitate mindfulness practice effectively during opportunistic moments in realistic settings, such as when a user is walking during a short break. We offer a design solution for individuals interested in building on their mindfulness capacity while reducing time or environmental constraints.

2 BACKGROUND AND RELATED WORK

2.1 Breath regulation in mindfulness practice

In recent decades, evidence-based therapeutic programs such as mindfulness-based stress reduction (MBSR), mindfulness-based cognitive therapy (MBCT), acceptance and commitment therapy (ACT), and dialectical behavioral therapy (DBT) have emerged in the mainstream to treat and prevent ill health [46, 47, 54, 90]. These interventions combine mindfulness techniques which commonly include guided meditations, body scanning and breath-awareness [68].

We choose to focus on the breath as an anchoring technique for mindfulness practice because of its accessibility to all levels of practitioners [1, 100], proven health benefits [19, 65], and feasibility of practice even while walking [91]. Breathing is usually an automatic process that works without conscious intervention [58], though directing our attention to the breath – through passive observation or active regulation – is one way in which we can gain awareness of our inner body state. Reducing the breathing rate to 6-10 breaths per minute, at a 1:2 inspiration to expiration ratio has been found to improve physiological and psychological conditions [63, 88].

While mindfulness interventions are usually accompanied by a set of instructions or practiced with a teacher [60], technological tools offer immersive solutions for breath guidance which can more easily be implemented by the novice practitioner. For instance, Shaw et al. [85] used virtual reality (VR) to provide feedback to new users on their mindfulness practice, while Vidyarthi et al. [95] created an immersive meditative system that connects users' respiration to music. Schein et al. [82] created an interactive device aimed at slowing and regularizing breathing in hypertensive patients. However, these solutions still require dedicated space and time from the user. There remains a gap in existing literature investigating systems that can effectively blend breath-based practice within users' daily tasks. We believe that an OHMD-based system can achieve this, potentially supporting mindfulness practices in casual on-the-go situations.

2.2 Audio and visuals in mindfulness-technology design

Numerous studies have explored the use of VR OHMDs for mindfulness applications. While some combined audio with visuals [26, 27], othersevaluated the single modality of visual animations for breath-guidance. Shaw et al. [85] applied expand-contract motions to the swimming jellyfish as a form of biofeedback and breath representation, while Abushakra and Faezipour [2] used the design of lungs in VR therapy to encourage breath regulation in patients with breathing disorders or lung cancer. Geometric designs have also been adopted by numerous breathing applications such as the iBreathe app [40] and Breathing Zone app [101].

Diverse soundscapes have also been created to facilitate mindfulness practice. Liu et al. [55] highlighted that users who listened to music experienced improved body awareness and experienced a faster passage of musical time, while Zeier [99] found that rhythmic sounds representing one's breathing patterns could induce the slowing of heart rate and relaxation. In addition, exposure to sounds of nature has also been linked to improved recovery from stress and mood [4, 8].

Mindfulness tools that integrate auditory and visual dimensions have been found to provide greater mindfulness benefits than audio- and visual-only technologies. Yildirim and Grady [97] compared between VR-based and audio-only guided mindfulness practice, and found that the VR (audio-visual) group reported higher mindfulness levels than the audio-only group. Similarly, Prpa et al. [72] designed an immersive virtual environment, exploring the mechanisms by which combined sound and visuals cues can enhance breath-focused mindfulness practice.

A range of mindfulness technologies have utilized visual and soundscapes to engage in breath synchronization [27, 64, 85], highlighting the potential of integrated audio-visual systems to support mindfulness state and well-being. Our study focuses on the design of breath-based mindfulness practice on the OHMD platform. As compared to mobile or desktop platforms, OHMDs are especially suited for casual walking situations [34, 74, 78], allowing users to remain present in the physical world whilst providing a high degree of audio-visual immersion. It remains unclear, however, how audio-visual systems should be designed to effectively support breath-guidance on OHMD.

2.3 Integrating daily tasks with mindfulness practice

A wide range of technologies that promote mindfulness in everyday life have been developed in recent years. PAUSE [18] and SIMA [50, 83] are popular mindfulness mobile applications for novice meditators. MindfulWatch [41] is a smartwatch-based tool that targets convenient everyday use; its sensing system captures breathing during meditation in real-time and offers feedback. While these solutions support real-time mindfulness practice, they target meditation as a separate and dedicated activity, instead of seamlessly integrating mindfulness practice into daily activities.

We have chosen to implement Mindful Moments on the OHMD, as the wearable Augmented Reality (AR) platform supports this larger aim of seamless computing support for human's daily activities. While VR users plunge into an entirely fictional reality, AR blends the virtual and physical world, allowing users to continue controlling their presence and activities in the physical world [23]. Given the context of mindfulness, our intention is not to entirely remove users from the "real world" via VR, but to use virtual aids to support them in maintaining their experience and attention of the present moment [47] and physical environment.

In addition, Mindful Moments approaches mindfulness delivery from a "casual practice" point of view, aiming to blend breath-based practice into everyday life. We believe that this not only removes barriers to consistent mindfulness practice, but emphasizes the importance of building mindful capacity in daily contexts, rather than only in controlled meditation spaces.

3 PILOT STUDIES: PRELIMINARY EXPLORATION OF DESIGN FACTORS THAT INFLUENCE BREATH-BASED MINDFULNESS PRACTICE ON OHMD

To understand how audio-visual systems can be designed for breath-based mindfulness practice on OHMD during casual walking situations, we conducted a series of exploratory pilots to narrow down on prominent visual and auditory design elements. In particular, our objective was to narrow down on a potential design that can sufficiently engage the user in mindful breathing without affecting their walking ability.

First, we explored the design of visuals (Pilot 1 & 2) suitable for our use case. We tested multiple visuals animated with the expand-contract animation that have been found to be beneficial for inducing mindful breathing [71, 75]. Once we narrowed down on a visual that was suitable for our objective, we conducted further pilots (Pilot 3 & 4) to explore audio elements that can complement the visuals.

The purpose of the pilots is only to identify a potential design suitable for casual walking in uncrowded indoor spaces. With each pilot iteration (see Table 1: Summary), we added a new user-preferred feature to the potential design, ultimately converging on a formative solution which we named Mindful Moments. Only in Study 1 do we begin a formal evaluation.

3.1 Participants and Apparatus

We recruited the same set of 6 participants (4 females, 2 males) from the university community for each pilot study. Their average age was 25.33 ± 2.85, and all were self-reported novices of mindfulness practice, with little or no experience.

For all pilots, visuals were displayed on an Nreal Light OHMD [52], which places the display in the center of the user's line of sight. It has a 52-degree field of view and a stereoscopic display with a resolution of 1920 x 1080 pixels. In air casting mode, its screen is 115 inches at 3 meters. The visuals were pre-loaded onto an iPad which was mirrored to the OHMD. In pilots 3 & 4 which focused on sound properties, audio was played through wireless headphones (Model: Bose QuietComfort 35 II) along with the OHMD apparatus.

The duration of the expand-contract animations was set to 3 seconds and 6 seconds respectively (see Section 2.1 and video for visualizations). This is because the expand-contract motion symbolises the inhale and exhale motion of breathing and prior findings have shown that a 1:2 inhale-exhale duration is advantageous for inducing mindfulness [53, 91].

