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Usability of an augmented reality bedtime routine application for autistic children

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ABSTRACT

Sleep problems are highly prevalent in autism and negatively impact the physical and mental health of children and their caregivers. Sleep education programs are often recommended as a first line-treatment to help parents implement healthy sleeping habits and a bedtime routine at home; however, the accompanying paper-based toolkits used in the bedtime routines have limitations related to engagement and adherence. To address these gaps, we iteratively developed and tested the usability of an augmented reality (AR) bedtime routine application. Our single participant design study ($n = 7$ child/parent dyads) found 86% compliance with the program and suggested good-excellent usability of the app with a trend toward increased willingness and faster completion of children's bedtime routines. This work supports the feasibility of using technology-based tools in sleep education programs and informs future clinical studies examining the effectiveness of these approaches for mitigating sleep difficulties.

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KEYWORDS
autism; augmented reality; children; sleep difficulty; usability

Introduction

Autism spectrum disorder (ASD; hereafter "autism") is a neurodevelopmental condition defined by differences in social communication and the presence of intense interests and/or repetitive behaviors (Psychiatric Association, 2013) with a prevalence of 1 in 36 (Maenner, 2023). Several medical and psychiatric conditions often co-occur with autism and can negatively impact daily function and lead to distress. Among these, sleep difficulties are highly prevalent and affect 44%-83% of children (Buckley et al., 2020; Richdale, 1999). These difficulties can include initiating and maintaining sleep, frequent and prolonged night waking, irregular sleep patterns, shortened sleep duration, and early wakings (Richdale, 1999). These difficulties occur across the range of intellectual ability (Richdale, 1999; Richdale & Schreck, 2009) and age (Hodge et al., 2014; Vargason et al., 2019). These challenges can negatively impact both the children and their caregivers and lead to decreased physical and psychological health and quality of life (Delahaye et al., 2014; Mannion & Leader, 2014; Medic et al., 2017; Meltzer, 2008). Poor sleep has also been associated with daytime behavioral and social challenges (Malow et al., 2014). While the nature of sleep difficulties in autistic children may be similar to non-autistic children, the factors contributing to these difficulties may be different (Lord, 2022). Further, bidirectional interactions between autism features and sleep difficulties have been reported (Roussis et al., 2021). For example, for some autistic children, behavioral features, such as difficulties with self-regulation, transitioning from preferred to non-preferred activities, and communication may contribute to difficulties in implementing positive bedtime behaviors (Malow et al., 2014).

Considering the prevalence and impact of sleep difficulties, there is a significant need for effective interventions. To this end, the first-line of intervention is often behavioral strategies delivered through parental education programs (Buckley et al., 2020; Morgenthaler et al., 2006; Rigney et al., 2018; Taylor & Roane, 2010). These programs (see Loring et al., 2016, 2018; Malow et al., 2006) focus on educating parents about healthy sleep practices and supporting the development and execution of these practices (Malow et al., 2014). A key component of sleep education programs is a bedtime routine or a series of activities that prepare a child for bed. These routines are often depicted as a paper-based visual schedule that is used by parents and children.

Promising evidence is emerging to support the effectiveness of parental education programs (Cuomo et al., 2017; Johnson et al., 2013; Papadopoulos et al., 2019; Vriend et al., 2011); however, adherence and motivation to complete the program components at home (e.g., the bedtime routine) still remain significant challenges (Hayes et al., 2010; Malow et al., 2014).

Objectives

To address the above gaps, we developed a technology-based approach to support the implementation of the bedtime routine visual schedule. We hypothesized that a technology component can help improve adherence and motivation to complete the bedtime routine in a timely manner. Digital screen media,

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including tablets, are highly prevalent in homes, are enjoyed by children, and accepted by families (Cardy et al., 2021). In the area of sleep education, there is encouraging evidence to support the acceptability, feasibility, and effectiveness (Quante et al., 2019; Werner-Seidler et al., 2019) of smartphone-based applications for the general pediatric population. These apps (e.g., Sleep Ninja (Quante et al., 2019; Werner-Seidler et al., 2019) feature training sessions, sleep tracking, recommended bedtimes, reminders to start a wind-down routine, and a series of sleep tips and general information about sleep. However, to our knowledge, there are currently no sleep applications designed for autistic children, specifically with a visual schedule format. In addition to developing the app, we conducted a study to evaluate its usability ("Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (*ISO 9241–11:1998(En), Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) – Part 11: Guidance on Usability*, 1998). Poor usability is a key contributor to low use or abandonment of health apps (Torous et al., 2018), and as such usability testing is a critical component of technology evaluation.

Methods

App design

The Bedtime Routine Application ("app") was designed through an iterative process of feedback from clinicians and families (see Supplementary Figure S1), including five parents of autistic children, a nurse delivering sleep education for families of autistic children, an occupation therapist, and a board-certified behavioral analyst. Based on these consultations, three principles guided the design of the app: (1) The app should be delivered on a device that is readily available to families; (2) The app should allow for the personalization of the sensory and language content, and (3) The app should be engaging for children, but non-stimulating to prepare the child for bedtime.

