Co-designing mind-body technologies for sleep with adolescents.

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Abstract

Sleep is critical for well-being, yet adolescents do not get enough sleep. Mind-body approaches can help. Despite the potential of technology to support mind-body approaches for sleep, there is a lack of research on adolescent preferences for digital mind-body technology. We use co-design to examine adolescent perspectives on mind-body technologies for sleep. From our analysis of design sessions with 16 adolescents, four major themes emerged: system behavior, modality, content, and context. In light of these key findings, we recommend that technology-based mind-body approaches to sleep for adolescents be designed to 1) serve multiple functions while avoiding distractions, 2) provide intelligent content while maintaining privacy and trust, 3) provide a variety of content with the ability to customize and personalize, 4) offer multiple modalities for interaction with technology, and 5) consider the context of adolescent and their families. Findings provide a foundation for designing mind-body technologies for adolescent sleep.

Introduction

Sleep is critical for the overall health and well-being of children, yet only 35% of children (ages 4 months to 14 years) in United States get sufficient sleep[1]. The rate of sleep problems increases with age, with studies showing that 73% of high school students do not get sufficient sleep[1]. Poor sleep and lack of sleep have been linked to adverse outcomes in adolescents, including poor cognition, psychosocial health, cardiometabolic health, and obesity[2,3]. Hence there is a need for interventions that target sleep in adolescents.

Mind-body approaches that focus on the interaction between mind, body and behavior (e.g., yoga, breathing exercises, meditation) have been shown to help treat sleep disorders and aid in sleep self-management in adolescents[4–7]. Mind-body approaches may improve sleep through several mechanisms including increased mind-body awareness, self-regulation, acceptance, and attention control[8,9]. Many existing mind-body approaches for youth have been delivered in person[10], in group settings[5], and in schools[6,11]. Yet each of these options have challenges. In-person and group sessions are expensive, have high drop-out rates, and are not accessible to all adolescents[5,10,11]. Additionally, delivery of mind-body approaches in school has been met with challenges including implementation and training, and are not available widely[12]. Digital technology has the potential to support learning and practice of mind-body approaches. A technology-based approach could deliver mind-body approaches digitally to adolescents making them readily portable, accessible, and scalable[13] and easier to integrate into daily lives and bedtime routines.

Despite the potential for technology to support mind-body approaches[13,14], there is very little work in technology-based mind-body interventions for adolescents in general[14,15] and even less focused on adolescent sleep[5]. A scoping review of mind-body approaches for adolescent sleep by Garbers et al found that only one of ten studies utilized technology to deliver the mind-body approach to adolescents[5]. Over the last decade, there has been increased focus on research on digitally mediated mind-body practices to support mind-body approaches for sleep but most of these have focused on adults[16]. For example, there has been a focus on supporting mind-body approaches through apps[8,17,18], interactive technologies like virtual reality[19,20], and intelligent chatbots[21]. The commercial mobile app space also has been flooded with mindfulness apps for adults. Systematic review of mindfulness-based apps have shown that a majority of apps are non-evidence based and even when scientific evidence supporting their effectiveness exists it is only for adult population[18] Thus, adolescents are left to use mind-body technology that are not specifically designed for their needs and preferences. Even though we know little about adolescent preferences for mind-body technologies for sleep systematic reviews of digital interventions for mental health have shown that adolescents prefer features like video, limited text, the ability to personalize, ability to connect with others[22]. However, an explorative review of 29 mental health apps from the app store for adolescents (including 7 that offered mindfulness exercises) demonstrated that there is an incompatibility between youth preferences and how apps deliver content [23]. The authors state that "*Youth mental health promotion apps did not appear to align with young people's preferences. Instead, young people*

are presented with a myriad of apps with minimal functionality." (p.12).[23] Yet one limitation of this review was that adolescents were not directly consulted about app design. Instead, youth preferences were indirectly inferred from the opinions of youth psychologists and literature[23]. Talking with adolescents to understand their preferences can help inform the design of tools that better meet their needs.