3.2 Procedure

At the start of all pilots, participants were shown a briefing video and trained to breathe along with the visuals on OHMD, i.e., to inhale as it expands and exhale as it contracts. All visualizations were animated using the expand-contract motion [71, 75] to guide 3-second inhales and 6-second exhales (see Section 2.1 and video for visualizations). During the session, participants were tasked with walking around the same floor of the building, at their own comfortable pace and direction. The indoor environment was well-lit and relatively quiet, providing ample space for participants to walk freely in. Participants provided post-experiment ratings on the following survey questions (7-point likert scale; 1 for Strongly Disagree, 7 for Strongly Agree) which was adapted from a previous design study [75]:

All pilot studies concluded with an open-ended interview. They used the within-subjects design, and conditions were counterbalanced with a Latin square.

3.3 Pilot study 1

To explore visual properties that can enhance mindfulness states without compromising walking abilities, we began by testing prominent breath-guiding animations featured in previous breath awareness studies (see Section 2) on OHMDs. These designs included both realistic (flower, human lungs and jellyfish) as well as abstract (circular light orb, geometric figure and horizontal bar) objects.

3.3.1 *Participant Feedback.*

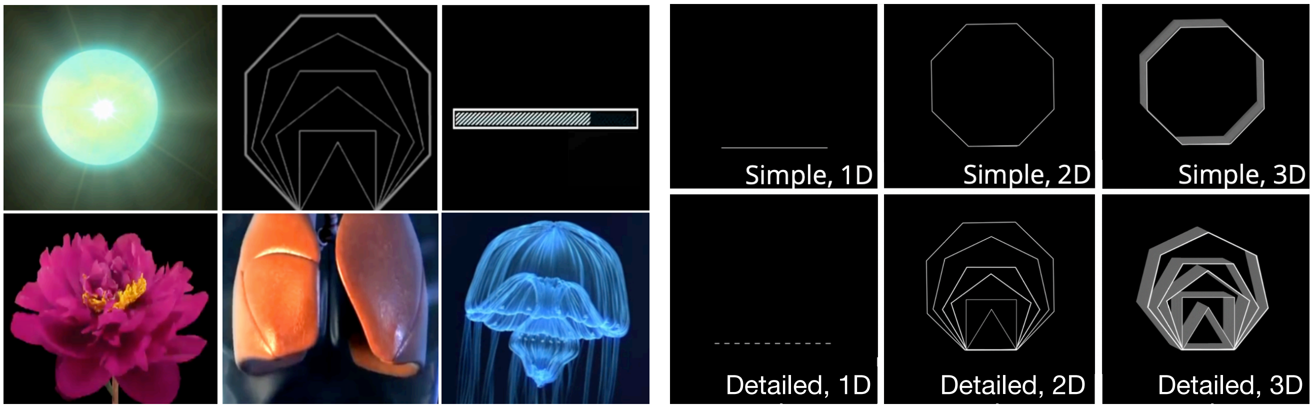
Most participants preferred abstract figures to realistic ones. Abstract representations were favored for these reasons:

Simplicity. Participants shared that visual representations with fewer colors such as the geometric figure are simpler, less distracting and therefore more pleasant. The geometric figure was favored as it consisted of white outlines rather than entire fills, thereby appearing more 'transparent' in nature, and are less likely to occlude users' OHMD view [74]. However, visuals that are overly simplistic seem not to capture sufficient attention, e.g. participants felt that the horizontal bar was simple in its representation but too boring, causing them to eventually disengage from the breathing practice.

Lack of literal association. In line with the Attention Restoration Process theory [49], abstract visualizations did not reinforce the interpretive tendencies of the mind (i.e. did not promote mind-wandering), and are thus better for mindfulness practice.

Clear visual guidance. Abstract representations were easier to follow due to obvious changes in expansion and contraction. Participants felt that the movement of the lungs and jellyfish (both realistic visuals) were harder to discern because of the complexity of detail. Furthermore, the OHMD, albeit worn stably, inevitably shakes as participants walk, making it all the more important for changes in expansion and contraction to be seen clearly.

Participant feedback suggests that visuals need to be clear and simple enough in breath-based guidance such that they do not distract users. In this regard, the geometric figure was found to be the most suitable with the highest mean ratings on all survey questions. However, the visuals also need to be interesting enough such that it provides a sense of immersion, motivating users to stay present with the breathing activity while they walk. To explore how this balance can be better struck, we conducted another pilot study



(a) Pilot 1

(b) Pilot 2

Figure 2: (a) Examples of abstract visuals (Top row, left to right: Light orb, Geometric figure, Horizontal bar) and realistic visuals (Bottom row, left to right: Flower, Lungs, Jellyfish) which expand and contract to provide breath-based guidance. (b) Geometric figure variations of Dimensionality and Shape complexity (Top row, left to right: Simple 1D, 2D, 3D; Bottom row, left to right: Detailed 1D, 2D, 3D). Videos are included as Supplementary Materials.

varying the Dimensionality and Shape complexity of the Geometric figure.

3.4 Pilot study 2

In this pilot we explored how the Geometric figure from Pilot 1 can be designed to balance between distraction and immersion levels during mindfulness practice. Prior investigations have shown that the dimensionality of visuals have an impact on our emotions, with 3D stimuli eliciting more intense emotions as compared to 2D counterparts due to visual processing differences [28, 94]. To delineate these effects, we vary two structural features of the Geometric figure: Dimensionality (1-dimension; 2-dimension; 3-dimension) and Shape complexity (simple shape with outlines; detailed shape with outlines and inlines). Participants underwent 2 blocks (randomized either with the Simple or Detailed). Within each block the order of Dimensions (1D, 2D, 3D) were counterbalanced using a Latin Square to account for order effects.

3.4.1 Participant Feedback. Detailed 2D was most preferred, followed closely by Simple 3D. Four factors influenced participants' survey ratings and preferences:

Occlusion. Participants felt that 3D figures on the OHMD screen were more occluding and distracting than 2D figures, "blocking" the user's view of the external environment while walking. 1D figures were too unnoticeable, while 2D figures seem to strike a good balance between 1D and 3D figures.

Continuity. Because breathing is a continuous activity, visualizations that enhance a sense of smooth continuity facilitated mindfulness. Most participants felt that the dashed lines in Detailed 1D evoked a sense of "brokenness" compared to other visualizations with fully formed lines. On the other hand, the synchronistic movement of outlines and inlines in Detailed shapes (compared to Simple shapes) added to a sense of flow and uninterrupted movement.

Visual guidance. More so than 1D figures, 2D and 3D figures offered clear visual guidance for changes in expand-contract movement.

Aesthetics. Aesthetics influenced the pleasantness of the mindfulness session. One participant shared that "the Detailed 3D feels like a graph with shadow, and is not elegant to me. The Detailed 2D is elegant" [P3]. One participant felt that "detail inside the Detailed 2D shape is aesthetically pleasing" [P1].

The feedback participants provided in Pilot 2 reinforces insights gained in Pilot 1, suggesting that the Detailed 2D visualization satisfies requirements relating to occlusion, continuity, clear guidance and aesthetics. Thus, we proceeded to test complementary soundscapes with the Detailed 2D Geometric visualization in the next pilots.

3.5 Pilot study 3

Pilot 3 focuses on audio that can be combined with visuals to enhance mindfulness practice in casual walking contexts. Existing literature suggests that connecting rhythmic respiration [99] with naturally-occurring sound [4, 8] or man-made music [55]) facilitates mindfulness practice. In contrast, Cheng [18] proposed that the predictable nature of rhythmic sound may trigger new thoughts, and favored non-rhythmic audio for mindfulness practice. Given the seemingly contradictory viewpoints, we compared Rhythmic vs. Non-rhythmic with Natural sounds vs. Man-made music to narrow down on suitable audio for our use case. Selected rhythmic variations include Ocean waves and Birdsong. Non-rhythmic counterparts include waterfall and rain soundtracks. Man-made rhythmic music selections include Classical music [17] and native American Earth drumming music [79]. Non-rhythmic selections include Binaural music [6] as well as the Tibetan singing bowl [36].