For the technology component, we developed an augmented reality (AR) application, delivered through a tablet, to enhance the implementation of the bedtime routine. AR superimposes a computer-generated image on the user's view of the real world through the user device's camera, and on the screen. This feature allows the child to follow the bedtime routine in real-time and at home in an engaging manner (Escobedo et al., 2014; Kim et al., 2014). Mixed Reality (MR) technologies, including AR, are increasingly gaining traction as a medium for delivering interventions in autism (Parsons et al., 2000). In the context of a bedtime routine, AR is a promising technological medium for the implementation of a visual schedule since it can digitally overlay the routine tasks and prompts on top of the corresponding physical objects in the user's environment. Recent literature reviews (Khowaja et al., 2020; Marto et al., 2019) suggest that AR can provide an effective intervention delivery medium to address skills in various domains including social skills, attention, academic learning, and understanding facial expressions and emotions (Marto et al., 2019). The application was developed using the Unity game engine (*Unity Technologies*). The application is intended for use with tablets to increase affordability (versus head-mounted displays).

App features

The main application screen shows a camera-view of the user's environment with the visual schedule superimposed on this view (Figure 1a). A virtual character guides the user through the visual schedule through movement across the screen and verbal prompts. Once a task is completed, the caregiver presents the child with a completion card (Figure 1b) to display in front of the tablet camera. Once the application detects the

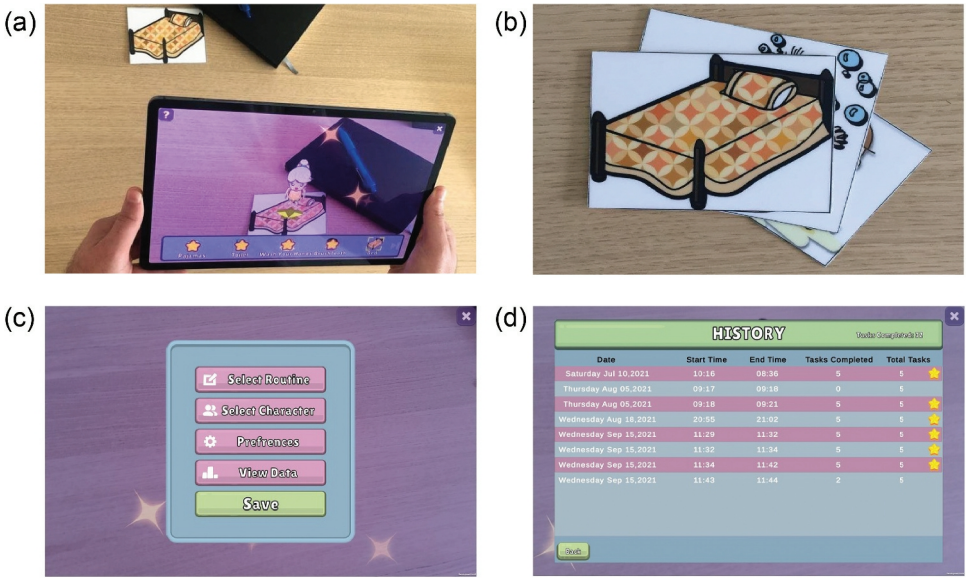

Figure 1. The App. (a) A user's perspective of the bedtime routine App. When the appropriate card is detected in the camera's field of view, a star appears above the card, the virtual character appears to pick it up, and the task is marked as complete; (b) the task cards used in conjunction with the bedtime routine App. Each bedtime task has a corresponding task card; (c) the settings menu of the app allows the customization of bedtime tasks, characters, as well as sensory, audio, and language preferences; (d) the "view data" menu allows the user to view their bedtime routine history.

completion card, a star appears on the screen and the virtual guide glides across the screen to collect this reward. Once all tasks are completed and the stars are collected, the virtual guide goes to bed and asks the user to do the same. The screen then slowly fades to black and the bedtime routine ends.

The sensory environment consists of calming background music together with stars floating across the user screen. The application settings page (Figure 1c) allows for customization of the bedtime routine tasks (choice of up to five tasks), the character (choice of animated human or animal), language complexity of the character commands and instructions (high and low demand), and sensory environment (sound volume, amount/intensity of floating star visual effect, and background music (choice of two)). App use and progress through the application are logged by the app and the data are accessible through the use history feature of the app (Figure 1d).

User study

To characterize the usability and the families' experiences of the app, we conducted a single-participant, AB design study. Phase A consisted of a 5-day baseline period where participants completed their usual bedtime routine (no app). In Phase B, participants used the app for 14 days to complete their bedtime routine. Ethics approval was obtained from the Research Ethics Board at Holland Bloorview Kids Rehabilitation Hospital. Electronic informed consent and assent were obtained from children and parents remotely over Zoom for Healthcare video conferencing (Zoom & PIPEDA/PHIPA Compliance Guide, n.d.) and using REDCap electronic data capture tools (Harris et al., 2009, 2019).