Digital tools work best when they are designed considering the needs of target users[24]. Prior research with technology-based mind-body interventions in adolescents shows poor engagement and adherence[14,15]. For example, Lahtinen et al found an app-based mindfulness intervention demonstrated efficacy in reducing anxiety and depression in adolescents yet had a high attrition rate of 41%[14]. Similarly, Antonson et al found in a study of an internet-based intervention for adolescents that only 20 of 282 participants (7%) logged on to the internet intervention and only one participant completed the entire intervention[15].

Given the potential of mind-body approaches to improve sleep for adolescents, there have been calls to engage adolescents to understand their needs, interests, and preferences in mind-body technologies[25]. Yet, there is a lack of knowledge about how adolescents think about mind-body technology and how to design mind-body technologies in ways that meet their preferences. We conducted a study to address this gap using the principles of co-design.

Participatory design and co-design are methods commonly used in human-computer interaction (HCI) research when designing technologies, including those used by children and adolescents. Participatory design prioritizes the perspective of adolescents by voicing their needs and preferences in the design of technology[26,27]. Druin states that "*the better we can understand children as people and users of new technologies, the better we can serve their needs (p. 2)*[26]. Cooperative Inquiry (CI) is a co-design method grounded in HCI research and theories of cooperative design, participatory design, contextual inquiry, activity theory, and situated action[27]. In CI method youth and adults are considered as equal and equitable design partners[26,27]. CI allows researchers to collect rich data from youth and has been used in the design of various technologies, including intelligent surfaces[28], social robots[29], and conversational agents[30]. CI involves a collection of design methods that can be adapted to best fit a research team's needs[31]. CI encourages practices that create equitable interactions and balance the power structure between adults and children in the design process. Practices include adults and children addressing each other on a first-name basis, eating snacks together, sitting at the same level for activities, and using informal language[26,27]. We focus on early adolescence (ages 10-15 years) as that is a key development phase where adolescents foster skills in self-regulation[32] and carry new skills to adulthood. Moreover, many adolescents are early adopters of technology and are interested in using technologies to support their mental health and wellbeing[33].

Methods

The purpose of this co-design study is to describe adolescent perspectives on mind-body technologies for sleep. Our study design is based on the concepts of CI by Druin, in which co-design participants are considered experts in their knowledge domain and children are treated as equals to adults in the design process[27]. Following the CI approach, we conducted two 60-minute virtual co-design sessions with 16 adolescents with pre- and post-surveys (Figure 1). All research procedures were approved by the University of Washington Institutional Review Board.

Figure 1. Study Design

Recruitment

Inclusion criteria for participating were: 1) adolescents between the ages of 10-15 years, and 2) having interest and/or experience in using mind-body approaches. We recruited a convenience sample of participants via two methods. The first recruitment method was to contact parents of adolescents who previously participated in a randomized control trial testing a mind-body approach intervention with adolescents who have sleep problems[34]. We distributed study flyers to parents of adolescents who completed the trial and consented to be contacted for future studies. The second method of recruitment was to distribute study flyers to parents of adolescents through professional networks (e.g., university parenting listservs). Parents of adolescents were invited to contact the study team after screening to provide consent and study enrollment. The adolescents provided assent for their participation in the study.

Pre-survey

We asked adolescents to complete a pre-survey that included demographic questions (i.e., age, sex, race, ethnicity), their experience with technology, and their experience with mind-body approaches.

Co-Design Sessions

We conducted two design sessions remotely over Zoom. One research team member moderated each session (SS) and other members helped and participated in session activities (ML, NR, SXR, LZ). Each design session consisted of three parts based on the principles of CI: ***social time, design activity, and discussion***. First, social time allowed for the participants to arrive, get settled, and interact to build rapport. We then asked a "question of the day" before introductions. The question of the day was open-ended, easily answerable by participants, and was used to level the power dynamic between adolescents and adults[35] who participated in the session. Second, we focused on one design activity per session. Finally, during the discussion, the entire group reflected on their experience of the design activity.

