SLEEPJ, 2020, 1–4

doi: 10.1093/sleep/zsaa178
Advance Access Publication Date: 4 September 2020
Letter to the Editor

LETTER TO THE EDITOR

When sleep goes virtual: the potential of using virtual reality at bedtime to facilitate sleep

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In the digital health era, the accessibility and advancements in virtual reality (VR) technologies (e.g. high-resolution head mounted displays, high frame rate, wide stereoscopic binocular field of view, and low latency), have turned the spotlight on VR as an emerging revolutionary diagnostic and therapeutic approach for several disorders, including phobias, depression, post-traumatic stress disorder (PTSD), and acute and chronic pain [1, 2].

VR could be considered a computer-generated simulation of a physical world, acting through immersion (level of sensory fidelity provided by a VR system) and presence (the user's subjective and phenomenological response to a VR system). These elements lead to a sense of "being there" in the VR place (place illusion) and to the belief that events in VR are really happening (plausibility illusion) [3]. VR systems provide the capability for designing and controlling simulated interactive environments, which can be used to modulate one's emotional state and physiology [4]. For example, in healthy undergraduates, Riva et al. [5] showed that even short exposure (about 3 min) of participants to anxious, relaxing, and neutral VR environments led to pre-to-post-immersion changes in participants' mood. Relaxing environments elicited greater perceived quietness and happiness and reduced anger, sadness, anxiety, and negative affect than neutral VR; opposite changes were detected after anxious environments, with the sense of presence being implicated in the participants' emotional experience.

While the majority of VR systems are designed for entertainment (e.g. gaming), the use of VR is growing within the health space. Initial studies of VR have shown promise in advancing the understanding of mental health disorders and to elicit specific therapeutic effects (e.g. VR exposure-based therapy for treating specific phobias, anxiety disorders, and PTSD; VR-based imagery rehearsal for nightmares; and VR as a distracting tool for acute and chronic pain) [1, 2]. For example, McNamara et al. [6] found that 4 weeks of use (twice each week) of an immersive VR intervention (ReScript) involving the manipulation of threatening images (to make them less threatening and improve mental control over the image) led to pre-to-post-intervention changes in perceived anxiety, nightmare distress, and psychosocial impairment due to nightmares, in 19 adult men and women reporting frequent nightmares.

While still in its infancy in the health field and requiring research and validation, we argue that VR has the potential to be useful as a clinical tool to promote sleep, facilitating the falling asleep process in those individuals with difficulties initiating sleep (e.g. sleep-onset insomnia). VR could work by distracting and immersing the user at bedtime in simulated relaxing realities designed to induce and control specific changes in mood and physiology that lead toward sleep-facilitating psychophysiological levels.

Falling asleep is a complex process characterized by several psychophysiological changes that are still not fully understood in the context of healthy sleep or insomnia. Indications of cortical and autonomic physiologic upregulation and cognitive and affective hyperarousal around sleep onset are frequently observed in individuals with insomnia [7]. For example, studies have reported elevated cognitive activity (worries, intrusive thoughts, rumination, and elevated anxiety)

[8], pre-sleep cortical (elevated high-frequency EEG activity), metabolic (elevated brain and whole-body metabolism), and autonomic (high heart rate, blood pressure, and cardiac sympathetic tone) activity [9] in people with insomnia compared with good sleeper controls. However, not all studies have replicated these findings, with some instead reporting overwhelming interindividual differences in physiological measures of hyperarousal [10]. Interventional studies suggest that modifying the bedtime state can alter subsequent sleep quality: Acute pre-sleep psychophysiological stress delays sleep onset and worsens sleep quality both in healthy sleepers and insomnia sufferers [11]. On the other hand, bedtime relaxation protocols appear to facilitate sleep onset and improve sleep [12, 13]. For example, one study found that when people with insomnia were instructed to imagine interesting and engaging, but also pleasant and relaxing situations (imagery distraction), sleep-onset latency was shortened and the discomfort associated with pre-sleep unwanted thoughts was reduced [8]. Emerging mind–body practices (e.g. mindfulness) may also reduce sleep initiation problems by targeting pre-sleep arousal [14].