Participants

We recruited seven parent-child dyads for this study ($n = 7$ children, $n = 7$ parents) from the Autism Sleep Education Program at Holland Bloorview Kids Rehabilitation Hospital. All participants met the following inclusion criteria: a community diagnosis of autism, 3–8 years of age, ability to communicate in English, and parent-reported difficulties with falling asleep.

Study protocol

Following consent, parents were asked to complete demographic and sleep questionnaires online using REDCap and were mailed the study tablet loaded with the Bedtime Routine App. Participants were provided with instructions on how to use the Bedtime Routine App and the tablet. Upon receipt of the study tablet, participants received a brief check-in e-mail to provide them with the tablet passcode and a reminder to record their child's baseline sleep habits for five days before they start using the Bedtime Routine App (including what time they went to sleep, how long it took them to complete their bedtime routine, and their willingness to go to sleep each night reported on a five point Likert scale). Following the five day baseline period, participants were asked to use the Bedtime Routine App each night for two weeks. Parents were asked to continue to document sleep habits each night of Bedtime Routine App use. At the end of their routine each night in the Bedtime Routine App, children were prompted to answer a single yes/no question that asked if they enjoyed using the Bedtime Routine App. After two weeks of use, parents were asked to complete a usability questionnaire as well as the sleep questionnaire using REDCap. Parents also completed a semi-structured debrief questionnaire over Zoom (see Supplementary 6).

Measures

App usability was quantified through the Mobile Application Rating Scale: User Version (uMARS). The uMARS is an adapted version of the MARS (Mobile Application Rating Scale) and has shown excellent internal consistency (alpha = .90) (Stoyanov et al., 2016). The uMARS questionnaire consists of 20 items, which are rated on a 5-point Likert scale (1= Inadequate, 2 = Poor, 3 = Acceptable, 4 = Good, 5 = Excellent). The uMARS has five subscales: engagement (entertainment, interest, customization, interactivity, target group), functionality (performance, ease of use, navigation, gestural design), aesthetics (layout, graphics, visual appeal), information quality (quality/quantity, visual information, credibility of source) and subjective quality (would you recommend the app, how many times would you use the app in the next year, would you pay for the app, overall star rating) (Stoyanov et al., 2016). The uMARS subscale also includes an additional 6 items (awareness, knowledge, attitudes, intention to change, help seeking, behavior change) to measure the user's perceived impact of the evaluated app. Supplementary Table S1 provides an overview of each item (5-point Likert scale; 1 = Strongly disagree to 5 = Strongly agree).

Adherence (usage) was calculated as the percentage of nights where at least one bedtime routine task was completed through the application. This was computed based on data from the automatic tablet logs which recorded the start and end of each app session as well as the name of the tasks completed. Responses from the debrief questionnaire were used to further characterize the experiences of the families and add context to the uMARS scores. As secondary measures, we collected the length of the bedtime routine and the child's willingness to complete the tasks. These were collected through parent-reported nightly logs recorded using a paper diary. We also asked the caregivers to complete the Child's Sleep Habit Questionnaire (CSHQ) before and after app usage. Although our study design does not permit conclusions on the clinical efficacy of the app as an intervention, this measure can inform the design of future efficacy studies.

Analysis

Responses from the demographics questionnaire were used to characterize the sample, sleep habits, and the families' previous experiences with technology. Descriptive statistics (reported as mean and standard deviation (SD), unless stated otherwise) were computed for the responses to the uMARS questionnaire. Caregiver logs were used to compute the length of the bedtime routine and characterize willingness to complete the routine. Interview notes recorded by two reviewers were used to

identify usability themes and gain insight into the uMARS responses.

Results

Participant characteristics

Table 1 shows the demographic characteristics of participants, their history of sleeping difficulties and interventions, and their experience with technology (for further details on participants' prior technology experience, see Supplementary Table S2). Participant 1 was a four-year-old boy who enrolled in the study with his mother. He did not have a history of sleep interventions or a set bedtime routine prior to the study but had difficulties falling and staying asleep. His skill level with technology was the ability to open applications from a mobile device's home screen. Participant 2 was a five-year-old boy. He participated with his father, and did not have a set bedtime routine or a history of sleep intervention, but had difficulties falling asleep. In terms of skill level, this participant was also able to open applications from a home screen. Participant 3 was an eight-year-old boy. He participated with his mother, however, he also spent time in his father's household. His mother completed questionnaires, but the debrief interview was conducted with both parents. Participant 3 had a set bedtime routine and had difficulties falling and staying asleep. He did not have any prior sleep interventions. His technology skills included opening different applications, recording a video, and playing different video games on a mobile or tablet device. Participant 4 was a seven-year-old boy who enrolled in the study with his mother. He had a history of taking medications (Seroquel, Trazodone, and Melatonin) to help with falling and staying asleep. He also had a set bedtime routine. His technology skills included opening different applications, and recording a video with a mobile or tablet device. Participant 5 was an eight-year-old girl who enrolled with her mother. She had difficulties in going to sleep and staying asleep and did not have a history of sleep intervention. She had a set bedtime routine. Her technology skills included opening different applications, recording a video, and playing a video game on a mobile or tablet device. Participant 6 was a six-year-old boy and enrolled with his mother. He had a set bedtime routine, was not taking any medications, and had no history of interventions for their difficulties going to sleep, falling asleep, or staying asleep. His parent reported he was sensitive to loud noises, and his technology skills included opening different applications, recording a video, and playing a video game on a mobile or tablet device. Participant 7 was a three-year-old boy with a bedtime routine, who participated along with his mother. He had a set bedtime routine, difficulty falling and staying asleep, no current medications or history of sleep interventions, and his technology skills included actions like opening different applications and recording a video.