Design Session 1 (DS1, August 2022): The goal of DS1 was to elicit information regarding adolescents' opinions on existing technologies for learning and practicing mind-body approaches for sleep. We began DS1 with ***social time*** by asking the adolescent participants to type their names and the name of the last book they read in the chat (question of the day) before starting introductions. For the ***design activity***, we used Line Judging[35,36] in which we asked the adolescent and adult research participants (members of the research team) to share their opinions on selected technologies for mind-body approaches. Line judging is a technique used to support children in evaluating multiple designs in an engaging way and when conducted in person it allows children to vote on a spectrum (i.e., from "really like" to "really dislike") using their bodies[35]. We modified the procedure to accommodate the online space by asking participants to type their votes in the chat window[36]. From a selection of technologies identified in literature review and available commercially, we presented five categories used for mind-body approaches for sleep: apps, smart speakers, smartwatches, other wearables (e.g., headbands, headsets, sleep masks), and standalone bedside devices (e.g., portable speakers). For each technology, we provided a short description of how it can support learning and practicing mind-body approaches for sleep. After each description we asked the participants to share their vote in the chat window as "Really Like", "Really Dislike" and "Not Sure" and then share the reason for their vote. Participants also had the option to change their vote if their opinion changed during the design activity. At the end of the design activity, we asked participants to pick their favorite option of all the technologies presented. Finally, we concluded DS1 with a ***discussion*** to hear about participants' experience with the design activity and to identify any additional technologies that could help participants learn mind-body approaches for sleep.

Design Session 2 (DS2, September 2022): The goal of DS2 was to ask adolescents to design their own technology to help them learn mind-body approaches for sleep. We used a modified online Comicboarding technique[36] where adolescents create a story together. Using Google Slides we provided templates with stock images and emojis that participants could 'drag and drop' into the comicboard. The emojis were chosen based on literature and prior work by the team. Adult researchers (members of the research team) looked up images online if needed. We began the session with