3.5.1 Participant feedback. Based on rankings and participant interviews, Binaural music was most favored, followed by Ocean waves. There was no clear consensus on natural vs. man-made sounds, though some participants felt that there was a mismatch between natural soundtracks and the immediate indoor environment. For instance, a user walking during a bright day may find it jarring to listen to rain and thunder during the mindfulness session. Overall, participants preferred Binaural music as the sound was characterized as slow, continuous, and calming. As one participant put it, Binaural music struck a balance between "not too active, and not too stagnant" [P4]. This aspect of the auditory experience can be related to the Relaxation Response theory [9] which puts forth that gentle and continuous movements in attentional objects can trigger mental and physical relaxation.

Participants also shared that they would have preferred for sound rhythms to be synchronized with the visuals and breathing pattern. When the audio is rhythmically in sync with the visuals, it could function as a cue for users to breathe in or out, in the same way the animated visuals provide breath guidance as it expands-contracts. These rhythmic cues appeared to pair well with smooth unchanging sounds in the background. Integrating insights, we proceeded to test these elements in Pilot 4.

3.6 Pilot study 4

Pilot 4 tested the rhythmic function of sound by comparing between 1 cue sounds, 2. sustained sounds and 3. the combination of both. Cue sounds are synchronized rhythm-wise to visuals, providing a clear sound to signal changes from inhale to exhale and vice-versa. Cue sounds also motivate participation in the breathing activity [81]. Sustain sounds on the other hand have no rhythmic structure, but provide smooth and long sounds in the background. Such 'drone' sounds are featured commonly in meditation and hypnosis music [24], and serve to provide a sense of immersion and relaxation. Both Natural and Man-made audio versions were used, thus bringing about a 3x2 factorial design.

3.6.1 Participant feedback. Sustained+Cue audio was most preferred, followed by Cue-only, then Sustained-only tracks. Participants shared that Sustained-only audio offered "no guidance for breathing" [P3] and is "no different from not having audio at all" [P2]. Cue-only sounds felt abrupt as "it starts and stops" [P5] without continuous sound. On the other hand, Sustained+Cue seemed to compatibly combine best features in Sustained-only and Cue-only sounds: "Synchronized rhythm [in Cue] helps me to follow the breath, while they suit each other when combined, as [Sustained] makes rhythm smoother" [P2].

Whether a track was Natural or Man-made did not seem to markedly affect user preference. While some participants did not find Natural ocean sounds pleasing (e.g. "Ocean waves do not give me a feeling of relaxation" [P1]), other participants thought the exact opposite. It may thus be ideal for OHMD designers to offer different Sustained+Cue soundscape experiences to users who may have different personal preferences.

3.7 Pilot Studies Summary

Together, our pilot studies (summarized in Table 1) offer preliminary insights into audio-visual designs for OHMD- and breath-based mindfulness practice in casual walking contexts. Aimed at understanding the first-person experience via subjective feedback, the pilot series has allowed us to narrow down on a potential design that is suitable for our use case. Thus, we integrated all user-preferred features (2D detailed geometric figure, and binaural music with both sustained and cue sounds) and named the combined design Mindful Moments. Mindful Moments is empirically evaluated in the next section, using objective and subjective measures.

4 STUDY 1: COMPARING MINDFUL MOMENTS WITH WALKING MEDITATION

Our pilot studies provided insight on the audio-visual attributes influencing breath-based mindfulness sessions on OHMD. We combined the user-preferred audio-visual features into a casual, on-the-go mindfulness technique, called "Mindful Moments", and evaluate it in two subsequent studies. In Study 1, we evaluated it against a Control walking condition, as well as a dedicated Walking Meditation session based on a practice devised by Kabat-Zinn [48], the founder of MBSR. We consider this Walking Meditation to be an established practice, i.e. the state-of-the-art, in terms of its mindfulness benefits. Extant literature suggests that MBSR techniques reduce instances of mind-wandering, leading to calmer physiological states, improved ratings on various mindfulness scales and attention task performance [16, 43, 67]. Since our study targets mindfulness practice while walking, all three conditions were implemented with users walking.

We predicted that our Mindful Moments design, which is intended for everyday walking situations, would perform comparably to Walking Meditation, and significantly outperform the Control walking condition. In order to capture a range of mindfulness effects, we measured participants' electrodermal activity (EDA) using the Empatica E4 Wristband, performance on the Sustained Attention to Response Task (SART), and supplemented this data with self-reported measures of state mindfulness via the Mindful Attention Awareness Scale (State MAAS).

4.1 Participants

We recruited 18 participants (9 males/ 9 females, Mean age = 21.67, SD = 3.83 years) from the university community, none of whom were participants in previous pilots. 2 of the participants self-reported prior experience using OHMD. 2 users considered themselves to have some experience in mindfulness practice (less than 2 years, at least once a week), while the rest had no experience. All participants were fluent in English at the university level. They were paid the standard compensation rate of 11 United States Dollars for their time.

4.2 Measures

The following measures were collected and analyzed to compare the different techniques.

4.2.1 Electrodermal Activity (EDA). Electrodermal activity (EDA), which measures skin conductance, is a commonly used physiological signal for detecting stress in laboratory and real-life environments [14]. Skin conductance increases during emotionally aroused or stressful states due to sweat [15], and is found to decrease with mindfulness exercises [51]. The EDA signal after filtration was decomposed in two components to measure stress levels.

Pilot	Goal	Conditions	Design selection (outcome)
1	Explore and identify a suitable visual form	**Abstract forms:** Light orb, Geometric, Horizontal Bar **Realistic forms:** Flower, Lungs, Jellyfish	Geometric figure is simple, clear, immersive, and relaxing. It presents as a suitable design
2	Investigate effects of shape dimensionality and complexity	**Dimensions:** 1D, 2D, 3D **Complexity:** Simple (outline only), Detailed (inline & outline)	**Geometric figure** that is **2D** and **Detailed** provides a sense of continuity, clear guidance, is aesthetic and not too occluding
3	Explore and identify a suitable audio type based on naturalness and rhythm	**Natural with rhythm:** Ocean, Birdsong **Natural without rhythm:** Waterfall, Rain&Thunder **Man-made with rhythm:** Classical music, Earth Drum **Man-made without rhythm:** Binaural music, Singing Bowl Audio paired with visual (Detailed 2D Geometric) narrowed down in Pilot 2	**Binaural music** and **Ocean Waves** are relatively calming and "not stagnant". No consensus on natural vs. man-made. Rhythm only matters if synchronized to visuals.
4	Investigate Sustained-cue function of audio	**Sustained-cue function:** Cue only, Sustained only, Sustained+Cue Audio paired with visual (Detailed 2D Geometric) narrowed down in Pilot 2	**Sustained and Cue sounds** are best combined. Cue function helps users follow breathing pattern. Sustained function gives relaxing sense of smooth continuity. Both man-made and natural tracks are suitable.

Table 1: Summary of the 4 pilots which as a whole explore audio-visual design attributes that can facilitate effective mindfulness practice on OHMD in casual walking contexts.