Adherence

On average, participants used the application for 11.29 ± 4.50 days over the two weeks. Participant 1 skipped a total of five nights of use due to reasons unrelated to the app (family situation). Participant 3 skipped the app for two nights as the child fell asleep earlier than usual. Participant 4 abandoned the app after two nights due to a lack of interest in the app and perceived demands of using the app. Participant 5 used the app for all 14 days; however, the parent only reported 3 days of use due to a misunderstanding in filling the questionnaires. Willingness logs were completed retrospectively for this participant. Participants 2, 6, and 7 used the app every day.

Usability

The overall and individual uMARS scores are shown in Figures 2 and 3, respectively. Data are reported in Supplementary Table S3, for reference. The overall app quality (mean score across the four objective quality subscales: engagement, functionality,

Table 1. Participant characteristics.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	Participant 7
Sex	Male	Male	Male	Male	Female	Male	Male
Gender	Male	Male	Male	Male	Female	Male	Male
Age (years)	4	5	8	7	8	6	3
Responding caregiver	Mother	Father	Mother	Mother	Mother	Mother	Mother
Diagnoses	Autism	Autism	Autism, ADHD, DMDD	Autism	Autism	Autism	Autism
History of sleep interventions	No	No	No	Yes (medications)	No	No	No
Child has a set bedtime routine	No	No	Yes	Yes	Yes	Yes	Yes
How often does the child need to be reminded to do bedtime routine tasks?	Always	Often	Often	Often	Often	Always	Rarely
Does the child have any sensory sensitivities?	Yes: Sounds and textures	Yes: Loud noises	Yes: Sounds	No	Yes: Light and sound	Yes: Loud noises	Yes: Touch and movement
Does the child have difficulties going to sleep?	Yes	Yes	Yes	Yes	Yes	Yes	No
Does the child have difficulties staying asleep?	Yes	No	Yes	Yes	Yes	Yes	Yes
Bedtime: Weeknights	21:00	23:00	20:00	20:00	21:45	19:45	19:45
Bedtime: Weekends	22:00	23:00	21:00	20:00	22:30	19:00	19:00
Participant's technology use (hours/day)	3	3	4	6	5	2	1
How much does your child like technology?	Likes	Likes	Likes very much	Likes very much	Likes very much	Likes very much	Likes very much