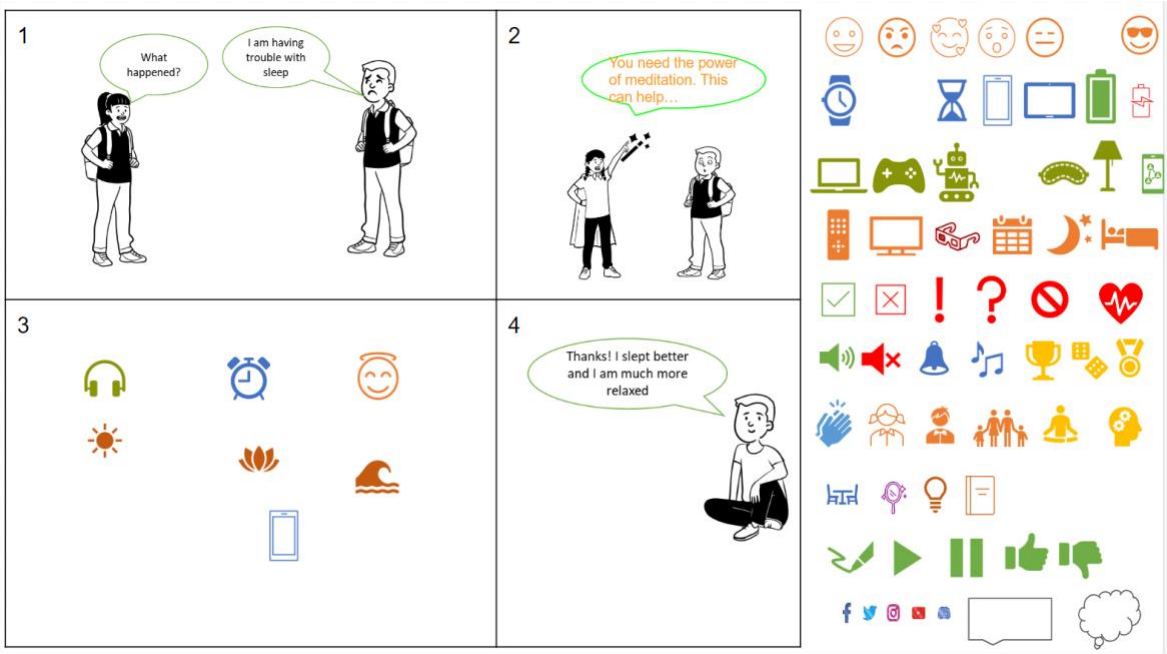

Figure 2. Comicboard completed by participant P1. Comic board (left) and emojis (right). Box 3 of the comic board was empty for adolescents to fill in.

social time by asking the adolescents to describe their day using stock images and emojis from a sample slide (question of the day). The intent was to familiarize participants with the Google Slides functions such as 'drag and drop'. Next, for the ***design activity***, we created two smaller groups to design a technology for mind-body approach for better sleep. We provided the adolescents with a scenario as a starting point (Figure 2) and asked them to complete box 3. First, we asked adolescents to comicboard individually. Subsequently, each group was asked to comicboard together. After that, the groups rejoined and one adolescent from each group presented their group's comicboard to everybody in the session. In the discussion to conclude DS2, we asked participants to share their opinions about the designs presented.

Post-survey

After DS2 the first and second authors (SS, ML) met to identify the main design ideas from the comicboards presented during the session. We then created an anonymous online post-survey that included 6 mind-body technologies designed during DS2 (Table 1). The survey asked the adolescents one open-ended question for each of the 6 design ideas: "What do you like or dislike about this idea?"

Table 1: Summary of mind-body technologies designed during DS2

Mind-body Technology	How can it help with mind-body approaches for sleep?	Additional features
1. An app for a phone 	• Plays audio such as guided meditations, nature sounds, and calming music	• Reminds youth to do mind-body approach regularly • Tracks one's heart rate and sleep • Gives youth rewards and badges • Works without the need for internet
2. A smart speaker 	• Talks and interacts with youth • Guides youth through mind-body approaches	• Contains a variety of mind-body activities • Designed with cool shapes and colors • Asks questions like: "*Good Morning, do you want to listen to a breathing exercise?"*
3. A fidget ball/cube 	• Offers multiple options and approaches to support mind-body activities to calm down	• Uses soft material(s) • Uses appealing color(s)
4. A neck speaker 	• Plays guided meditations near one's ear to listen to and fall asleep	• Has buttons to play, pause, and control volume • Allows comfortable overnight wear, even if you lay on your side
5. A virtual reality headset 	• Plays guided meditation and music while showing calming pictures	• Can be designed to be lightweight
6. A robot 	• Talks and interacts with youth • Guides youth through meditation while also playing music	• Includes a variety of voices • Learns the routine and makes suggestions: "*I noticed you didn't sleep well yesterday – try this meditation today.*"

Data Analysis

We describe pre-survey data using descriptive statistics. After completing the design sessions, the first author (SS) transcribed the Zoom recordings. The recordings consisted of approximately 350 minutes of video data (excluding social time). A subset of co-authors (SS, ML, NR, SJX) analyzed the data, which included the participants' line judging votes, chats, discussions, comic board artifacts, and post-survey responses. We used affinity diagramming, an inductive approach used to organize ideas into themes and concepts[37]. To create the affinity diagram, the co-authors iteratively grouped the data into themes using sticky notes. The co-authors met multiple times to refine the themes.