The E4 captured participants' EDA at 4Hz. Following Poh et al. [69], we first applied a low-pass filter to the signal (Hamming window, 1024 points, cut-off frequency of 1 Hz) to reduce motion artifacts caused by expected physical movements while walking. Next, the filtered signal was decomposed into its two components, tonic and phasic using the cvxEDA tool [37]. Following Can et al. [14] we computed the following features for each component to measure stress levels.

- **Mean tonic.** The tonic component indicates slow changes in skin conductance. To capture changes in skin conductance level over time, we computed the average tonic level during the condition that participants underwent.
- **Phasic peaks.** The phasic component indicates sudden event-related changes in skin conductance, characterized by peaks in the signal. Using a peak detection algorithm introduced by Gamboa [32], we detected the number of peaks in the phasic signal (in 100 sec), as an indicative measure of stress levels.

4.2.2 SART. The Sustained Attention to Response Task (SART) [77] was used to assess mind-wandering, a cognitive dimension that suggests a lack of mindfulness [29]. The SART is a commonly used test, and its performance markers have well-established neural and behavioral correlates, as well as known test-retest stability [22]. The SART version used in the study was approximately 5-6 min in length, designed by Stoet [87] on PsyToolkit. Participants were continuously shown an array of single digits ranging from 1 to 9, and instructed to respond (by pressing the spacebar) as quickly as possible after any digit, except for 3, flashed on the screen. In terms of performance markers, we measured response accuracy as well as response time coefficient of variability (RT CV).

- **Response accuracy:** Response accuracy comprises different error types.
  – Commission errors: The number of target trial errors, i.e. number of times a participant fails to withhold their response (pressing the spacebar) after seeing digit 3. Commission errors suggest that the task is being performed in an automated rather than controlled fashion [77]. There are 25 target trials in one test, thus the maximum commission error score is 25.
  – Omission errors: The number of non-target trial errors, i.e. number of times a participant fails to respond after seeing digits 1, 2, and 4-9. Omission errors suggest a total disengagement from the task [21]. There are 200 non-target trials in a test, thus the maximum omission error score is 200.
  – Combined SART error: This score is the composite of both error types, suggesting attentional failures as a whole during the SART.
- **Response time coefficient of variability (RT CV):** RT CV is calculated by dividing the RT standard deviation by the RT mean for correct non-target trials. Variability in response speed as reflected in the RT CV has been found to index mind wandering [7, 59, 98], and is the result of periodic speeding and slowing of response times as attention fluctuates [86]. Higher RT CV suggests more attentional lapses and mind wandering. Conversely, lower RT CV indicates a better mindfulness state.

While SART errors indicate marked distraction, RT CV complements it by highlighting slight occurrences of mind-wandering [59].

4.2.3 Mindfulness Attention Awareness Scale (MAAS). For our study, we conceptualized mindfulness as a dynamic mental state with high temporal and contextual resolution, as opposed to a long-term trait that suggests a way of being. Thus, we used the state

Mindfulness Attention Awareness Scale [11], a 5-item questionnaire (based on a 0-6 scale) designed to assess the short-term or current expression of mindfulness. The MAAS was administered after each session ended, as part of a post-questionnaire on Google Forms. We calculated the mean of all 5 items, with lower scores reflecting higher state mindfulness. Lower state mindfulness in the MAAS is associated with fast and careless responding in the SART [20].

4.3 Apparatus

For the Mindful Moments condition, we reused the OHMD, wireless headphones and indoor walking environment from our earlier pilots (Figure 3(a)).

For all conditions, participants were fitted with an Empatica E4 wristband on their non-dominant hand, which captured real-time EDA. The E4 is a widely used instrument for this purpose [38]. It has similar stress detection accuracy as medical grade ECGs, and its stress detection power is comparable to laboratory sensors for wrist and finger skin conductivity [61].

For the computerized SART (Figure 3(b)), a standard laptop was placed in a quiet room, with participants sitting on a chair, with a desk of comfortable height in front of them. Post-questionnaire Google forms were filled with the same laptop.

4.4 Method

A fully counterbalanced within-subjects design was used to compare between Mindful Moments, Walking Meditation, and Control. Each of the 3 sessions were administered on separate days within the span of a week for each participant. To avoid being confounded by the time of day, timings for each session were randomized. Participants met in the same room on university campus every session for their briefing.

4.5 Procedure

After giving informed consent, participants were briefed on their assigned condition (Mindful Moments, Walking Meditation or Control) of that day, and familiarized with the computerized SART via a practice session. Briefing and procedural details unique to each of the 3 conditions are described below.

4.5.1 Mindful Moments. During the briefing, participants tried on the NReal OHMD and headphones. They were played the Mindful Moments video (included as Supplementary material), and instructed to inhale and exhale according to the visualization's expansion and contraction. Participants practiced breathing along to Mindful Moments for 1 minute as they sat, familiarizing themselves with the breath-based guidance.

Then, the experiment began with a 5-minute casual walking calibration, while the experimenter silently followed behind. This ensured that the Empatica E4 was well-calibrated and reduced spillover physiological effects from participants' prior environments. After the calibration, the experimenter manually started the Mindful Moments video on the participants' OHMD, and participants were asked to walk freely for another 5 minutes as they followed along with the Mindful Moments breath guidance.

4.5.2 Walking Meditation. During the briefing, participants were shown a 2.5 minute instruction video on walking meditation (included as Supplementary material). The instruction video was based on an audio recording from Kabat-Zinn's Guided Mindfulness Meditation Series 3 [48], edited to include only direct instructions for walking meditation practice. Audio pauses and general information on mindful awareness and meditation were left out. Strohmaier et al. [89] had similarly edited mindfulness practice recordings to create shorter versions that conveyed essential content. To enhance clarity of instruction, the edited audio track was paired with a recorded video of an experimenter attempting walking meditation according to the instructions. Captions of key instructions were also included in the video. After viewing the video, participants were asked to practice walking meditation in the briefing room for 1 minute.

After 5 minutes of walking calibration, participants were asked to begin 5 minutes of Walking Meditation at a nearby corridor in the same building.

4.5.3 Control. After the 5-min walking calibration, participants were asked to walk casually for another 5 minutes.

After each session, participants returned to the briefing room to perform the SART, followed by the subjective ratings survey (MAAS) and an open-ended interview. Each session lasted about 35-40 mins.