Within this framework, VR has the potential to serve as a distractor for moving an individual's mind away from worry, rumination, negative cognition, and anxiety. It is also possible that a relaxing sleep-suitable VR experience could induce a relaxed state, and thus facilitate sleep initiation. In a pilot

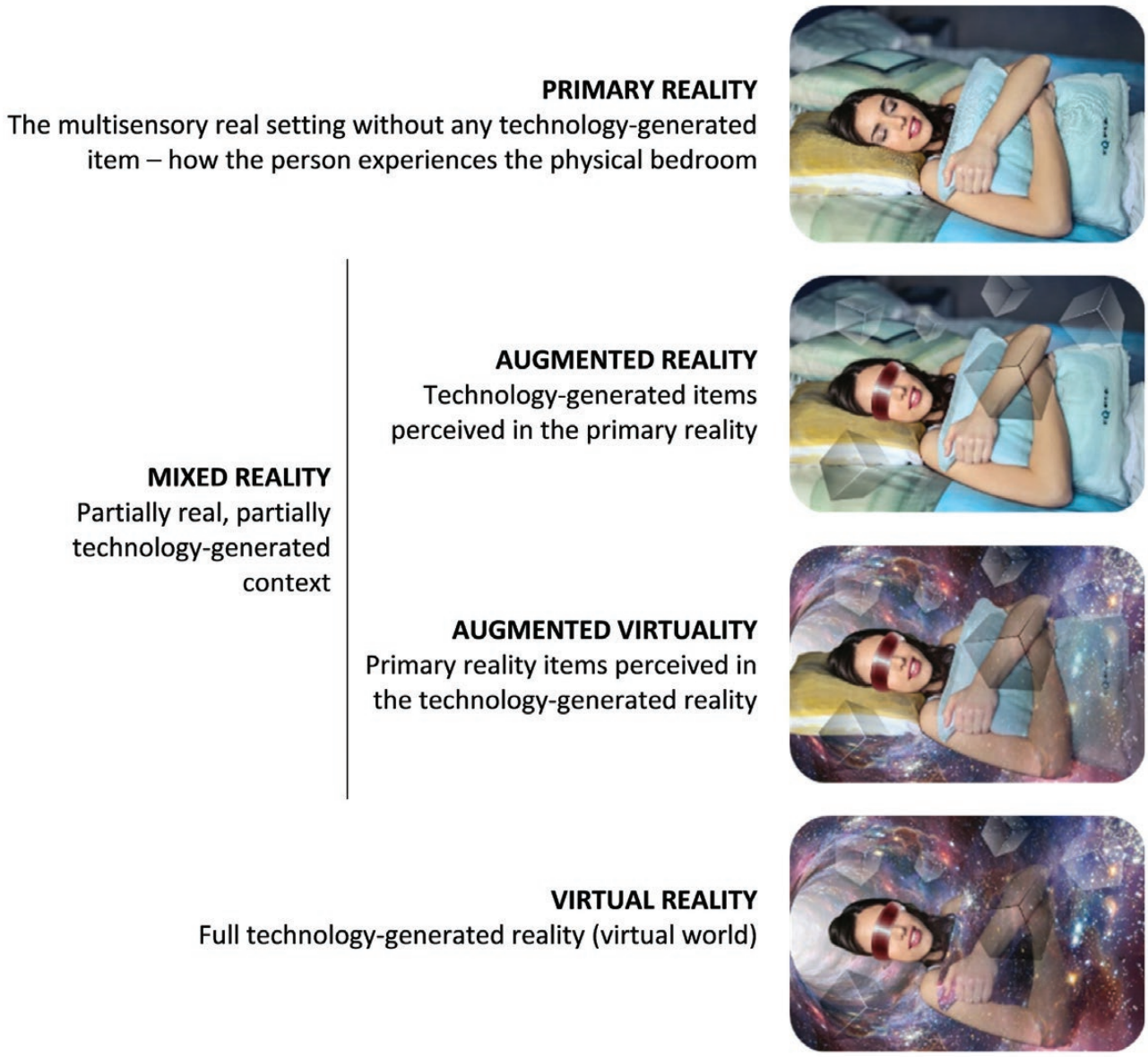

Figure 1. Schematic representation of the experience of falling asleep in subjective (primary, "individual's bedroom") and external technology-generated augmented reality, augmented virtuality, and virtual reality. The immersion in technology-generated realities usually involves immersive visual and immersive auditory experiences, or even tactile and olfactory experiences, and thus it could be suitable to accommodate the biobehavioral dynamic of the falling asleep process, in which a person usually transitions from eyes-open to eyes-closed states. A person could begin relaxing by receiving the full virtual reality sensory experience, and switch to a different sensory experience when closing their eyes (e.g. immersive audio only), until they fall asleep. Also, bedtime light exposure can be controlled, and blue light-filtering technology easily integrated, reducing the impact of blue wavelengths on melatonin secretion.