Results

1. Participants

Sixteen adolescents ages 10-15 years participated in two virtual design sessions (Table 2). Twelve participants completed both sessions and four participants completed only one session. All 16 participants completed the pre-survey, and 12 participants completed the post-survey. Most participants reported regularly using smartphones (10/16) laptops and laptops (11/16). Participants had experience with breathing exercises (8/16), relaxation approaches (7/16), meditation (6/16), and yoga (6/16). Participants described learning these approaches from their parents (7/16) and school (4/16). While 7/16 participants reported using YouTube for practicing and learning mind-body approaches, 6/16 reported not using any technology to practice and learn mind-body approaches.

Table 2: Participant Characteristics

	n=16 (%)
Sex	
Male	7 (47%)
Female	9 (53%)
Race	
White	10 (63%)
Asian	2 (13%)
Other	4 (25%)
Ethnicity	
Not Hispanic/Latino	16 (100%)
Mind-Body Approach Experience	
Less than 6 months	6 (38%)
About 6 months to a year	2 (13%)
Greater than a year	4 (25%)
Have never practiced	4 (25%)

2. Considerations for designing mind-body technologies for adolescents' sleep

Four themes emerged that reflect participants' perceptions about mind-body technologies for adolescent sleep: 1) Expected system behavior, 2) Modality, 3) Content, and 4) Context.

2. 1. Expected System Behavior: What do adolescents expect from mind-body technologies?

Participants expected mind-body technologies to be multifunctional, to be distraction-free, to be privacy- and trust-enhancing, and reflect intelligence.

Multifunctional*:* Adolescent participants preferred technologies that supported multiple mind-body approaches more than technologies that supported only one mind-body approach. As P16 indicated: "*It* [a smartwatch] *helps with sleep, activities, physical and mental activities to be specific. And it's just like a phone on your wrist.*" Similarly, P11 liked an app for mind-body approaches: "*There are lots of options. You can play music, or you could listen to something which is talking about how it helps you sleep.*" P1 described a multifunctional device that involved different senses and practices: "*Maybe it also like is a light and maybe it also makes sound machine noises and maybe it also has like lots of different types of meditation or mind practices and, maybe it would give more motivation to actually get into it.*"

Distraction-free: Even though participants preferred multifunctional technology, they were also concerned about being easily distracted by functions unrelated to mind-body practices. P15 summarized preference with wearables: "*They* [wearables] *are definitely a lot less distracting because there's not like a screen that you can touch or get distracted or you're using an app that you're not supposed to.*". Multiple participants were particularly wary of distractions on smartphones. P14 remarked: "*You could also get distracted like you could go to email. You could start watching like YouTube, not what you're supposed to do*." Additionally, P8 shared: "*I dislike that it could tempt the user to get on the device*."

Privacy- and trust-enhancing: Participants highlighted their distrust toward unknown brands and the importance of privacy. When discussing wearables, P6 stated: "*I trust, like Apple and Google…but it is just like these companies that are making these weird, these random I don't know, like headband things. It just… doesn't feel right."*

Participants were also concerned about the technology tracking them and invading their privacy. P10 liked standalone devices because "*it doesn't feel like a robot is watching me sleep*." Similarly, P1 said: "[It's] *weird that they* [technology] *can understand what I'm thinking... they can track things about me…they know how to calm me down. They are just creepy.*"

Reflect intelligence: Participants were interested in technologies that understood the participant and responded intelligently. When talking about designing a robot P11 imagined: "*I think it will be cool if the robot kind of interacts with me, depending on my mood and asks' how is your day'. And I reply, 'I'm tired'. It will be cool if the robot replies*

'Maybe try this [mind-body activity] *today. This can help you."*" Similarly, P1 talked about a robot that could track sleep patterns: "*It's good, like when it tracks my breathing and then also maybe like my sleep then I can like track my progress and maybe see what I need to do.*" Participants also talked about their annoyance when technology was not intelligent. P7 shared their experiences with existing technology: *"I often get irritated after attempting to use a smart speaker for mind-body approaches because I often have to repeat myself or ask it several times. And it is more difficult in my opinion because it is not as easy to specify what I would like*."