4.6 Results

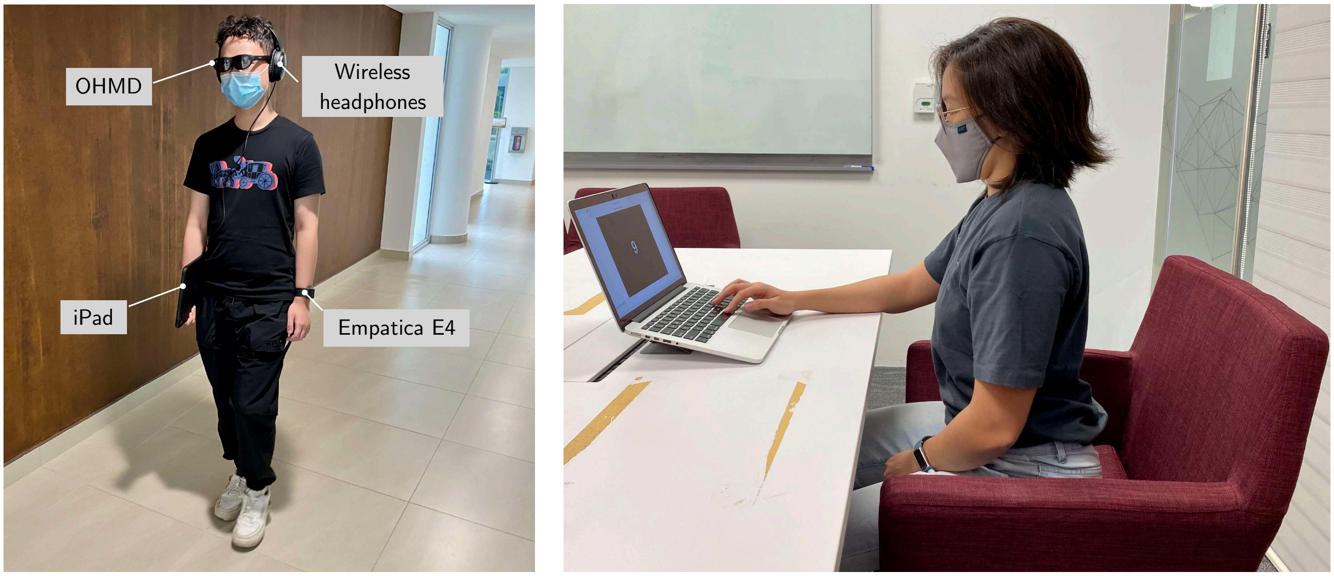
To analyze the results, we applied one-way repeated measures analysis of variance (ANOVA), followed by multiple means comparison with bonferroni correction (if parametric and normal). If the data was non-parametric or non-normal, Friedman's test was used instead with post hoc Conover's test. Normality and sphericity were tested using the Shapiro-Wilk and Mauchly test. For violations of sphericity, Greenhouse-Geisser ($\epsilon < 0.75$) corrections were used to adjust the degrees of freedom.

4.6.1 Stress and Arousal.

- **EDA - Mean Tonic.** A one-way repeated measure ANOVA did not reveal significant differences between the conditions ($F_{2,34} = 0.796, p = 0.459, \eta_p^2 = 0.045$). Overall, Mindful Moments had a lower mean tonic (M = 0.50, SD = 0.272), which suggests lower stress and arousal levels than Walking Meditation (M = 0.62, SD = 0.31) and Control (M = 0.567, SD = 0.22), though this is likely due to random variations.
- **EDA - Phasic peaks.** The Friedman's test did not show a significant main effect ($\chi^2_{(2,N=18)} = 4.0, p = 0.135$), suggesting no difference in sudden event-related stress or arousal peaks. Mindful Moments (M = 29.76, SD = 17.46) had a lower number of phasic peaks than Walking Meditation (M = 38.46, SD = 17.3) and Control (M = 35.16, SD = 14.17), but given the high p value, they may be comparable.

4.6.2 Attention and Mind-wandering.

- **SART - Commission error.** The Friedman's test did not show a significant main effect ($\chi^2_{(2,N=18)} = 2.0, p = 0.368$). Overall, Mindful Moments had the lowest commission error score (M = 5.11, SD = 3.924), followed by Walking Meditation (M = 5.61, SD = 3.867) and Control (M = 5.72, SD = 3.286).



(a) Apparatus for Mindful Moments

(b) Computerized SART test

Figure 3: (a) The Mindful Moments apparatus included the Nreal OHMD, wireless headphones, iPad, and Empatica E4 wristband; (b) The computerized Sustained Attention to Response Task was completed on a standard laptop, with participants seated in a quiet room.

Differences between conditions are likely due to random variations.

- **SART - Combined SART error score.** The Friedman's test did not show a significant main effect ($\chi^2_{(2,N=18)} = 0.806, p = 0.668$). Overall, Mindful Moments had a lower SART error score (M = 5.56, SD = 4.033) than Walking Meditation (M = 5.89, SD = 4.1) and Control (M = 5.83, SD = 3.348). This is likely due to random variations, suggesting that accuracy and mind-wandering levels for Mindful Moments is not significantly different from Walking Meditation, and may thus be comparable in performance.
- **SART - Response time coefficient of variability (RT CV).** A one-way repeated measure ANOVA showed significant differences between the conditions ($F_{2,34} = 3.609, p = 0.038, \eta_p^2 = 0.175$) shown in Figure 4(a). Bonferroni post-hoc tests revealed that Mindful Moments (M = 0.376, SD = 0.0529) had a significantly lower RT CV than Walking Meditation (M = 0.421, SD = 0.0915) ($p = 0.041, d = 0.649$), and almost significantly lower than Control (M = 0.423, SD = 0.0963), with a p-value of 0.071. There is no significant difference between Control and Walking Meditation. This suggests that Mindful Moments resulted in lower levels of attentional lapses and mind wandering.

4.6.3 Mindfulness state.

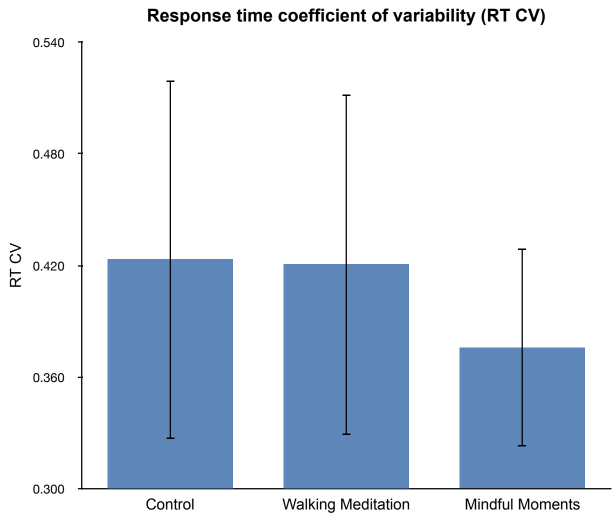
- **Self-reported MAAS.** A one-way repeated measure ANOVA showed significant differences between the conditions ($F_{2,34} = 16.54, p < 0.001, \eta_p^2 = 0.493$) shown in Figure 4(b). Bonferroni post-hoc tests revealed that Mindful Moments (M = 1.64, SD = 0.929; p =0.001) and Walking Meditation (M = 1.58, SD = 0.953; p =0.001) had a significantly lower MAAS score than Control (M = 2.89, SD = 0.924). There is no significant difference between Mindful Moments and Walking Meditation. This suggests that Mindful Moments and Walking Meditation resulted in significantly better mindfulness states than in the Control. Mindful Moments and Walking Meditation performed comparably to each other, without significant difference.

4.6.4 Preference. Between Mindful Moments and Walking Meditation, more participants preferred their Mindful Moments session (55.6%) to Walking Meditation session (44.4%), albeit by a small margin. Reasons for their preferences were explored in the post-experiment interview and discussed in the next section.

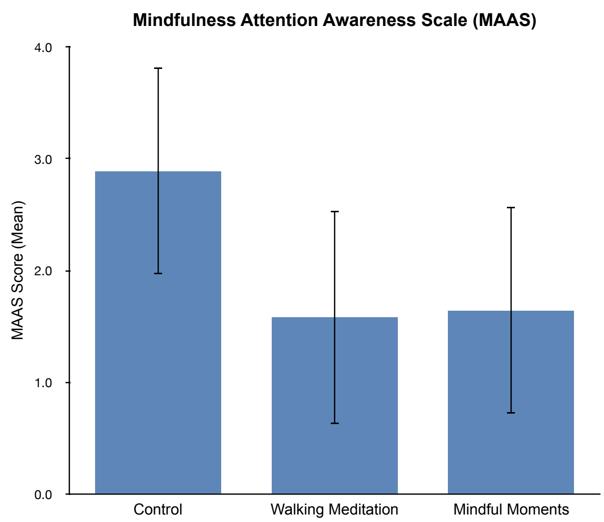
4.7 Discussion

Overall, participants found the Control session, which only involved casual walking, to be uninteresting and "very boring, with nothing to focus on, only me and my thoughts [P15]". The state MAAS scores showed that the Control had significantly poorer mindfulness ratings than both Mindful Moments (43.3% improvement from Control) and Walking Meditation (45.3% improvement from Control). Without any mindfulness-based guidance, P13 shared that "the walk was quite repetitive" and they felt like "dozing off". As a result, participants generally experienced less motivation to maintain present-moment awareness during Control sessions.