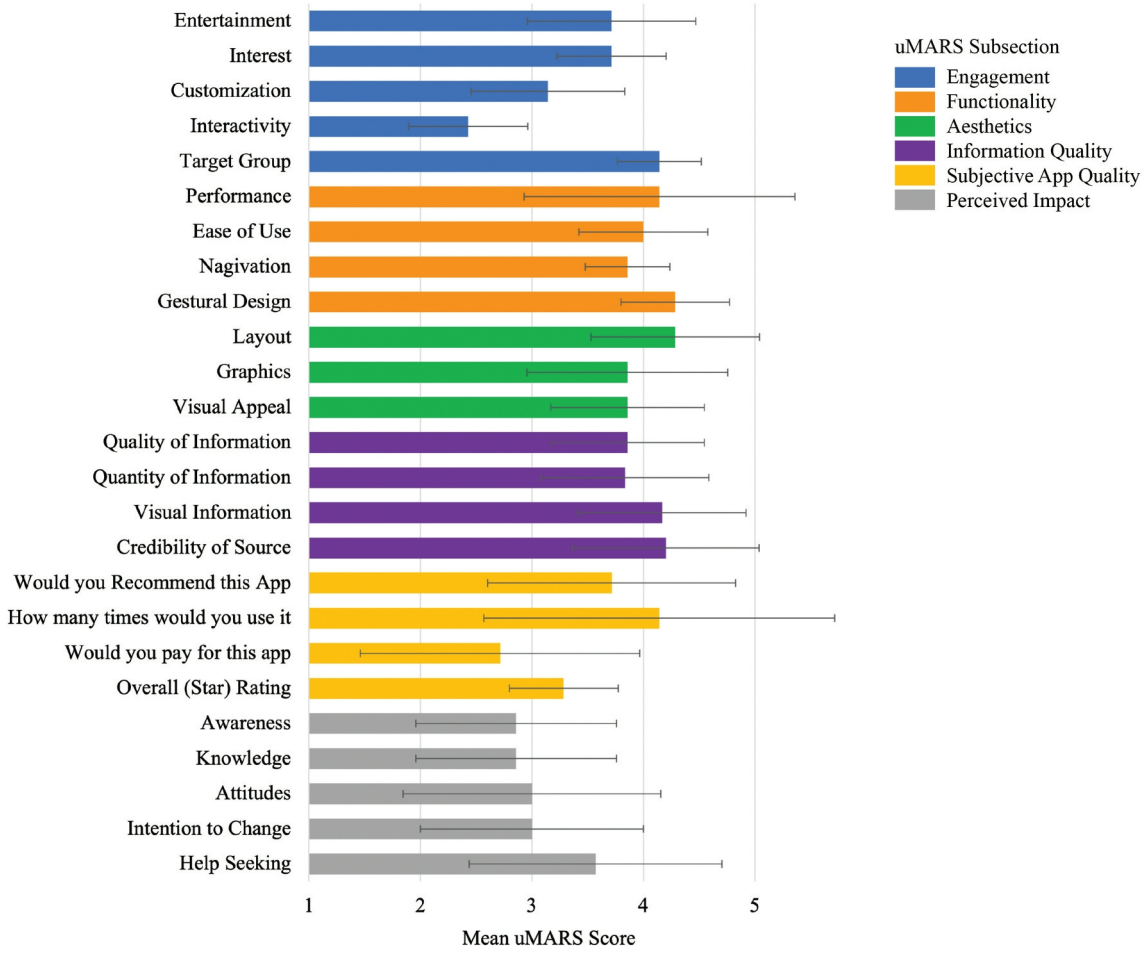

Figure 2. Mean uMARS item scores. Columns represent the mean for each item across participants. Error bars represent standard deviation.

aesthetics, information quality) was acceptable (3.87 ± 0.42). Parents' feedback during the debrief interviews (see Supplementary Tables 4 and 5) is used to contextualize the uMARS ratings below.

Engagement

Across participants, the engagement subscale received a mean rating of acceptable (3.43 ± 0.39; includes entertainment, interest, customization, interactivity, and target group). Five participants found the app entertaining and interesting to use; however, two participants (Participants 3 and 5) indicated that interest level waned after the first week of use. All participants enjoyed scanning the reward cards and found the task helpful, except for Participant 4 who found the cards increased the task demands, and most enjoyed the level of engagement the app brought to their bedtime routine. Regarding customization, the debrief interviews revealed that some of the families did not know about some of the customization options while others would prefer greater levels of customization. Parents reported that greater customization and complexity of the app were areas for improvement (see Supplementary Table S5). The lowest scores for the engagement subscale were received for interactivity. This item probed features such as user input, reminders, sharing options, and notifications which did not exist in this app.

Functionality

A mean rating of good was received for the functionality subscale (4.07 ± 0.53; includes ratings of performance, ease of use, navigation, gestural design). Further probing functionality, five families indicated that they had no difficulties navigating the app. Participants 2 and 5 found it difficult to hold the tablet and position the camera. Participant 3 provided the lowest functionality scores and highlighted four challenges: 1) occasional difficulties scanning the cards due to lighting conditions or background texture, 2) an error when cards were scanned too quickly, 3) the lack of a "back" button for the visual schedule, and 4) slow movement of the character across the screen.

Aesthetics

A mean rating of good was received for the aesthetics subscale (4.00 ± 0.61; includes layout, graphics, visual layout). Caregiver interviews revealed that participants found the layout, graphics, audio, and visuals of the application appealing (see Supplementary Table S4). All the participants strongly liked the AR aspect of the application, with four participants commenting on how integrating the familiar real-world environment into the app aesthetics was appreciated by their children.