2. 2. Modality: What modality would adolescents use to interact with mind-body technology for sleep?
Participants included a variety of input and output modalities for interacting with the mind-body technologies.

***Input*:** Speech and touch were the most common modalities participants preferred for interacting with mind-body technologies. Some participants described fidget cubes and physical buttons on devices like wearables and neck speakers. Some participants preferred voice interactions due to its convenience and ease of use. P7 said about smart speakers: *"I just like how I don't really have to do anything except talk to it."*

***Output*:** Participants mentioned a wide variety of output modalities including voice, sounds, visuals, and videos for mind-body technologies for sleep. Some participants expressed interest in having a voice guide them through meditation. P7 suggested an app or podcast that would provide "*just guided meditations. And maybe some breathing exercises."* Adolescents also mentioned a variety of preferred sounds, including "*rain sounds"* (P7), "*white noise"* (P16), "*calming music"* (P7), *"relaxing music"* (P13), and *"lo-fi, music with no words"* (P16). Lastly, P11 described what they might see while using a virtual reality headset: "*I think it should be like pictures that you see, calming pictures that you think are calming*."

2.3. Content: What content do adolescents prefer in mind-body technologies?
Participants envisioned that mind-body technologies could offer personalized and customized content, rewards, reminders, and content that is cost- and ad-free.

Personalized and customized: Participants preferred that technologies provide them with a variety of mind-body content tailored for them. Participants also expressed the preference for personalized support for many mind-body approaches that could "*guide you through the meditation*" (P12), "*calm all your thoughts*" (P12), and "*be a stress reliever*" *(P5).* P1 talked about an intelligent smart speaker named "Anna" in their design that recognized the participant and provided a personalized mind-body approach for the participant: "*Hey Anna, let's do this type of meditation. Or maybe it'll ask me, 'What, what meditation would you like to do?"*" Participants also preferred the ability to customize a voice, music, and colors. For example, P14 felt that a mind-body technology "*should have lots of different voices and varieties so that you don't have to just listen to one thing like if you don't like it, or if it's like annoying, you can like, change it*." Similarly, P15 talked about customizing a wearable device: "*I like it because it seems that there are a lot of different* [mind-body activities] *that you can choose from.*"

***Rewards*:** Participants indicated an interest in receiving rewards to stay motivated. P1 indicated interest in receiving rewards for "*achievement cause like it keeps, it brings you back. A lot of times, if I'm working towards something, I have a lot of motivation to go back and continue and do then I can get farther along. And then like I get them* [rewards]. *It's a sense of like accomplishment and like pride.*" Similarly, P4 appreciated rewards as motivation: "*I think it would help if there was some sort of incentive. I'm not sure how you'd be able to do that on an app. But maybe you get some sort of reward for doing enough lessons, or, if you like, keep up the streak of doing the mindfulness lessons for a certain amount of days sort of like on 'Duolingo.'"*

Reminders: A common challenge that participants indicated with practicing mind-body approaches was remembering to do the mind-body activity regularly. Some participants wanted the technology to provide reminders and notifications. When talking about wearable devices P14 remarked: "*I bet you'd forget to do it* [mind-body approach]. *Well, if you had your like phone or computer or a smartwatch, and it sent like notifications you'd remember to do it, and you'd save time for that.*" P8 talked about how smartwatch reminders could help: "*The notifications can remind me during the day, whenever I need them, and help me when need them. And when I don't*."