As hypothesized, our results suggest that a casual session of Mindful Moments is comparable to the state-of-the-art Walking



(a)



(b)

Figure 4: (a) Response time coefficient of variability (RT CV); (b) Self-reported MAAS values for 18 participants

Meditation session; this is reflected in EDA signals (mean tonic and phasic peaks), SART error score (commission error and combined SART) and self-reported MAAS ratings. Moreover, Mindful Moments led to a 10.7% lower response time variability (RT CV) than Walking Meditation on the SART, indicating significantly lower levels of mind-wandering and better mindfulness state. Results indicate that Mindful Moments has the potential to improve sustained focus and reduce attentional lapses even after one-session [45]. This is supported by participant feedback, that "the audio helped her focus, and the visual helped to center her attention [P16]", and "I was not distracted, and felt my mind wandered less today compared to during the Walking Meditation [P14]". P1 felt the focusing effects of Mindful Moments even after the session; she shared that it positively affected her performance on the attention test, because every time she caught their mind wandering during the test, she was more able to remind herself to focus on the test. If she made an error on the test, she also felt that she was able to accept and not take the mistake too harshly, and was thus less agitated.

As detailed in the Methods section, poor SART response accuracy is associated with prominent levels of distraction that happen when participants respond automatically to the task rather than with control [77], as well as when they completely disengage [21]. Our results reveal no significant difference between Mindful Moments and Walking Meditation for SART response accuracy. This suggests that both session types perform comparably on the level of pronounced distraction. However, Mindful Moments (with its significantly lower RT CV) demonstrates greater success at reducing subtle mind-wandering than Walking Meditation [59].

This reduction of subtle mind-wandering but not pronounced distraction may be attributed to the saliency of visuals and audio in Mindful Moments, which makes it easier for novice practitioners to follow along with the breath-based guidance. Our earlier pilots demonstrated that the 2D-detailed geometric animation (see Pilot 2) provides clear visual guidance; its rhythmic expand-contract movement directs users to inhale and exhale accordingly. It strikes a good balance, covering enough screen space to be noticeable, but does not excessively occlude the OHMD screen. The sustain-cue function of the audio track (see Pilot 4) provides the listener with both a sense of continuous, smooth immersion as well as guidance to breathe in or out according to rhythm. Combined, Mindful Moments "acts as an anchor" [P5], providing clear prompts for mindful breathing, thereby reducing instances of subtle mind-wandering.

Pronounced distractions may be an inevitable experience of casual walking with OHMD, where users may occasionally need to turn their attention to the ever-changing external environment in which they physically navigate. In a real-world environment, this shifting of attention from the on-screen activity to their physical space is important for keeping users safe from accidents, in which case such "pronounced distractions" to the mindfulness activity are desirable. There are other obvious cases for which Mindful Moments should momentarily become the secondary task. For instance, a Mindful Moments user may also need to greet a passer-by they recognize. It is of greater importance then to ensure that Mindful Moments allows for easy switching of attention between the on-screen activity to the surrounding environment. The majority of participants in this study have confirmed that this is indeed the case: "It is easy to manage attention between the external environment and on-screen visuals." [P16]

Walking Meditation on the other hand requires greater self-initiation into the practice, as unlike Mindful Moments, it does not provide in-the-moment guidance. As explained by P1, Walking Meditation may lead to deeper meditative states but this is not easily achieved for beginners, requiring a lot of discipline on their part: "Mindful Moments is relatively straightforward, and easier for me as a beginner. It guarantees to pull me back into the present." Similarly, P13 shared: "The external guidance of Mindful Moments greatly helps me ease into the practice, whereas Walking Meditation has to entirely be a personal effort." In addition, participants shared that Mindful Moments made it easier for them to return to the guided breathing whenever they got distracted: “It’s easier in Mindful Moments than in Walking Meditation to bring oneself back whenever distracted” [P5]. This further substantiates the lower levels of subtle mind-wandering in Mindful Moments sessions.

Participants who preferred Walking Meditation highlighted that unlike Mindful Moments, it does not constrain them to a set breathing pattern: “Walking Meditation was more free” [P9]. P10 and P17 expressed similarly that the breathing did not feel natural because Mindful Moments required longer breaths, and they had to put greater effort into following its breathing pattern. Despite posing as a potential hindrance to one’s experience with Mindful Moments, a large body of literature on breathing practice confirms the psychological and physiological benefits of slower, controlled breath rates that are between 6-10 beats per minute, with a 1:2 ratio of shorter inspiration followed by long expiration [63, 88, 91]. This frustration relating to controlled breathing may be especially prominent at the beginning stages of Mindful Moments, when one is unaccustomed to slowing down, though increased relaxation as an after-effect is likely to follow. According to P12, Mindful Moments prompted her to breathe slower which led her to “calm down”. While P2 felt that it initially required effort to slow down and follow the breathing pace of the video, it became more natural over the 5-min session.

In summary, OHMD-based mindfulness practice can boost practitioners’ mindfulness states as effectively as traditional Walking Meditations. The OHMD platform is a relatively new but increasingly-used technology for the everyday person [66]. Despite its novelty, and only 2 out of our 18 participants having worn an OHMD prior to the experiment, the majority preferred their Mindful Moments (55.6%) to Walking Meditation session (44.4%). This hints at Mindful Moments as a promising design for future adoption, one that could encourage novice practitioners to integrate regular mindfulness practice into moments of their day.

5 STUDY 2: FIELD STUDY OF MINDFUL MOMENTS

From Study 1, we found that the Mindful Moments design is comparable to Walking Meditation in terms of its mindfulness effects. To understand how Mindful Moments can be practically applied and blended into everyday life, we conducted a study in realistic office and work-from-home settings.

The office and work-from-home settings were chosen for two reasons. Firstly, while Mindful Moments is intended for a digital future wherein smart-glasses are widely adopted by mass consumers and worn on a regular basis, the current setup is such that participants do not wear them throughout the day. Hence, the apparatus was placed at a “mindfulness station” in the office or home, such that participants could conveniently access and run Mindful Moments at their own time and preference. Secondly, these settings are where users spend a substantial amount of time; they undertake both work and leisure activities such as eating, strolling, video-watching during breaks. Thus, we observe how Mindful Moments can be integrated into typical parts of daily life in these settings.

The study was conducted over three days, such that users could access and experience Mindful Moments at different times of their day either at home or in the office. The study elicited insights relating to when users prefer using Mindful Moments, how it benefits them in different situations, as well as the challenges they encounter with Mindful Moments sessions.

5.1 Participants

We recruited 15 volunteers (7 males/ 8 females, Mean age = 25.6, SD = 3.18 years) from the university community. Participants were self-reported novices of mindfulness-based practices with little or no experience.