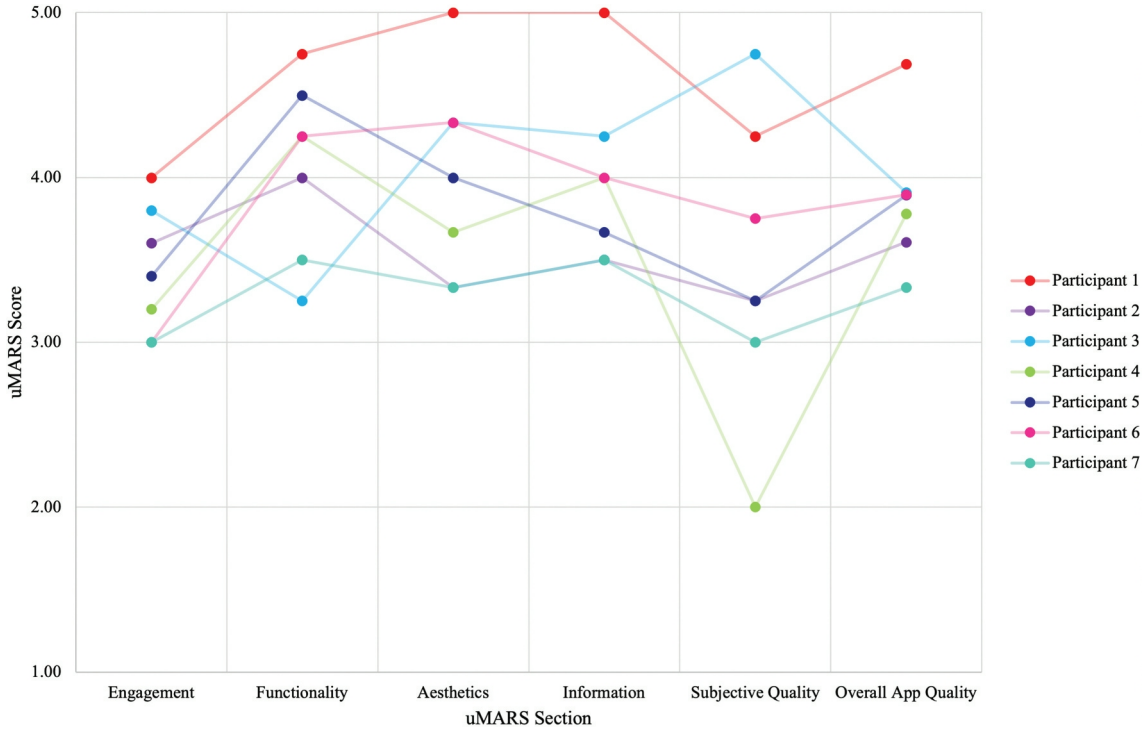

Figure 3. Mean uMARS subscale scores (engagement, functionality, Aesthetics, information, and subjective quality subscales, and overall app quality) for each participant.

Information

A mean rating acceptable was received for the information subscale (3.99 ± 0.53; includes information quality/quantity, visual information, credibility). Four participants found the visual information and the explanation of concepts as good or excellent. During the debrief interviews, all participants found the app setup instructions clear and easy to follow.

Subjective app quality

A mean rating acceptable was received for the subjective app quality subscale (3.46 ± 0.89; includes items of would you recommend, how many times would you use it, would you pay for it, star rating). Four participants indicated that they would use the app more than 50 times in the next year, if relevant to them.

Perceived impact

A mean rating of good was received for the perceived impact subscale (3.10 ± 0.28). Consistent with our hypothesis, the interviews revealed that the main effect of the app was to help children and families complete their bedtime routine faster. During the interview, parents indicated that they saw meaningful and practical benefits including introducing consistency into the bedtime routine, faster completion of the routine, and increased motivation for completing the routine. Some parents suggested expanding the app to include other types of routines (e.g., morning routine), and to allow for creation of more task types to make it suit their needs (see Supplementary Table S5). Three participants suggested that the app could be more valuable for younger children (six years or less).

Likeability

In response to the question prompt "Did you Like this App?" presented to the child participants at the end of their bedtime routine each night, all participants selected "yes" every night of use except for Participant 4 who did not select a response.

Table 2. Parent-reported duration of participants' bedtime routine during the baseline (days 1–5) and intervention (days 6–19) periods. Duration reported as mean and standard deviation (SD), in minutes.

	Length of Routine (minutes)			
	Baseline		Intervention	
	Mean	SD	Mean	SD
Participant 1	49.00	29.24	34.44	12.10
Participant 2	12.25	2.63	3.77	0.93
Participant 3	32.00	8.37	20.42	8.11
Participant 4	94.00	45.61	115.00	49.50
Participant 5	19.00	8.22	25.83	8.78
Participant 6	55.00	8.66	44.00	8.61
Participant 7	52.00	7.58	40.93	19.11

Table 3. Participants' parent-reported willingness to go to bed, reported on a 5-point likert scale (1: not at all willing, 2: not willing, 3: neutral, 4: willing, 5: very willing), reported as mean and standard deviation (SD).

	Willingness to Go to Bed			
	Baseline		Intervention	
	Mean	SD	Mean	SD
Participant 1	3.00	1.00	3.00	1.00
Participant 2	2.00	1.15	4.00	0.00
Participant 3	2.00	0.00	2.77	1.42
Participant 4	2.25	1.50	2.33	1.15
Participant 5	2.80	0.84	3.67	0.58
Participant 6	3.60	0.55	3.93	0.62
Participant 7	4.00	0.00	3.62	0.77

Impact on sleep habits

Length of routine

Participants' reports of bedtime routine length suggested a trend toward a decreased routine length for nearly all participants (Table 2). The results for Participants 4 and 5 are difficult to interpret due to missing data (see Supplementary Figure S2). Note that prior to participation, parents of Participants 1 and 2 reported that their children did not have structured or consistent bedtime routines; rather, these children carried out various bedtime tasks unsystematically each night. For these participants, the duration of the baseline bedtime routine was reported as the total length of time from when they started getting ready for bed each night until they were finished. For the intervention period, parents of Participants 1 and 2 selected up to five bedtime routine tasks for their child in an order of their choosing and measured the total length of the bedtime routine in the same manner as during baseline.