Cost- and ad-free: Participants also shared their feelings about cost and advertisements on existing smartphone apps. P13 talked about the extra cost to eliminate Spotify ads: "*You can get premium. And if you don't have premium, then those ads. So I can see how it could be a little annoying if like you're just like listening* [mind-body approach] *and then all of a sudden like an ad comes on.*" P10 also indicated that ads can be annoying: "*Sometimes you are listening to really great music, and it just says,' Do you want car insurance?'"*

2.4. Context: What is the importance of context in designing mind-body technologies?

When considering mind-body technologies for sleep, participants indicated that they should be able to use the technology without disturbing other sleeping family members, without relying on the internet, and without sacrificing comfort. Adolescent P4 imagined "*something near the head so it's not noisy for other people*" and felt that smart speakers "*can be too distracting for other people sleeping*." Participants also talked about the ability to use technology without the internet as P10 indicated "*It doesn't have to connect to the internet like Audible, or if you're still listening to some music, then you can pause and play it even if there's no internet*".

Adolescents indicated their preference for comfort if the technology is worn during sleep. As P14 remarked, a "*headset would be a nice idea, but it might be a little uncomfortable to sleep with. But if there was a way to make it so that it was like comfortable when you sleep. That would be a good idea*." Similarly, P4 said: "*I like to listen to it* [mind-body approaches] *on headphones, but I always find that when I'm trying to fall asleep the headphones are very uncomfortable because I don't sleep on my back. So maybe some device that would just make it more comfortable to listen to the podcast and sleep, or, you know, lie on your side*." Even with devices that were on their bedside participants preferred technology that was comfortable to sleep next to as P16 stated: "*It* [standalone devices*] just doesn't look very pleasant to sleep next to I guess.*"

Discussion

Given the promise and need for digital mind-body approaches for adolescent sleep, there is a lack of knowledge about adolescents' perspectives on the design of mind-body technologies. Through co-design sessions grounded in CI principles, four themes emerged that reflect participants' perceptions about designing mind-body technologies for sleep: 1) Expected system behavior (multifunctional, distraction-free, privacy- and trust-enhancing, and reflect intelligence, 2) Modality (variety of input and output modalities), 3) Content (personalized and customized content, rewards, reminders, and content that is cost- and ad-free), and 4) Context (consider adolescent context at bedtime). Our findings, based on perspectives of adolescents, carry implications for the design of digital mind-body technology for sleep in adolescents.

First, adolescents had expectations about how mind-body technologies might behave. Adolescents preferred technologies that support multiple activities and functions rather than a separate technology just for the mind-body approach. Yet at the same time, adolescents were concerned about being distracted by devices that support multiple functions, particularly smartphones. Research on adolescent concerns about distraction by technology is lacking. There is extensive literature on the concept of media multitasking or task switching where adolescents multitask with different devices or between media and other activities there is very little work investigating the concept of adolescent switching between different activities (e.g. different apps) on a single media or 'task switching'[38,39]. Previous work with adolescents has shown that adolescents multitasked with their smartphones and switch to different apps due to notifications, messages, social media prompts, or boredom with a particular activity[39]. Central to learning and practicing mind-body approaches is developing self-regulation. Experts suggest that self-regulation that arises out of learning mind-body approaches can transfer to other aspects of daily life including technology use and task switching[9]. Future work could explore the relation between self-regulation and task switching in the context of digital mind-body approaches for sleep among adolescents.

Second, adolescents had expectations about the intelligence and accuracy of mind-body technology for sleep. They preferred to interact with highly intelligent technology. Their expectations of advanced intelligence are consistent with prior literature regarding adolescents' interactions with conversational agents[30] and augmented reality[39]. Adults' experiences with using artificial intelligence-enabled conversational agents for mind-body approaches such as Wysa have shown promise[18,21]. Wysa, an emotionally intelligent chatbot, detects negative moods of users and suggests mindfulness exercises to relieve stress[18]. While some users of Wysa had good experiences, some users expected the chatbot to understand them better and to avoid repeating themselves[18]. Future work could explore how intelligent technology can be leveraged to deliver mind-body technology for adolescent sleep.