5.2 Apparatus

The apparatus remains unchanged from the Mindful Moments condition in Study 1. This time, participants were briefed on how to independently run Mindful Moments with the Nreal Light OHMD and wireless headphones which connected to the iPad. All equipment was left on a table in the office building (“mindful station”) or university student dormitory which participants could easily access. As in Study 1, each Mindful Moments session on OHMD lasted 5 minutes, and participants had to follow along with the breath-based guidance of the video while walking.

5.3 Procedure

Participants were instructed to select 3 full working days to participate in the experiment. For each working day, they had to run 3 or more Mindful Moments sessions. They had the freedom to pick their own session timings (the reasons of which may provide interesting insights), but were encouraged to spread out their timings such that they could experience Mindful Moments under a variety of situations. Immediately after each session, participants filled in a Google forms survey on their own device.

After completing their participation, we conducted a 15-min open-ended interview with participants to elicit further insights on Mindful Moments sessions. We report the insights thematically in the next section.

5.4 Data Analysis

Interviews were audio-recorded, transcribed, and coded by two of the co-authors following Thematic Analysis. Themes related to beneficial effects, preferred situations of use, long-term adoption and more were derived inductively from data based on both their frequency of occurrence and perceived substantive significance.

6 RESULTS AND OVERALL DISCUSSION

We combined key insights gained from Study 2’s field investigation and the overall study on Mindful Moments. Following that, recommendations are provided for future designs of breath-based mindfulness systems on OHMD.

6.1 Well-being effects of Mindful Moments practice

Our comparison in study 1 demonstrated that a single casual Mindful Moments session led to comparable mindfulness effects as the state-of-the-art Walking Meditation session in terms of lower physiological arousal, improved attention and self-reported mindfulness state. Our findings from the field study were consistent with study 1’s, showing that Mindful Moments is able to improve users’ energy, relaxation, mood and focus levels. Common post-session feedback included "I feel relaxed and happy" [P7] and "it helped me to concentrate" [P1]. These results reinforce findings which suggest that the mechanisms of mindfulness involve not only relaxation, but beneficial shifts in cognition, emotion, physiology and behavior [39]. It is likely that well-being effects will amplify with regular mindfulness practice [76] via Mindful Moments. Overall, Mindful Moments works to synergistically improve the biopsychosocial health of a person after a short single session as well as from continued practice over several days. This makes it useful even for novice practitioners who are not yet dedicated to regular practice, conferring immediate benefits even after a brief session. The flexibility of space and reduced time-costs associated with Mindful Moments may further encourage regular mindfulness practice among everyday users.

6.2 Symbiotic relationship between video and audio

While our pilot studies helped us to narrow down on an audio-visual design that is effective for breath-based mindfulness practice on OHMD in casual walking contexts, the exact mechanisms by which participants utilize the audio-visual channels remained unexplored. User feedback collected in our field study suggests that each channel came in use at different stages of the Mindful Moments session. In particular, participants felt that the animated visuals were especially useful at the start of every session. The visuals served to ease them into the practice and guide them to breathe according to rhythm (i.e. "the video helps with entry into the breathing exercise" [P6]).

Once their breathing pattern was established and regulated, they had less need to focus their attention on the OHMD visuals. Instead, they would naturally turn to the audio as a guide for maintaining their breathing pattern, which allowed them to then focus their visual attention on the external environment as they walked. The audio is rhythmically synced to the visuals, and given its cueing function (refer to Pilot 4 for details on the audio sustained-cue function), listening to the audio was sufficient for participants to maintain their controlled breathing pattern throughout the session. According to P5, "after a while, it was easy to follow the breathing pattern by just listening to the audio". The freeing up of visual resources and reliance of the auditory channel is particularly useful when implementing Mindful Moments in busier environments, as users will need to give more attention to path navigation [74].

The visuals not only served as an initial guide to breath regulation – it facilitated the easy return to the breath whenever participants got distracted. According to P6, "when I got distracted and lost focus, visuals helped me get back on track". Distractions occurred sometimes due to natural disruptions, such as when participants turned their attention to passers-by. Participants shared that the visuals helped them to return to rhythmic breathing whenever they momentarily lost track of it. Despite having their OHMD screen superimposed over their visual field, they could still effectively walk and navigate their external environment while experiencing Mindful Moments. Overall, participants felt that the video and audio worked complementarily to create an "immersive atmosphere" [P2], and added to the overall pleasant experience.

6.3 Ideal usage of Mindful Moments

User feedback from study 2 also suggests ideal times for use of Mindful Moments. Mindful Moments appeared most beneficial in two situations: after mentally draining tasks, and after long periods in sedentary positions. Both situations are common experiences during a work day, where studying or office work typically involves sitting in front of a computer for stretches of time. Participants from our field study consistently reported that after a mentally strenuous task, Mindful Moments provided opportunities for much-needed mental breaks and rejuvenation. P2 ran Mindful Moments after a one hour meeting, and reported improved post-session relaxation scores, sharing that it "increased mental clarity". Similarly, P8 who read for 2 hours before the session expressed that "it felt good to have a short break and move around after". These findings are consistent with current literature, which have shown that breathing-based walking facilitates bio-psychological well-being [53]. Mindful Moments in such situations can be likened to active "microbreaks". Radwan et al. [73] found that 2–3 minute microbreaks of light intensity exercises supported the physical and mental health of office workers without negatively impacting productivity, and suggests that Mindful Moments serves a similar purpose for its users.

On the other hand, when participants had urgent or unfinished tasks ahead, Mindful Moments seemed to be interruptive in nature. Altmann and Trafton's memory for goals model [3] postulated that active rehearsal is required in order for the worker to resume interrupted tasks; the mental processes involved in active rehearsal may undermine one's mindfulness state of being in the present moment. P6 was in the midst of a research task and shared: "I can feel how the need to complete my subsequent task is affecting my focus for this session." Furthermore, the mental effort required to resume unfinished tasks after Mindful Moments may be especially significant, given that the immersive mindfulness experience eases practitioners into a relatively different state of mind. As P3 aptly described: "The Mindful Moments audio and visuals are very immersive so it takes me away from my current situation, making it harder for me to go back to my unfinished task."

Overall, we found that the ideal usage of Mindful moments is closely tied to users' need for recovery from a prior task. This need varies widely from person to person, depending on each unique situation. Decisions to take a break are also influenced by the individual's perceived performance of their previous task, an insight closely aligned with that of Bosch and Sonnentag's [10].

6.4 Behavior change intervention

Participants alluded to Mindful Moments as a potential intervention for behavioral change. For instance, P14 found over multiple sessions that Mindful Moments replaced her previously automatic habit of social media feed scrolling in her free time, especially before sleeping. She expressed that the 5-min activity supported her in "breaking out of her night time routine of watching TikTok videos", in turn improving her sleep quality. Given that the everyday use of smart-glasses will likely increase in the near future [35], mindfulness practices on OHMD can function as a tool to provide more "space" and "distance" from habitual behavioral patterns, helping users break away from unwanted habits.

6.5 Design Recommendations

The perceived time-cost and situational requirements (e.g. quiet environment) associated with traditional types of mindfulness practice acts as a barrier to the initial adoption and continuity of mindfulness practice. Furthermore, mindfulness interventions often require recorded or live instructions from a trained teacher. Without guidance, practices tend to be less accessible to the novice practitioners who may not have built a foundation of mindful-awareness [25]. We leverage the advantages of the OHMD platform and set out in our study to design a system that provides in-the-moment breath guidance for practitioners as a means of addressing these pain points.