Willingness to complete routine

During the debrief interview, six of the seven families indicated that the app helped their children complete their bedtime routine. For Participant 4, the parent indicated that the app added an additional step/expectation to their bedtime routine that the child did not like. Table 3 presents participants' willingness to complete their bedtime routine as documented each night during the baseline and intervention periods (also see Supplementary Figure S3). In line with what was reported during the debrief interviews, there was a trend toward increased willingness during the intervention period for four of the six participants (Participant 2, 3, 5, and 6).

Sleep outcomes

Reduced bedtime resistance following app use (compared to baseline) was reported on the CSHQ for Participant 1, 3, 4, and 6 (see Figure 4).

Discussion

In this study, we examined the experiences of seven families with an AR app to support the home implementation of a bedtime routine for 4 to 8 year old autistic children. Six out of the seven families in our study (86%) completed the two-week intervention period, a completion rate comparable to other sleep education programs for autistic children (70.0% (Malow et al., 2014) – 80.0% (Malow et al., 2016). From a technical perspective, no major challenges were reported by participants, supporting the feasibility of using AR technology on widely available tablet devices at home.

One of the most challenging aspects of designing the app was to ensure a balance between excitement and engagement and the need for calmness before bedtime. Our data also support the feasibility of using a technology-based intervention at bedtime as none of the participant families reported difficulties with removing the device after the bedtime routine was completed. This is encouraging given the theoretical concerns around the negative impact of screens on sleep and the anticipated challenges with the removal of a highly motivating stimulus (screen) before bedtime.

Participant responses suggested acceptable to good usability for the bedtime routine app developed. The high scores on functionality support the feasibility of using AR-based technologies in home environments. AR is a relatively new technology that may be unfamiliar to many families, particularly younger children. Despite the fact that some of the children in our study did not have high proficiency with technology, all families were able to learn and use the app without major difficulties. The app also received high scores on the aesthetics subscale, supporting the appropriateness of the layout and graphics. Participant interviews revealed a preference for the AR-based visual schedule over the paper-based version citing increased motivation and engagement. This is also supported by the high likability of the app expressed by the children in this study. Future studies are needed to directly compare paper-based and screen-based visual schedules.

High ratings were also received for the quality and quantity of information. This is likely due to the iterative consultations with clinicians (sleep educators, occupational therapist, behavioral analyst) as well as families during the development of the app and its content. While the app focused on the visual schedule component of a sleep education program, with the goal of augmenting existing clinical programs, parents expressed a desire for additional information to be added to the app including education around the benefits of good sleep hygiene.

Overall, the participants found the app entertaining and interesting to use. This high level of interest was not unexpected given the novelty of AR technology. The interest level, however, waned after the first week of use for the two oldest participants (8 years old) who also had the most experience