Third, adolescents shared their feelings about trust and privacy of mind-body technology. Adolescents' concern for privacy of mind-body technology is consistent with prior literature on children and "creepy technologies"[41] and social robots[29]. Similar to prior work, participants in our study did not discuss concerns about data mining or identity theft[41]. Instead, their concerns focused on distrust of brands, tracking, and lack of privacy. Future research could explore how adolescents' perspectives on privacy and trust influence their engagement with mind-body technologies.

Fourth, adolescents talked about their preference for mind-body technology having different modalities. Indeed, research with mind-body approaches on smartphone apps has shown that these tools have very limited interaction options[23]. Future work might explore further adolescents' interaction preferences and modalities and engagement with mind-body technologies for sleep.

Fifth, adolescents indicated a preference for specific content in mind-body technologies. Adolescents want to customize and personalize the mind-body technology experience. This supports prior research that personalization and customization are important factors for engagement with technology for adolescents[22]. Other studies suggest that existing mental health apps for youth offer very low customization and choice[16,23]. Thus, future work should further explore adolescent preferences for content and design. Additionally, the adolescents were interested in rewards and reminders to practice mind-body approaches. Previous research has demonstrated that features like gamification and reminders increase engagement and sustained technology use[42]. Yet mindfulness teachers and experts believe that principles of mindfulness are process-oriented and are not aligned with achievement-oriented features like rewards or games[44]. Future work is needed to explore these tensions.

Finally, adolescents acknowledged that mind-body technology for sleep should fit well within their context and daily lives. Solutions should reduce disturbances to family members who may be sleeping, work without internet, and be comfortable to wear or sleep next to at night. Our findings iterate the call for design supporting family-centered informatics[45] that takes into account family and adolescent activities, routines, and norms. Further work is needed to understand the challenges families face in helping foster healthy routines including practicing mind-body approaches for adolescents as they increasingly gain independence around sleep and media use habits.

In light of these key findings, we recommend that technology-based mind-body approaches to sleep for adolescents be designed to: 1) serve multiple functions while avoiding distractions; 2) provide accurate and intelligent content while maintaining privacy and trust; 3) provide a variety of content with the ability to customize and personalize; 4) offer multiple modalities for interaction with technology; and 5) consider the context of adolescents and their families. Research has shown that there is a lack of fit between adolescent preferences and technologies designed for youth[23]. Our findings provide a summary of adolescents' perspectives that may improve the fit between the design of mind-body technology and youth preferences for mind-body technologies.

Despite the rich data collected in our study, there are limitations. First, the adolescents did not interact with or perform mind-body approaches with the technologies during co-design sessions. Since we conducted the sessions remotely, while we solicited their initial reactions to a selection of technologies, we were not able to capture their impressions on the usability of existing commercial mind-body technologies. Future research should explore the usability of existing mind-body technologies for adolescents in the context of improving sleep. In addition, we recruited a convenience sample of participants from one metropolitan area in the USA and the adolescents' economic, social, and cultural backgrounds were fairly homogenous. The results are not generalizable. Lastly, four adolescents did not complete the study after DS1. Our next step is to extend the scope of this research by recruiting a larger more diverse sample of adolescents with various levels of experience with mind-body approaches (intermediate to expert) to explore their perspectives. Another future direction is to evaluate the feasibility and effectiveness of a digital mind-body tool designed for sleep with adolescents. Despite these limitations, this study has several strengths including using co-design that directly engaged adolescents to obtain their detailed preferences on digital mind-body technology for adolescent sleep.

Conclusion

Given that mind-body approaches have been found to reduce sleep problems in adolescents and that existing design guidance for digital mind-body tools only addresses adults, our findings fill a gap in better understanding the perspectives of adolescents. Adolescents expressed preferences for system behavior, modality, content, and context of digital mind-body sleep interventions. Mind-body technologies that are designed to meet these needs and preferences have the potential to improve sleep among adolescents. Future work should explore the transferability of these findings in a larger group of participants.

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