For future designers, we consolidate properties for breath-based audio-visual designs that we have found desirable in our studies, and provide pointers on how such a system could be used by practitioners.

6.5.1 Audio-visual design. Our overall finding is consistent with extant literature that combining visuals with audio can deepen mindfulness practice and enhance mindfulness effects. Visuals and audio work symbiotically to support the mindful function.

(1) Animated visuals are especially useful for initiating users into the practice of breath regulation, guiding them to breathe rhythmically. It is also helpful for re-initiating distracted users back into the breath-based practice. The following properties are desirable for visuals:
   (a) The visualization should be converted into abstract form, instead of kept as a realistic naturally-occurring object. For example, an image of a Sun could be abstracted into a circular shape. Users are more likely to interpret and analyze familiar and realistic objects, thus, abstract forms are more suited for supporting mindfulness practice.
   (b) The animated visualization should strike a balance between showing sufficient detail but not too much complexity; well-balanced details in visuals are more aesthetically pleasing and can capture the attention of the user without distracting them out of a mindful state. A good guideline would be to use a 2-dimensional shape that has outlines, no color fills, as well as some basic inlines (refer to Pilot 2 for our example of the Geometric figure).
   (c) The expand-contract motion is suitable to signal changes in inhales and exhales, and should be visually clear such that users are easily able to distinguish between the expansion and contraction of the object.
   (d) In keeping with past investigations, slower, controlled breath rates of between 6-10 beats per minute, with a 1:2 ratio of shorter inspiration followed by longer expiration is suitable for breath guidance.
(2) The audio track is particularly important for guiding users to maintain their breathing pattern once they have eased into the practice. Turning to the audio as a background guide frees up their eyes, allowing them to place more visual attention on the external environment as opposed to the OHMD screen when walking.
   (a) Man-made or natural sounds can be used depending on the user's personal preference, though the track should include two key components: sustained sounds that give rise to a sense of smooth uninterrupted flow to the mindfulness activity, and cue sounds that are rhythmically synchronized to the visuals.
   (b) The cue sound should be pleasant instead of jarring in tone, repeated rhythmically according to the breathing pattern, such that it can signal changes from inhale to exhale and vice-versa.

6.5.2 Using Mindful Moments. Mindful Moments is best used after mentally draining tasks, and after long periods in sedentary positions. However, the physical and mental benefits of Mindful Moments reduces when participants are already previously engaged in physically strenuous activities. Designers should choose to initiate the mindfulness practice at opportunistic moments, rather than abruptly stop users in the middle of an ongoing task. When moments are wisely selected, Mindful Moments can boost productivity on subsequent tasks, though it can also disrupt the work flow when implemented at inappropriate moments. Advantageously, our study has shown that even a brief Mindful Moments session of 5 minutes could boost mindfulness in users. Its accessibility and reduced time-costs will hopefully encourage regular mindfulness practice among everyday users.

In its current iteration, Mindful Moments runs via a tethered AR headset setup, where it is wired to an iPad. While this cabled connection allows for a faster, more reliable and secure connection [33], it can also be awkward for users to carry an iPad during the activity. We envision that future iterations provide a more seamless experience, where a kiosk system automatically starts the application when the user turns on the wireless OHMD, and external smart-devices can be removed from the setup.

6.6 Limitations & Future work

Mindfulness is a complex and multidimensional construct, which can be conceptualized as a long-term trait (i.e., a mindful capacity or mindfulness as a way of being), or a momentary state (i.e., a mode of mindfulness that a person becomes in a particular moment of time) [92]. Given the main focus on one-session effects in our study, we have only looked at state mindfulness as opposed to trait mindfulness. To fully comprehend and evaluate the effectiveness of Mindful Moments, future investigations should aim at tracking long-term changes over regular usage. This ensures that mindfulness designs satisfy both state-or-trait aspects of mindfulness. Improved trait mindfulness as a result of consistent Mindful Moments practice suggests that the design is able to facilitate an internalization of mindfulness, such that users are able to maintain higher levels of mindfulness and therefore well-being in their daily lives. We also believe that Mindful Moments can be integrated into daily scenarios other than casual walking. Future studies can explore how similar audio-visual design principles can be extended to a wider range of daily activities involving repetitive movement, such as when OHMD wearers are exercising.

Novelty effects accompanying the initial use of Mindful Moments may have also influenced the results in this paper. Previous works [56] have suggested that there are two ways in which designs help users enter mindful states: via extrinsic processes (e.g., guided audio instructions) and via intrinsic, more self-reliant processes (e.g., by using a simple timer) which tend to fade into the background and does not require users' constant attention. Since the latter type also works in the "background", users of such technologies may not rely as much on the novelty of design in order to stay mindful. For Mindful Moments, feedback from participants suggest that its primary function is to initially guide users into mindful breath regulation, and its secondary function is to help users return to the breath upon distraction or mind-wandering (refer to Discussion section). In between, the maintenance of breath regulation is facilitated by sustained-cue function of the audio, which requires minimal attention from users, allowing users to focus on other activities such as path navigation. Mindful Moments thus achieves the purpose of being an initial guide to mindfulness, subsequently moving into the background of users' attention. In this sense, the need for novelty after multiple uses may be lessened. Future works should also investigate the longer-term effect of technologically-assisted designs like Mindful Moments, to evaluate if it improves self-sufficiency in breath-based mindfulness practice, such that long-term users may transitionally move to a walking meditation even without the OHMD for instance.

In addition, our pilots and experiments were all carried out in an indoor environment. This controlled for changing weather and light conditions and was thus a more suitable environment for mindfulness practice. We note that visibility issues on the OHMD may be more prominent in outdoor environments due to natural lighting [31], and for this reason, future research can include testing in outdoor environments. The focus on indoor environment usage also limits the generalizability of our study to other real-life environments and activities, which may more specifically be linked to safety concerns. Our results indicate that when users are walking indoors in a relatively uncrowded environment, they benefit from the use of Mindful Moments while navigating their environment safely and without issue. However, in highly complex navigation scenarios (i.e., crossing roads or navigating a crowded place outdoors), the use of Mindful Moments may prove unsafe. Hence, we recommend using Mindful Moments while performing less intensive mobility tasks, though future studies can expand into different environmental contexts, so as to gain insight on effective OHMD mindfulness designs for situations involving other activities besides walking as well as more complex mobility tasks.

Another limitation of our study is that it is based on a moderate sample size of younger adult participants from the university community. While the overall study has revealed significant results, and could benefit from additional replications to enhance the scientific validity of our results [12]. Future studies can address this limitation by expanding the demographic and age criteria.

7 CONCLUSION

This study contributes an investigative analysis of breath-based mindfulness practice on OHMD in casual walking settings. Over four pilot studies, we explored various visual and auditory factors that influence mindfulness effects and user preference. These factors included the abstract or realistic representation of visuals, visual dimensionality and complexity, as well as the rhythmic function and naturalness of sound. We then evaluated the combined design, Mindful Moments, in a within-subjects study, comparing it with the state-of-the-art Walking Meditation and Control walking condition. As indicated by results on sustained attention performance, mindfulness state scores and physiological measures, we found that Mindful Moments performs comparably to Walking Meditation. Finally, we showed that Mindful Moments can facilitate mindfulness practice effectively in realistic settings, such as during a typical work day at the office. Based on our findings, we also provided recommendations for future designs of OHMD- and breath-based mindfulness practice. Easily integrable into casual moments of the day, our proposed design supports individuals under time or environmental constraints who wish to improve their overall well-being through mindfulness practice.

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