study of 16 women suffering from insomnia symptoms (most with difficulty falling asleep), we showed that being immersed in a relaxing environment (provided via HD visual/audio immersive technology) while performing slow diaphragmatic breathing across the sleep-onset period, reduced bedtime physiological arousal (a reduction in heart rate of about 5 bpm and increases in total heart rate variability) [13]. The intervention also resulted in fewer nocturnal awakenings, less sleep fragmentation, and lower heart rate during sleep compared with no intervention [13]. While this implementation suggests that VR could be applied to help individuals fall asleep, either directly or via enhancing the relaxing effect of paced breathing, the underlying mechanisms and extent to which VR may directly contribute to these effects are unclear, and further research is required.

Across the falling asleep period, an individuals' biobehavioral dynamics, level and content of consciousness, sensory thresholds, and processing change. We argue that several strategies used to facilitate sleep relate to some form of distraction and the attempt to immerse oneself in an "alternative reality" in the context of relaxation. Reading a book, visual imagery, and listening to relaxing environmental sound all involve some partial movement into an alternate reality. The careful application of VR-related technology has the potential to achieve an even greater movement away from an environment (primary reality) to which poor sleep may have become a conditioned response. One conceptualization of how this might work is to view different technologies as enabling a person to move along a continuum from full awareness of the actual physical reality through increasing levels of immersion and presence to a complete acceptance of a different "virtual" reality, hitherto only available in dreams or perhaps hallucinations (self-generated VR). With the development of appropriate sleep-promoting interfaces, technologies on this continuum could involve augmented reality, augmented virtuality or a full computer-generated VR [15] (Figure 1). Whether it will ever be possible to completely remove our anchor to the physical world when experiencing a simulated VR environment while falling asleep, remains an open question, however, these different forms of virtual technology open up the possibility of different applications in clinical sleep medicine and research to investigate and modulate an individual's experience and the psychophysiology of the falling asleep process.

Current work has only scratched the surface in using VR as a potential sleep facilitating tool. Implications of falling asleep in virtual realities require further discussion, and comparisons are needed with the gold-standard treatment of insomnia (cognitive behavioral treatment for insomnia [CBTi]) and with other sleep-promoting bedtime mind–body relaxation techniques (e.g. deep breathing, progressive muscle relaxation, visualization, and guided imagery techniques) to determine mechanisms (e.g. determining whether autonomic, cognitive, and emotional pathways are involved) and efficacy of VR-based interventions. In a direct comparison, CBTi was shown to lead to larger improvements in subjective and objective sleep outcomes compared with progressive muscle relaxation training [16]. A recent exhaustive metanalysis of randomized controlled trials concluded that full CBTi as well as its individual components, including relaxation techniques have large effect sizes (Hedges $g > 0.56$) for the treatment of insomnia, with relaxation alone working particularly well for shortening sleep-onset latency [17]. Authors recommend that more high-quality research is needed to compare different treatment components with one another [17], a recommendation that should also be applied to any emerging VR-based sleep interventions. In particular, future work should carefully examine efficacy of individual components of any VR-accentuated relaxation procedures to determine whether the VR component does indeed add value. A possibility that should also be explored is that the immersive experience of VR could improve the engagement of an individual with other techniques, thus enhancing their efficacy.

Further work is also needed from a technology standpoint if VR is to be applied as a sleep-facilitating tool accessible to patients in different communities and regardless of socioeconomic status. The current state of VR technologies poses several challenges for adoption, including its high cost, which limits accessibility and scalability, and questions around the form factor of VR headsets, which are not yet suitable for sleep. If these barriers can be addressed, further investigations into VR applications in the sleep field (e.g. insomnia treatment, pre- or mid-sleep VR exposure-based therapy for PTSD) could open new lines of research and future possibilities for the treatment of sleep disorders.

Funding

This study was supported by the National Heart, Lung and Blood Institute (NHLBI) grant R01 HL139652 (M.dZ.). The content is solely the responsibility of the authors and does not necessarily represent the official views the National Institutes of Health.

Conflict of interest statement. The authors declared no conflict of interest related to the current work. M.dZ., F.C.B., and I.M.C. have received research funding unrelated to this work from Ebb Therapeutics Inc., Fitbit Inc., International Flavors & Fragrances Inc., and Noctrix Health, Inc. I.M.C. is a member of the board of Forest Devices.

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