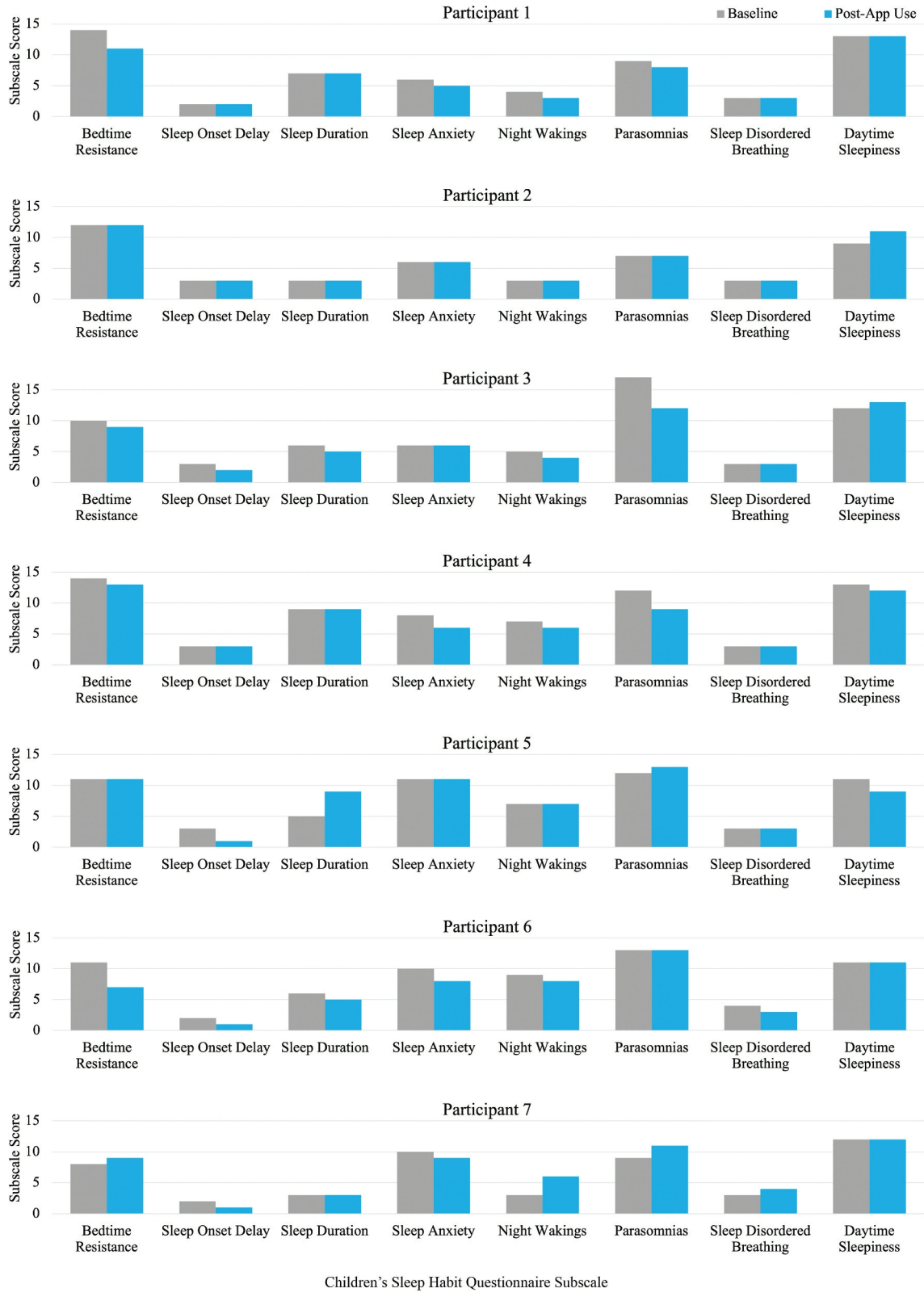

Figure 4. CSHQ questionnaire results.

with technology. This suggests that the bedtime routine app may be more appropriate for younger children or those without an existing bedtime routine. Consistent with this, caregivers of the older participants indicated that the app may be more helpful for children six years and younger who are just beginning to establish a bedtime routine. The lowest scores for usability were received for interactivity, with participants citing a lack of features such as bedtime reminders, app notifications, and added prompts. These features may be interesting future additions to the app and should be explored. It is notable that one of the participants in the study abandoned the app citing increased demands. This participant did not

enjoy the addition of the app to their existing bedtime routine, and felt it was a burdensome additional step. In particular, they found the scanning of the reward cards taxing. While the app provided customization options for sensory and language demands, future versions should consider customization of the task demands to allow for further personalization (e.g, checking off a list instead of scanning a task card).

While our study design and sample size did not allow for examining the impact of the app on sleep habits, preliminary trends toward increased willingness to complete the routine, faster routine completion, and decreased bedtime resistance were observed for some participants. We hypothesize that drivers of positive changes in sleep habits may be the app's ability to increase the motivation level and provide tangible incentives for completing the routine. Future studies with longer intervention periods and randomized controlled trial designs are needed to further examine the clinical impact of such an app.

The user study of this project was conducted in the real, uncontrolled environment of the participants' houses. This was one of the strengths and limitations of this study. Having this realistic testing environment was a strength since it allowed for usability testing in real use-cases. This was particularly important given the relative novelty of AR as a feature. Nevertheless, the uncontrolled study environment also limited our interpretation of the data due to missing parent-reported data. Finally, our study design and sample size did not allow us to draw conclusions on the effectiveness of the app.

This study included extensive consultations with parents of autistic children and clinicians, and feedback from autistic children was elicited during the evaluation phase. It is critical that the autistic people are engaged throughout the design phase and further incorporation of these perspectives are an important direction for future work. Additionally, the proposed app has been developed based on a sleep program for autistic children and their families and evaluated in this population. However, the proposed strategies, including visual schedules and personalization of cognitive, language, and sensory demands, may be applicable to other neurodivergent children. Future studies are needed to further examine this potential.

Conclusions

This work examined the usability of an AR-based app for implementing a bedtime routine for autistic children. Our results suggest that the app was usable and feasible, although future versions should enhance interactivity and personalization features.

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Disclosure statement

A Kushki is the inventor of a software, holly, and may benefit from its commercialization. She has received consulting fees from Shaftesbury and DNAStack. She is a contributor to virtual reality products School Bus VR, Gentle Dental, and Subway Sensations by WellWave and may benefit from their commercialization.

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Consent to participate in research

All participants provided informed consent to participate in this research. Participants who did not demonstrate capacity to provide consent provided assent to participate, and informed consent from their parent/guardian was obtained.

Data visibility statement

Due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data is not available.

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